# The Impact of Intermittent Pain in Women with Osteoarthritis of the Knee on Biomechanics and Muscle Activation Patterns during Level Walking and Stair Descent

By

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# DEDICATION

To my parents, this is but a small part of a lifetime of sacrifice, diligence, and patience. All of you contributed a tremendous degree of effort to provide this opportunity. I merely seized the opportunity. For your steadfast devotedness, I am eternally grateful. To my grandparents, you also were an influential force in forging me into the man I am today. In that way, you will never know how much you mean to me. Never forget that no matter where I go, I will always be your grandson. To those listed here, I love you all.

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ABSTRACT

Osteoarthritis of the knee (KOA) is a degenerative, incurable, and highly debilitating disease. Among those experiencing KOA symptoms, most diagnoses are female. Of the symptoms associated with KOA, none are more detrimental than pain. Existing evidence has established that chronic pain results in irregular muscle activity above and below the knee during activity. This phenomenon, in turn, leads to abnormal joint loading and substantial alterations in gait patterns. However, the understanding of the effects of intermittent pain remains limited.

Therefore, the primary objective of study one was to evaluate the impact of intermittent pain on muscle activity above and below the knee during walking and stepdown tasks in women with KOA (n = 7), compared to controls (n = 10). Study two aimed to investigate the influence of intermittent pain on gait parameters, and foot pressure distribution during walking and stepdown tasks among women with KOA (n = 7) compared to controls (n = 10).

The findings from study one revealed that intermittent pain significantly altered mean and mean peak muscle activity, in the semitendinosus of the pain group, during the load acceptance phase of a stepdown task. There was no discernible influence of intermittent pain on muscle activity during walking. Study two revealed that there was no significant impact of intermittent pain on gait parameters and foot pressure distribution. Essentially, intermittent pain altered muscle activity, without significantly altering participants' walking patterns or the way force was distributed across the foot.

In conclusion, intermittent pain primarily affects muscle activity rather than walking patterns or force distribution. Consideration of additional controls such as

disease severity, foot arch height, fitness level, and motion analysis assessment might provide more insights. Given the significance impact of pain, future researchers should incorporate these controls, and others, to precisely investigate the effects of intermittent pain.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER III

LIST OF APPENDICES

CHAPTER III



CHAPTER IV

# CHAPTER I: DISSERTATION INTRODUCTION

Osteoarthritis of the knee (KOA) is a degenerative joint disease that severely limits the use of the diseased joint(s) and is also the most diagnosed form of osteoarthritis impacting millions of individuals worldwide (Arthritis Foundation, 2020; Centers for Disease Control, 2020). To date, there is no cure, and KOA often progresses to severely limit or halt daily life (Arthritis Foundation, 2020; Centers for Disease Control, 2020). In fact, KOA is considered the most limiting disease in terms of walking and navigating stairs (Hatfield et al., 2021; Hunter et al., 2014; Igawa & Katusuhira, 2014).

In a healthy leg during walking, the quadriceps contract and create a shear force on the tibia, which serves to drive the lower leg forward; however, to counteract this force and create a stable knee for ambulating, the hamstrings also contract resisting this force (Hortobágyi et al., 2005). This allows for healthy individuals to properly load the knee joint, while walking and performing other functional tasks. In contrast, osteoarthritis of the knee (KOA) is associated with reduced knee joint stability, increased pain, higher rates of co-activity, altered walking patterns, lower walking speed, altered biomechanics, overall loss of function, and decreased quality of life (Al Amer et al., 2018; Astephen et al., 2008; Childs et al., 2004; Costello et al., 2021; Fritz & Michelle et al., 2009; Hodges et al., 2016; Hortobágyi et al., 2005; Hunter et al., 2014; Igawa & Katusuhira, 2014; Munoz-Organero et al., 2017; Neogi, 2013; Nuesch et al., 2011; Paquette et al., 2014; Sharma, 2021; Zeni & Higginson, 2009)

Furthermore, those with KOA who exhibit altered biomechanical function, muscle activation patterns, walking patterns, muscle weakness and higher rates of co-

activation, tend to exhibit increased rates of joint loading, which has been shown to advance KOA disease progression and ultimately leads to total joint replacement (Hatfield et al., 2015, Hodges et al., 2016). This problem can become expensive, both socially and financially, for the sufferer and society, as those with KOA have reported sleep deprivation, loss of income and loss of employment (Hawker et al., 2010; Hunter et al., 2014). In these ways, KOA is a serious burden (Hunter et al., 2014).

Given the serious nature of the disease, there are aspects of KOA that require a clearer understanding, with particular focus on how these symptoms interact with one another and ultimately negatively impact an individual who has KOA. A more precise description of this relationship is paramount regarding the most impactful symptom of KOA, pain (Sharma, 2021). Most commonly, self-report measures, including validated scales like the Western Ontario and McMaster Universities Arthritis Index (WOMAC), Knee Injury and Osteoarthritis Outcome Score (KOOS), Visual Analogue Scale (VAS), and Numeric Rating Scale (NRS) have been used to gather data on reported pain (Al Amer, et al., 2018; Angst et al., 2001; Bellamy et al., 1988; Childs, et al., 2004; Collins et al., 2016; Hodges et al., 2016; Kersten et al., 2010; Kersten et al., 2014; Ornetti et al., 2011; Roos et al., 1998; Yuen et al., 2019).

While using the scales above, researchers have discovered that reported pain, in combination with altered muscle activity patterns, has led to and may be the cause of, severely altered movement, walking patterns, and pressure mapping during functional tasks in those with KOA (Childs et al., 2004; Costello et al., 2021; Hodges et al., 2016; Hortobágyi et al., 2005; Wilson et al., 2017). Although these researchers provided valuable insight regarding the impact of reported pain on the previously listed outcomes,

a description of how intermittent pain impacts variables like these would be invaluable, given that type of pain is more limiting and more distressing as reported by those with KOA (Hawker et al., 2008a). To date only one scale assesses this type of pain, the Intermittent and Constant Osteoarthritis Pain Index (ICOAP). To the author's knowledge, no literature exists which describes the impact of intermittent pain on any outcomes in those with KOA.

*Dissertation Purpose*

The purpose of these proposed studies is to assess the impact of intermittent pain, in women with KOA, on muscle activity above and below the knee, foot pressure distribution, gait parameters, and knee joint function, during level walking and a step down, while controlling for confounding variables.

# CHAPTER II: REVIEW OF LITERATURE

This review begins with a brief overview of knee osteoarthritis (KOA). The following section includes a review of pain in KOA, which is followed by sections detailing the various types of measurement of that symptom. The section to follow is a review of the impact of KOA and reported pain on muscle activity, above and below the knee. The last section describes the impact of KOA and pain on kinetics and kinematics, when compared to controls. That is, how KOA and pain impacts gait characteristics in terms of the knee joint and pressure distribution of the foot.

## *Osteoarthritis of the knee (KOA)*

Osteoarthritis of the knee (KOA) is a common, incurable, and severely limiting disease, which impacts the elderly and women to a significant degree, with up to 37% of those diagnosed with the disease being 60 years and older (Arthritis Foundation, 2020; Centers for Disease Control, 2020; Mobasheri & Batt, 2016; Sharma, 2021). These numbers are expected to worsen, as the US population ages (Gill, 2017; Sharma, 2021). Diagnosis and pathological progression of KOA may be assessed using several methods; including, assessment of medical history, physical examination performed by a physician, radiographic imaging, and in rare instances, joint aspiration, but a common and validated method is grading radiographs of the affected joint(s) through the Kellgren-Lawrence (KL) scale (Kellgren & Lawrence, 1957; Kohn et al., 2016; Sharma, 2021). The KL scale ranges from 0 to 4 (no OA to most severe OA) and provides objective indications of joint space narrowing and degradation (Kohn et al., 2016).

Even though there are several methods available to track and diagnose KOA, the symptomology of KOA can vary from person to person in terms of severity and type

(Sharma, 2021). Regarding the variability of symptoms, it is vital from a clinical perspective to gather a clearer understanding of the connection between the disease and symptoms, which some researchers claim is often difficult (Sharma, 2021; Wilson et al., 2017). Some of these symptoms can include pain, muscle weakness in the diseased joint, joint stiffness, reduced physical activity, impaired sleep, and overall disability (Sharma, 2021). Of the symptoms listed here, the most concerning of all is pain (Arthritis Foundation, 2020; Sharma, 2021). Oddly, there is no standard measure for pain, nor is there a complete understanding of how pain negatively impacts the function of those with KOA. Gathering information like this would be invaluable for clinicians to develop more efficacious treatment plans earlier in disease progression (Wilson et al., 2017).

*Pain in KOA*

The foremost symptoms related to progression through the stages of KOA are increased pain and loss of function, with the dominant symptom being pain (Neogi, 2013). Pain experienced by individuals with KOA is chronic but can vary in nature, ranging from a persistent dull ache to intermittent severe pain, both of which can halt daily life (Neogi, 2013). This can make pain difficult to study long-term, as it can fluctuate and evolve (Sharma, 2021).

In the lower extremity, pain is acknowledged as the principal cause of mobility impairment, especially in older adults, as it has been shown to lower physical activity and increase sedentary time (Gay et al., 2019; Guccione, 1994). Given the complexity of pain associated with KOA, and its severe impact, several scales have been generated to provide a means of tracking its impact on functional tasks.

*The measurement of pain in KOA*

According to Bellamy and Buchanan (1984), at the time, several indices existed for the uni and multidimensional tracking of symptoms with rheumatic diseases (Lee et al., 1973; Ritchie et al., 1968; Steinbrocker et al., 1949), but there were only two viable options for osteoarthritis (Bellamy & Buchanan, 1984; Doyle et al., 1981; Lequesne, 1980). Regarding KOA specifically, the Lequesne index gathers data on pain, maximum walking distance, ADLs, and sexual disability in the hip while the Doyle index gathers measurements in joint tenderness following pressure or movement (Bellamy & Buchanan, 1984; Doyle et al., 1981; Lequesne, 1980). Bellamy and Buchanan (1984) noted that although these scales existed at the time, neither had been used in research, and they produced concerning levels of variability. Therefore, these researchers set out to review the available means of tracking symptoms for osteoarthritic patients to create a more efficacious measurement process (Bellamy & Buchanan, 1984).

Sixty-three osteoarthritis clinical trials were selected for further analysis which included several measurement variables gathered through visual analogue scales (VAS) and Likert type scales (Bellamy & Buchanan, 1984). Of high importance to these researchers were how frequently a measurement was made on each variable, the type of instrument used to gather data in the studies, the type of scale used in those instruments, and the responsiveness of each variable (Bellamy & Buchanan, 1984). Although more are listed by Bellamy and Buchanan (1984) the most reported of all symptoms was pain and physical function.

Regarding pain and function as highlighted in the Bellamy and Buchanan (1984) study, a later publication by Bellamy and Buchanan (1986), focused solely on these two

variables. Bellamy and Buchanan (1986) referred to these variables as discomfort (pain and stiffness) and disability (physical, social, emotional). Referring to aspects of KOA as disability wasn't popularized, or fully described, until Jette (2006), but this term essentially meant that Bellamy and Buchanan (1986) were referring to pain and loss of function as factors directly caused by KOA that ultimately led to distress in the sufferer. Bellamy and Buchanan (1986) cite work related to psychological aspects of rheumatic diseases and OA, which is likely where the listed terms above including disability originated (Baum, 1982; Currey, 1970; Lunghi et al., 1978).

To more elucidate the impact of pain and subsequent disability experienced by participants with OA, Bellamy and Buchanan (1986) selected 100 out-patient individuals with hip and/or KOA. The results of this study showed a high degree of variability from person to person and from day to day; however, it was revealed that pain and disability were not only significantly prevalent in the participants, but highly important to them, as these symptoms caused dysfunction (Bellamy & Buchanan, 1986). Recall that at this time, there was no reliable and valid means of gathering data in OA patients, which Bellamy and Buchanan (1986) described as only a few scales which were not meant to assess the multidimensional symptoms of OA.

Ultimately, this study, and a later validation study by Bellamy et al. (1988) led to the creation of the Western Ontario and McMaster Universities Arthritis Index (WOMAC), which included subscales such as pain, stiffness, and physical function. This scale has been used extensively in KOA research as a valid means to track pain itself and pain as it relates to activity (Ackerman et al., 2014; Bellamy et al., 1988; Gandek, 2015;

Razek & El-Basayouni, 2016). Notably, this scale is best used in older and less active individuals (Bellamy et al., 1988).

Following the creation and validation of the WOMAC questionnaire, an additional self-report measure was developed to track reported pain and its impact on ADLs and function in individuals who suffered from knee injury. This questionnaire is known as the knee injury and osteoarthritis outcome score (KOOS). The KOOS questionnaire was originally designed by the researchers Roos et al. (1998). Specifically, these researchers reported on the development of the KOOS, which was meant to track pain, swelling, restricted range of motion, ADLs, sport and recreation function, and knee-related quality of life in young and middle-aged participants with ACL injury, meniscus injury, or post-traumatic osteoarthritis (Roos et al., 1998). This questionnaire was also tested for test-retest reliability, construct validity, and responsiveness to clinical change (Roos et al., 1998). Ultimately, Roos et al. (1998) identified seven factors, which included pain, early disease specific symptoms, late disease specific symptoms, function, quality of life, activity level, and satisfaction.

Not surprisingly, questions from the WOMAC, related to pain, stiffness, and function were also included in the KOOS, and were kept in the fully written form (Bellamy et al., 1988; Roos et al., 1998). According to Roos et al. (1998), this was to safeguard content validity of the KOOS for older populations as that is the target population of the WOMAC. This is an important distinction regarding these scales, as depending on the population selected, more than one questionnaire may be needed to gather valid report measures. Furthermore, the similarity between the KOOS and WOMAC means that the WOMAC score can be calculated from the data gathered on the

KOOS, as the ADLs section of the KOOS, is equivalent to the function section of the WOMAC (Roos et al., 1998). Other sections of these questionnaires show the same relationship.

Ultimately, these researchers were able to draft the KOOS, which was meant to cover the five dimensions of KOA and included pain, symptoms, activities of daily living, sport and recreation function, and knee-related quality of life. Regarding that list of items, Roos et al. (1998) noted that this self-report measure allows a clinician, in roughly 10 minutes, to gather comprehensive, reliable, valid, and reproducible information, with minimal bias, and should be considered in the tracking of reported knee injury and osteoarthritis symptoms in young active participants (Collins et al., 2016; Roos et al., 1998; Roos & Lohmander, 2003).

The above scales are valid and reliable measures of assessing pain and pain as it relates to function in those with KOA. Scales like the WOMAC and KOOS offer a multidimensional self-report measure that can cover a large array of activity levels and ages (Bellamy et al., 1988; Bellamy, 1989; Roos et al., 1998). However, pain in this population can transform in it its intensity and type (Sharma, 2021). This variability is not considered by the scales in this section, which creates a considerable gap in available means to track pain, in an efficacious manner, and could negatively impact a participant. Luckily a somewhat new scale exists that manages to separate and measure pain in its different forms (Hawker et al., 2008a).

*The measurement of intermittent pain in KOA*

Although a valid means of gathering self-reported pain during function, the WOMAC, KOOS, and other scales, may not attain the necessary level of specificity

needed to track pain in KOA given this symptoms variability within a patient, and amongst patients (McAlindon et al., 2015, White & Master, 2016). Therefore, researchers developed a more comprehensive pain scale known as the Intermittent and Constant Osteoarthritis Pain scale (ICOAP) to address this issue (Davison et al., 2016; Hawker et al., 2008a; Pham et al., 2004).

According to Hawker et al. (2008a), of the types of pain an individual with KOA can experience, none is more debilitating than intermittent and intense pain. This is especially true when pain is not predictable, which of course is not assessed by questionnaires like the WOMAC, KOOS and others (Davison et al., 2016; Hawker et al., 2008a). Intermittent pain has even been associated with higher rates of future physical function decrease (Davison et al., 2016). Hawker et al. (2008a) thus sought to utilize focus groups to create and ultimately analyze this new scale.

Hawker et al. (2008a) provided participants with broad and open-ended inquiries detailing the characteristics of hip and knee pain associated with OA over time. Once these broad questions had been answered, more specific questions were asked surrounding what aspects of pain each participant found most limiting (Hawker et al., 2008a). The transcripts from these focus groups were then analyzed by 2 or 3 researchers to identify main them, which were then coded to allow for content analysis to occur in order trends in responses over time from early- to late-stage KOA (Hawker et al., 2008a). A patient generated index (PGI) was then selected to identify more accurately which main concerns participants had regarding hip and KOA pain (Hawker et al., 2008a). Lastly, this PGI was descriptively analyzed and given back to the participants and researchers to ensure it accurately reflected what had been gathered during the focus

group (Hawker et al., 2008a). Following this analysis, 11 items were generated and were considered a valid and comprehensive means of evaluating constant or intermittent pain in those with late-stage hip and KOA (Hawker et al., 2008a)

As the name suggests, the 11-item ICOAP can assess and separate self-reported constant or chronic (items 1-5) and intermittent pain (items 6-11), and has demonstrated, in addition to the above findings, high retest reliability as well as high internal consistency when compared to the WOMAC and KOOS pain subscales across different languages and cultures (Davison et al., 2016; Kessler et al., 2011 Maillefert et al., 2009; McAlindon et al., 2015; Moreton et al., 2012). In terms of correlation with other scales, the ICOAP showed high correlation with the pain subscales of the WOMAC and KOOS, but only on questions related to pain, which suggests further that the ICOAP is a valid means of assessing pain, as it stands on its own (Hawker et al., 2008a). This scale is also now a recommendation from OARSI to improve research participant care by providing clinicians with a more efficacious scale to track pain (McAlindon et al., 2015).

Much like pain, loss of mobility and function in individuals with KOA can reveal itself in several ways, and there is a dearth of literature demonstrating a loss of function through various mechanisms (Al Amer, et al., 2018; Childs et al., 2004; Hortobagyi, et al., 2005; Igawa & Katsuira, 2014; Lim, et al., 2015; Yuen et al., 2019). For instance, decreased mobility has been observed in persons with KOA during level walking and stair descent (Childs, et al., 2004). Notably, individuals with KOA were shown to have decreased knee excursion that was attributed to stiffer joints and higher muscle activation patterns (Childs, et al., 2004).

These altered muscle activity patterns have been documented to occur above (Hodges et al., 2016; Yilmaz et al., 2010) and below the affected joint in persons with unilateral KOA (Childs et al., 2004). Interestingly, even with the creation of the ICOAP, and the recommendations by OARSI, this scale does not appear in any of the research discussed in the next sections. That is, pain as measured by any scale listed in this section, and its impact on outcomes has been thoroughly described; however, there exists no research that describes the impact of intermittent pain on outcomes, such as muscle activity, biomechanics, and pressure distribution during functional tasks.

*The impact of KOA and pain on muscle activity*

Muscle activation patterns above and below the knee, have been shown to change significantly because of KOA disease progression (Bennell et al., 2011a; Hodges et al., 2016; Hortobágyi et al., 2005; Miyazaki et al., 2002). One suggested mechanism behind altered muscle activation is increased joint load due to muscle weakness (Hodges et al., 2016). These measures become more important as KOA advances, as higher rates of joint loading could ultimately lead to increased structural joint degradation (Hodges et al., 2016). Tracking this alteration in muscle function can be accomplished through noninvasive, and valid, surface electromyography (sEMG).

One group of researchers investigated muscle activation changes in individuals with KOA, and documented changes in muscle activity of 24 subjects with unilateral KOA and compared those sEMG results to 24 age and gender matched individuals without KOA (Childs et al., 2004). Pain was also assessed for group differences using a subsection of the WOMAC and an 11-point NRS (Childs et al., 2004). These differences were measures on tasks like walking (2 or 3 attempts) on a level surface at a controlled

speed and descending a 20-cm step (5 attempts) (Childs et al., 2004). Of those with symptomatic unilateral KOA, a KL scale rating of a 2 or 3 was needed to participate (Childs et al., 2004).

To clarify radiographic classification, the Kellgren Lawrence (KL) scale or grade is a common tool used by researchers and rheumatologists alike to classify the severity of OA (Kellgren & Lawrence, 1957; Kohn et al., 2016). The KL scale classifies joints, which includes joints other than the knee, based on radiographic evidence of joint change or damage. The classifications are as follows; 0 equals no radiographic evidence of OA, 1 equals osteophyte formation on the joint margins (Doubtful OA), 2 equals definite presence of ossicles within joint and minimal OA, 3 equals narrowing of the joint and bony deformation and moderate OA, 4 is the most severe classification and usually involves extreme body deformation and joint space narrowing (Kellgren & Lawrence, 1957). While KL scale has been validated for use with KOA, it is limited in its ability to track joint change (Kohn et al, 2016).

To gather data on muscle activity patterns, a surface electromyography (sEMG) system was used (Childs et al., 2004). The muscles selected for sEMG analysis were the vastus lateralis, medial hamstrings, tibialis anterior, and medial gastrocnemius (Childs et al., 2004). Muscle activity yielded interesting findings with the vastus lateralis, medial hamstrings, tibialis anterior and medial gastrocnemius being 1.5 times more active than the same muscles in control participants (Childs et al., 2004). Co-activation was also higher in KOA participants during walking and the step task (Childs et al., 2004). This study, in many ways, provided a foundational set of data and definition of what co-activity is, and how it reveals itself in this population.

The muscles of the KOA participants in the Childs et al. (2004) study had higher muscle activity, but also longer duration muscle activity, especially during stance. This meant that during the functional tasks, the four muscles assessed were active sooner and stayed active longer in the KOA group when compared to the control group (Childs et al., 2004). Therefore, abnormal co-activity really meant that the muscle groups during ambulation such as the hamstrings and the vastus lateralis (quadriceps) and the gastrocnemius and tibialis anterior were not active as they should be during normal walking (Childs et al., 2004). This also meant the muscles of the rear and lower leg were far too active during normal gait (Childs et al., 2004). This is in a simplified form is abnormal co-activity (co-activity) (Childs et al., 2004). Also of importance, those with KOA reported significantly higher pain than the controls, which corresponded to lower reported activity levels and less movement in the knee (Childs et al., 2004). Childs et al. (2004) mentions this but did not discuss any connection between pain and subsequent muscle alteration. Luckily, a later study analyzed co-activity specifically, and how this disorder impacts those with KOA (Hortobagyi et al., 2005).

Co-activity, in the above ways, presents an interesting issue for those with KOA. Hortobágyi et al. (2005) studied sEMG in those with KOA, only with particular attention to co-activation and its impact on walking. It was hypothesized that those with KOA would exhibit higher hamstring coactivity when compared to non-KOA controls (Hortobágyi et al., 2005). This is of course consistent with what Childs et al. (2004) described one year earlier. Hortobágyi et al. (2005) compared the muscle activation patterns between participants with unilateral KOA to age- and gender-matched controls.

Sixty-six participants were included in this study, which were separated in a KOA group, a non-KOA group, and a non-KOA young adult group (Hortobágyi et al., 2005).

The KOA group participants had a KL grade of $\geq 2$, had reported knee pain, had difficulty rising from a chair, and ascending or descending stairs (Hortobágyi et al., 2005). Regarding the testing procedures, each participant underwent three laboratory visits with sEMG occurring on the second visit during activities such as level walking, stair ascent, and stair descent (Hortobágyi et al., 2005). The muscles included were the vastus lateralis, biceps femoris, tibialis anterior, and gastrocnemius lateralis (Hortobágyi et al., 2005). Five successful trials were gathered from each participant (Hortobágyi et al., 2005).

Hortobágyi et al. (2005) took the sEMG (normalized to a maximal voluntary isokinetic contraction) values gathered during movement, and generated ratios such as biceps femoris divided by vastus lateralis (BF/VL ratio), and biceps femoris divided by biceps femoris max (BF/BFmax ratio), which was to ensure proper interpretation of sEMG results as, according to Hortobágyi et al. (2005), those with OA often yield poor quadricep activation when compared to the hamstrings. This ratio of sEMG activity to maximal sEMG activity was calculated for all three activities and included other muscles such as the vastus lateralis to vastus lateralis max ratio ($VL/VL_{max}$ ratio) and gastrocnemius to tibialis anterior ratio (GL/TA ratio) (Hortobágyi et al., 2005).

In addition, this method was to ensure that the hamstrings were not interpreted as artificially high rather than the primary cause, which was abnormal quadricep activation (Hortobágyi et al., 2005). There is something worth noting about this method. The isokinetic method used by Hortobágyi et al. (2005) is different from the accepted method

of normalizing an sEMG value to the average of 2 or 3 maximal voluntary isometric contractions (MVIC), which was and has been used before and after this study (Childs et al., 2004; Hatfield et al., 2021; Hodges et al., 2016; Rudolph et al., 2000). The method used by Hortobágyi et al. (2005) instead used a fixed speed of 90° per second, and had participants perform maximal concentric and eccentric contractions, with both the quadriceps and hamstrings, against a dynamometer. Therefore, the results discussed below are slightly different than those found by the studies mentioned previously, and after.

Hortobágyi et al. (2005) noted that when compared to healthy young and old controls, those with KOA had higher co-activity across all coactivity ratios. For instance, the BF/VL ratio in KOA participants was 1.6 times higher than the healthy control groups (Hortobágyi et al., 2005). Regarding the $VL/VL_{max}$ ratio, the KOA group recorded co-activation values that were 1.9 times higher than the healthy control groups (Hortobágyi et al., 2005). Not only were these ratios higher in the KOA group when compared to non-KOA participant groups, but the BF/VL ratio yielded 25% higher coactivation results when compared to the $BF/BF_{max}$ ratio, which was also a significant finding (Hortobágyi et al., 2005). The GL/TA ratio yielded significant findings as well, as those with KOA yielded 38% higher and 25% higher co-activation values when compared to the healthy young and healthy old non-KOA groups (Hortobágyi et al., 2005).

The results of this study demonstrated that those with KOA tended to have higher hamstring muscle activation patterns than those without KOA (Hortobágyi et al., 2005). This was a similar finding in the Childs et al. (2004) study even when considering the difference in muscle activity normalization. It was also noted that those with KOA

performed activities such as walking, stair ascent and stair descent, with a much higher relative muscle activation pattern in the hamstrings, which according to Hortobágyi et al. (2005), explained why those with KOA walk and navigate stairs with much less knee flexion than healthy controls. Essentially, the hamstrings, or hip extensors, produce much higher activation patterns to alleviate the diseased knee joint, by transferring force generation to the hip (Hortobágyi et al., 2005).

Hortobágyi et al. (2005) noted that the increase in hamstring muscle activation during walking occurred slightly before the heel strike, and throughout stance phase. According to Hortobágyi et al. (2005), this is all evidence of an attempt by the body to stabilize, via new intrinsic neurological control, the diseased joint(s) throughout a gait pattern. These findings are fascinating as this knew intrinsic control to alleviate the damaged joint may be due to pain (Hortobágyi et al., 2005). This is one of the first studies to suggest that pain may be a mechanism that drives altered muscle function. However, this type of pain was merely a 0 to 5 Likert type scale, which does not encompass the complexity of pain.

In addition to the findings mentioned above, tracking muscle activity has provided insight concerning joint load. This altered muscle function does not come without consequence (Hodges et al., 2016). In healthy joints, the proper coordination of muscle activity contributes greatly to the loading of the joints (Hodges et al., 2016; Hortobágyi et al., 2005). Given the importance of symptom management in KOA, researchers have explored this method of symptom tracking, as it relates to co-coactivity and joint load (Hodges et al., 2016).

Hodges et al. (2016), included participants from a previous study, which focused on comparing insole use in KOA patients (Bennell et al., 2011b). Additionally, participants met inclusion criteria that were 50 years and older, had reported knee pain on the medial aspect of the knee of greater than a 3 out of an 11-point scale (0 being no pain;10 being max pain), and had x-ray evidence of KOA via a KL grade of a 2 or 3. In addition, the most symptomatic leg was used to undergo sEMG (Hodges et al., 2016).

Data gathered included pain and physical function using the WOMAC, sEMG at baseline, gait measures at baseline, and disease progression via MRI joint alterations at baseline and 12 months (Hodges et al., 2016). Muscles used to undergo sEMG during walking included the biceps femoris, vastus lateralis, semimembranosus, and vastus medialis (Hodges et al., 2016). Walking measurements included 5 trials of walking at a self-selected pace over a 10-meter walkway while heel strikes and toe offs, stride length, stride width, stride time, stance time, and walking speed were monitored (Hodges et al., 2016). Joint alterations were calculated as volume of change, via internal joint image, at 12 months subtracted from the values gathered at baseline (Hodges et al., 2016). These changes were then converted to a percentage to track percent joint change over time (Hodges et al., 2016). This study used a prediction model with the aforementioned factors predicting cartilage degradation at 12 months from baseline (Hodges et al., 2016).

According to Hodges et al. (2016), when controlling for confounding variables, medial knee co-coactivity duration was significantly positively correlated with cartilage loss at 12-months. This was true for stance phase and during gate cycles (Hodges et al., 2016). Specifically, for every gait cycle, if duration of co-coactivity increased by 1%, there was a 0.14% increase in cartilage loss at 12-months from baseline (Hodges et al.,

2016). In contrast, lateral knee muscle co-activation was inversely correlated with medial knee cartilage degradation (Hodges et al., 2016). This is more than likely a protective mechanism or even the unloading mechanism mentioned by Hortobagyi et al. (2005). Lastly, sex was a significant predictor of cartilage loss at 12 months from baseline with women losing more cartilage (1.61%) than men (Hodges et al., 2016).

According to Hodges et al. (2016), this study provided the first evidence that co-activation is related to KOA progression, especially in the medial compartment. Specifically, the distribution of knee joint load alters following changes in muscle activation patterns (Hodges et al., 2016). It is important to note that although Hodges et al. (2016) reported novel findings, it is understood that KOA severity directly impacts co-activation and walking speed (Hubley-Kozey et al., 2009). Hubley-Kozey et al. (2009) found that when compared to an asymptomatic control group, those with moderate KOA, which was designated by KL grade, had more severe co-activation. Furthermore, those with severe KOA had even higher rates of co-activation than the moderate KOA group and control group (Hubley-Kozey et al., 2009).

Given the findings discussed here, it is important to consider KOA disease status, progression and muscle activation patterns of those distinct groups when gathering data on this population. Although Hodges et al. (2016), Hortobagyi et al. (2005), and Childs et al. (2004) gathered data on pain, there was very little mention of this symptoms impact. That in many ways is still unclear, especially regarding the most impactful form of pain, intermittent pain. Lastly, the muscle activity changes that occur in this population are important to discuss, but even more so is how KOA and its symptoms impact functional tasks.

*The impact of KOA and pain on kinetics and kinematics*

Osteoarthritis of the knee (KOA) is not only the most diagnosed form of OA, especially after age 50 in women, but according to researchers it is the leading cause of walking difficulty in sufferers when combined with co-morbidities such as aging (Fritz & Mitchell, 2009; Guccione et al., 1994; Na et al., 2018; Nuesch et al., 2011; Sharma, 2021). Joint alterations and muscle activity patterns greatly change the gait parameters (kinematics) of those with KOA, usually leading to lower preferred walking speed, difficulty navigating stairs and increased overall walking difficulty (Hatfield et al., 2021; Na et al., 2018; Zeni & Higginson, 2009). This walking difficulty can lead to negative health consequences, such as fall risk with decreased preferred walking pace (< 1 m/s). Therefore, the biomechanics of walking, and the changes that occur leading to walking difficulty, is crucial to elucidate, as the inability to walk in a normal cyclic fashion has been tied to joint tissue breakdown and eventual knee replacement (Griffin & Guilak, 2005; Hatfield et al., 2015; Hodges et al., 2016). Given the importance and limiting ability of pain in those with KOA, it is vital to explain how pain has been viewed as a symptom by past researchers, and ultimately what it still unknown.

With these questions in mind, several researchers have analyzed KOA and how this disease, and symptoms such as pain, impact walking mechanics amongst other tasks including navigating stairs (Costello et al., 2021; Igawa & Katusuhira, 2014; Munoz-Organero et al., 2017; Na et al., 2018; Wilson et al., 2017). Several modes exist to analyze an individual's gait parameters (kinematics), walking force production, and foot pressure mapping (kinetics), but common methods are the use of camera systems, joint analysis software, force plates, force walkways, and insole pressure sensors (Costello et

al., 2021; Igawa & Katusuhira, 2014; Munoz Organero et al., 2017; Na et al., 2018; Wilson et al., 2017).

For instance, Na et al. (2018) assessed the impact of KOA and reported pain, on walking kinematics and kinetics, when compared to healthy controls. Regarding the group with KOA, participants were stratified based on responses from the knee outcome survey (KOS) (Na et al., 2018). To be clear, this is not the KOOS that was discussed in the previous section. Na et al. (2018) used one question from the KOS which assessed how the joint with KOA impacted the participant's ability to walk.

Participants that recorded walking as not difficult or minimally difficult were assigned to a not difficult to walk group, while participants that recorded that walking was somewhat difficult or were unable to walk were assigned to the difficult to walk group (Na et al., 2018). Those groups were matched for sex and age as well as to a control group (Na et al., 2018). Na et al. (2018) described in detail the inclusion and exclusion criteria, but more applicable to this review is that participants were included in the KOA groups if they reported a Kellgren Lawrence severity of $\geq 2$, and knee pain $\geq 3$ out of a Likert type 0 (no pain) to 10 (worse pain imaginable) scale.

Na et al. (2018) selected force plate analysis to gather kinetic information by requiring participants to walk at least 5 times at a self-selected pace $\geq 1.0$ m/s, over a 10-m walkway. To gather motion analysis data (kinematics) during the walking trials, each participant was filmed while wearing retroreflective markers on their pelvis, lateral femur, lateral tibia, and dorsal surface of the foot (Na et al., 2018).

Based on the above findings, reported walking difficulty and pain in KOA participants coincided with abnormal walking kinetic and kinematic parameters when

compared to healthy controls. For instance, the control group showed much larger adduction excursion and knee extension moments in comparison to the KOA groups (Na et al., 2018). The results also revealed that participants in the KOA groups who reported a higher difficulty in walking, also demonstrated less movement. This is true, because participants with at least moderate reported walking difficulty demonstrated smaller peak knee extension moments when compared to those with little or no reported walking difficulty and control group (Na et al, 2018).

Furthermore, Na et al. (2018) noted a consistent decrease in average knee flexion excursion during weight acceptance, extension excursion, and peak extension from the control group to the no difficulty group, followed by difficult to walk group, which suggested that those with pain and KOA recorded the smallest amount of movement. Interestingly, this type of knee stiffness as indicated by lack of mobility during movement has also been found during stair descent (Igawa & Katusuhira, 2014).

In addition, those with KOA exhibited much different walking force patterns than the control group, which according to the authors, was more than likely due to pain, instability, joint effusion, and leg muscle weakness as KOA symptoms often negatively impact the quadriceps (Farrokhi et al., 2015; Na et al., 2018; O'Connell et al., 2016; Sharma et al., 2003). Worsening symptoms coincided with detriment to walking both kinematically and kinetically; however, these researchers did not associate pain in the same fashion. These researchers also used a simple Likert type scale that does not capture the complexity or variety of pain. Findings like these are noteworthy, but still missing vital information.

In addition to the above findings, pressure inserts fitted to the bottom of the foot in shoes of KOA sufferers have yielded relevant findings. Most importantly, Munoz-Organero et al. (2017). assessed the impact of KOA and pain on gait parameters with particular focus on pressure distribution. A total of 28 participants were recruited for this study, with 14 placed in a KOA and knee pain group, and 14 in a control group (Munoz-Organero et al., 2017). Interestingly, these researchers did not use any classification system (i.e. KL scale) for OA, rather they used a system based on age and pain. In the author's opinion, this system is highly flawed and lacks the precision necessary to track accurately the multitude of symptoms associated with KOA, but accurate classification was not the main outcome of this study. These researchers did however attempt to control the variability associated with pain by only allowing those that reported a 2, 3, 4, or 5 on an NRS scale (Munoz-Organero et al., 2017).

Munoz-Organero et al. (2017) noted that they were interested in comparing early KOA patients to controls but provided no evidence to suggest that early-stage KOA also presents lower reported pain levels. This is important to note because KOA can progress without any change in pain and vice versa (Arthritis Foundation, 2020). This could have been a problem, as allowing a wide range of joint status could have introduced variability. The results, which will be discussed next, should be taken with a degree of scrutiny.

Results, even with the previously discussed limitations, revealed interesting findings. The participants with KOA tended to load body weight on the center of the foot and tended to use two-leg strategies to bare their weight when compared to healthy controls (Munoz-Organero et al., 2017). Specifically, participants with KOA transitioned

from the heal to midfoot much faster than their healthy control counterparts (Munoz-Organero et al., 2017). Furthermore, the amount of time the KOA and pain participants spent maximally loading the center of the foot was drastically lower than the controls (Munoz-Organero et al., 2017). According to the researchers, this was more than likely an attempt to lessen the time spent with maximal load of the most painful joint (Munoz-Organero et al., 2017). Interestingly, the researchers mentioned that as reported pain worsened, so did the walking asymmetries (Munoz-Organero et al., 2017).

Regarding the midfoot portion of walking, KOA participants in this study spread his or her body weight over the center portion of the foot while healthy controls loaded the central part of the foot and then moved to the medial portion of the foot (Munoz-Organero et al., 2017). In the author's opinion, these researchers were describing the rolling motion of normal walking (heel, outside foot, middle foot, ball of the foot) in the healthy controls, and a flat foot strike in the KOA participants. This pressure alteration coupled with the time differences mentioned previously, describe poor walking mechanics. Although concerning limitations are associated with this study, this study does appear to expose an apparent linear relationship between worsening pain and worsening outcomes. With more precise controls and accounting for intermittent pain, an even clearer conclusion could be drawn regarding pain's impact on those with KOA.

An example of a study with more precise control has been provided by Costello et al. (2021), who completed a descriptive analysis to quantify the differences in dynamic ground reaction forces (GRF) during walking between knees with knee pain and KOA (KL grade $\geq 2$) and knees without KOA and pain, while accounting for multiple confounders. Costello et al. (2021) described these confounding variables in detail, but

more applicable to this review is the relationship between KOA, gait speed, gait parameters, and pain.

Costello et al. (2021) used participants that were a part of a larger study by Segal et al. (2013) from the Multicenter Osteoarthritis Study (MOST). These participants were placed into groups of those with or without knee pain, and both with KL grade of $\geq 2$ (Costello et al., 2021). Participants were stratified into either a pain and KOA group, a KOA only group, a pain only group, and a control group (Costello et al., 2021). Following placement into the groups, 3-dimensional GRF data was gathered during 5 attempts along a 5.3-meter walkway at a self-selected speed (Costello et al., 2021).

Costello et al. (2021) discussed several findings in detail including interaction terms and thoroughly explained analyses; however, most applicable to this review are the findings regarding vertical GRF, medial-lateral GRF, and anterior-posterior GRF. The vertical GRF waveforms revealed, while adjusting for confounders (sex, age, BMI, and race) other than gait speed, legs with pain and KOA, and legs with just pain, produced flatter curves with lower peaks, and had higher mid-stance force than legs without pain and when compared to the control group (Costello et al., 2021). This could be indicative of guarding due to pain, or even the flat foot strategy described by Munoz-Organero et al. (2017). When gait speed was accounted for, only the group that had pain and KOA produced findings like the one described previously (Costello et al., 2021).

Findings like those above meant that the disease and the associated symptoms were directly impacting sufferers and altering his or her gate pattern. For instance, legs that had KOA only, while controlling for confounders including gait speed, produced higher medial-lateral GRF in the early phase of stance when compared to the late phase

of stance. In addition, the groups with KOA and KOA with pain had higher magnitude lateral peak GRF in early, and late stance including higher medial force in mid-stance compared to the without KOA (pain only) and control group (Costello et al., 2021). Interestingly, Costello et al. (2021) noted that the above relationship existed with gait speed or without gait speed. This was the only time that relationship occurred. This means that pain may not be only the most important or distressing symptom to those who suffer from KOA, but also the most impactful.

Lastly, Costello et al. (2021) noted that it is still unclear whether these results developed from painful KOA, but also that pain and KOA led to detrimental limb loading. Thus, it is vital to continue research like this to allow others to design a more efficacious approach to exercise as a treatment for KOA. However, as mentioned in a previous section, intermittent pain is different from other types of pain, and a scale like the ICOAP is more specific at targeting the debilitating aspects of pain when compared to the WOMAC, which may be one reason why the ICOAP is a recommendation by OARSI (Hawker et al., 2008a; McAlindon et al., 2015). To the author's knowledge, a study considering the findings of past researchers, which assesses the impact of intermittent pain on functional movements, does not exist. A study like that would only improve future interventions meant as therapy for KOA patients, as it could provide a more thorough understanding of KOA symptom impact.

With the above being discussed, a much less common research focus is how pain itself directly impacts muscle activation patterns, joint alterations, movement patterns, and pressure distribution in those with KOA. To be clear, several of the researchers to this point have included reported pain in data collection and analysis and have even

suggested varying degrees of its negative influence, but none have focused on this symptom directly. This is interesting considering pain is the principal concern for most KOA sufferers, and as previously discussed, is acknowledged as the principal cause of mobility impairment, especially in older adults, and is therefore by far the most limiting factor (Gay et al., 2019; Guccione, 1994; Neogi, 2013; Sharma, 2021). Wilson et al. (2017) researched this interaction.

According to Wilson et al. (2017) and other sources, joint damage and KOA symptoms are not always well correlated (Dieppe, 1992; Hannah et al., 2000). To aid in more accurately describing the two, Wilson et al (2017) described OA as an illness related to pain and symptoms, while the disease is related more so to joint tissue damage. This distinction is important, as many individuals who present as asymptomatic have considerable radiographic evidence of disease (KL grade) while others present symptoms (usually pain) with no evidence of disease at all (Arthritis Foundation, 2020; Lawrence et al., 1966). This more than likely makes it difficult to track symptoms and disease progression with any consistency, which might provide a reason why most researchers avoid the topic all together. Nonetheless, Wilson et al. (2017) noted that it is vital to develop a more efficacious approach to early detection and intervention in OA patients, given the difficulties the disease and illness present.

Therefore, Wilson et al. (2017) assessed differences in knee joint movement patterns (kinematics), force production (kinetics), and muscle activation pattern differences, during walking, between a symptomatic KOA group and an asymptomatic KOA group while controlling for KL grade. Inclusion criteria included participants with a KL grade of at least 2, as diagnosed by an orthopedic surgeon, and having reported pain

and symptoms (Wilson et al., 2017). This diagnostic criterion was based on work by Altman et al. (1986) as a part of the American college of rheumatism, which described classifying KOA in terms of pain and symptoms. Participants were then assigned to a symptomatic group or an asymptomatic group if, at the time of the study, he or she had never reported knee pain (Wilson et al., 2017). In addition, all participants reported the ability to walk a city block, jog 5 meters, and ascend stairs in a reciprocal manner (Wilson et al., 2017).

The activities completed by the participants included 5 walking attempts along a 6-meter walkway at a self-selected pace, while 3-dimensional motion (kinematics) analysis of the most symptomatic limb occurred (Wilson et al., 2017). The walking kinetic and kinematic analysis showed a common trend for the symptomatic group, which revealed that this group walked at a slower self-selected pace, had longer stride and stance times, and had less knee extension, flexion, and plantar flexion strength when compared to the asymptomatic group (Wilson et al., 2017). The symptomatic group also reported higher total pain, stiffness, and function on the WOMAC (Wilson et al., 2017). Other significant findings regarding the symptomatic group were increased reported stiffness, decreased function, and increased pain (Wilson et al., 2017).

Although not the focus of this section, it should be noted that co-activity was elevated above and below the knee in the symptomatic group, as the lateral hamstring was reported as exponentially higher than the quadricep during a gait cycle (Wilson et al., 2017). To clarify that point, Wilson et al. (2017) described that there were lower flexion moments in the early stance phase, but also in mid-stance phase. This suggests, and supports, that symptomatic individuals tend to have stiffer joints, and a higher degree of

co-activation (Hortobágyi et al., 2005; Wilson et al., 2017). However, unlike Hortobágyi et al. (2005) who described this mechanism as a response to a weak joint by increasing co-activation to stiffen and support the compromised joint under new intrinsic control, Wilson et al. (2017) suggested that pain was the driving force behind these changes during gait.

It is not that Hortobágyi et al. (2005) was incorrect, rather instead of joint weakness being the primary cause, it could be that pain drives this mechanism. For instance, Wilson et al. (2017) described that the symptomatic group showed greater amounts of torsional loading, which ultimately places stress on the free nerve endings, which would lead to pain. The asymptomatic group did not have this joint alteration, and did not show increased stiffness, less movement, and the other significant findings discussed previously. Therefore, the findings of this study demonstrate a similar guarding mechanism, but the reason for this mechanism has shifted (Wilson et al., 2017).

*Conclusions*

Although the findings discussed in this section are vital in describing more accurately the impact of KOA symptoms, and how symptoms of this disease alter the joint(s), movement patterns, and pressure distribution in those with KOA, there is one aspect of KOA that is yet to be fully explained. The impact of reported intermittent pain in those with KOA, as measured by a validated and recommended scale like the ICOAP, on outcomes such as muscle activity above and below the knee and gait parameters.

# CHAPTER III: THE IMPACT OF REPORTED INTERMITTENT PAIN IN THOSE WITH OSTEOARTHRITIS OF THE KNEE ON MUSCLE ACTIVITY ABOVE AND BELOW THE KNEE DURING LEVEL WALKING AND STEP DOWN

## *Introduction*

Osteoarthritis is a disease characterized by pain, stiffness, reduced joint mobility, and muscle weakness (Sharma, 2021). This disease can impact multiple joints to varying degrees; however, osteoarthritis of the knee (KOA) is the most common form of OA impacting over 30 million individuals in the United States (Arthritis Foundation, 2020; Centers for Disease Control, 2020; Mobasheri & Batt, 2016; Sharma, 2021). According to Kohn et al. (2016), OA has impacted 4% (250 million) of the world's population, and according to Inacio et al. (2017), diagnoses are expected to grow an additional 26,000 per 1 million individuals by 2032. Moreover, it has been reported that people have a 45% chance of developing OA across their lifetime (Hootman et al., 2016), with a substantial increase after age 50 (Oliveria et al., 1995).

Notably, females are at a much higher risk (2- to 3-fold) of developing KOA, are disproportionately diagnosed with KOA, experience more intense symptoms of KOA, experience pain more intensely, report pain in clinical trials more frequently, produce drastically different movement patterns, and generate different muscle activity patterns when compared to males and female controls (Hame & Alexander, 2013; McKean et al., 2007; Phinyomark et al., 2016; Sharma et al., 2021; Sims et al., 2009; Zajdman et al., 2022). Ultimately, the pathology and progression of KOA will elicit alterations within and around the affected joint(s) that drastically degrade function (Arthritis Foundation, 2020).

Several researchers have demonstrated that those with KOA have produced altered muscle activity patterns above and below the knee during activities such as walking and navigating stairs (Childs et al., 2004; Costello et al., 2021; Hatfield et al., 2021; Hodges et al., 2016; Hortobágyi et al., 2005; Hubley-Kozey et al., 2009; Miyazaki et al., 2002; Wilson et al., 2017). Several studies have reported increased hamstring activity and altered co-activation above and below the knee in persons with KOA during standing, walking, stair ascent, and stair descent (Childs et al., 2004; Hortobagyi et al., 2005; Lyytinen et al., 2016). This issue can become detrimental, as this pattern of muscle activity has been shown to accelerate knee joint degradation and worsen symptoms via increased joint load (Bennell et al., 2011a; Hodges et al., 2016; Hortobagyi et al., 2005).

There are several proposed mechanisms for this alteration in muscle activity including altered knee joint angle and compensating for weak and underactive quadriceps (Childs et al., 2004; Costello et al., 2021; Hortobágyi et al., 2005; Lim et al., 2015; Wilson et al., 2017). It has been suggested that there is an association between altered muscle activity patterns and pain in persons with KOA (Wilson et al., 2017). For example, Wilson et al. (2017) discovered that those with reported pain and clinical evidence of KOA demonstrated abnormal co-activation of the lateral hamstring and the quadriceps during a gait cycle when compared to asymptomatic controls (Wilson et al., 2017). Such findings demonstrate a connection between altered muscle activity patterns and pain that is observed in persons with KOA.

Reported pain leading to detrimental muscle activity alteration, and ultimately abnormal joint load, is not surprising considering pain is the most limiting and impactful factor of this disease, especially in older individuals (Gay et al., 2019; Guccione, 1994;

Sharma, 2021). The impact of severity of pain is also important to note, as it has been suggested that as pain worsens, so do symptoms (Munoz-Organero et al, 2017). Although findings like these are invaluable, none of these studies accounted for the most distressing form of reported pain, intermittent pain (Hawker et al., 2008b). This type of pain has been correlated with a decrease in physical activity over time, suggesting it is also pernicious (Davison et al., 2016). Given its impact, a scale known as the intermittent and constant osteoarthritis pain index (ICOAP) was created to track intermittent pain and quantify its severity (Hawker et al., 2008a; Hawker et al., 2008b). It has even been recommended that this scale be used to gather data on pain in this population (McAlindon et al., 2015).

Although there are several proposed mechanisms regarding how KOA and its symptoms alter muscle activity around the knee joint, a detailed description of how intermittent pain impacts muscle activity of an individual with KOA does not exist. Creating this source of information would provide valuable information on symptomology that could assist in therapeutic interventions.

Therefore, the purpose of this study is to evaluate and describe the impact of reported intermittent pain on muscle activity, above and below the knee, during level walking at a self-selected pace for 6 meters, and during a 20-centimeter stair descent in women with KOA. Given the findings of past research, those with KOA who report intermittent pain, should yield higher mean peak and overall mean muscle activation in the semitendinosus when compared to healthy controls. Additionally, co-activation ratios calculated for those with KOA and intermittent pai should reveal higher rates of

abnormal coactivation in the semitendinosus in comparison to the vastus lateralis, and in the medial gastrocnemius when compared to the tibialis anterior.

## *Materials and Methods*

### *Study Design*

This study, and procedures herein, were approved by the Institutional Review Board at Middle Tennessee State University (see Appendices A & B). This exploratory study utilized a non-randomized case-control design. This design ensured that the impact of intermittent pain on muscle activity above and below the knee during a 6-meter walk, and 20-centimeter stair descent was assessed in a pain group when compared to a control group.

### *Participants*

Participants, in the pain group, included women ($n$ = 7) that had a clinical diagnosis of KOA, and self-reported intermittent pain as obtained by the ICOAP index (Childs et al, 2004; Hawker et al., 2008a; Hawker et al., 2008b; Kessler et al., 2011; Wilson et al., 2017). Those in the control group included women ($n$ = 10) who had no diagnosed KOA or reported intermittent pain. This age range was reflective of more than 88% of those diagnosed with KOA being 45 years of age and older (United States Bone and Joint Initiative, 2018). Given the previously discussed complex sex differences related to these outcomes, this study focused on female participants, while male participants were excluded. Regarding confounders in both groups, age, and body mass index (BMI) have been shown to directly impact walking mechanics and lead to differences in knee joint load in this population; therefore, these variables were treated as

covariates in the analysis portion (Costello et al., 2021; Harding et al., 2012; McKean et al., 2007).

For clarity, body mass index (BMI) is an anthropometric ratio of mass in kilograms to height in meters squared ($kg/m^2$) and is separated commonly by classification (*ACSM's Guidelines for Exercise Testing and Prescription*, 2022, p. 63).

Participants were excluded from either group if they were unable to demonstrate the ability to safely walk distances greater than 200 ft without the use of assistive devices during the data collection visit, had a history of ligament injury to the involved knee, had undergone total knee arthroplasty, or had any neurological disease(s) that impacted walking (Childs et al., 2004; Hortobagyi et al., 2005; Wilson et al., 2017). In addition to the above criteria, participants were excluded from either group if they were unable to, during the data collection session, navigate stairs in a reciprocal manner (Childs et al., 2004; Wilson et al., 2017).

Furthermore, interarticular injection is a common pain management strategy (Mora et al., 2018). The duration of pain relief experienced by an individual using this type of pain management is dependent on the dosage and type of medication administered, which can range from 2 weeks to 6 months (Arroll & Goodyear-Smith, 2004; Bellamy et al., 2006; Buyuk et al., 2017; Da Costa et al., 2021; Hirsch et al., 2013; Law et al., 2015; Mora et al., 2018; Yavuz et al., 2012). Given this variability, any participant who reported having had an interarticular injection within 6-months of the data collection session was excluded. (Deyle et al., 2020; Fransen et al., 2015; Sinusas, 2012). Given the commonality of oral pain medication used in this population, it was not requested that participants cease pain medication use (Deyle et al., 2020; Fransen et al.,

2015; Sinusas, 2012). This determination was due primarily to the small impact some oral and topical pain medication have on pain in those with KOA (Da Costa et al., 2021; Hmamouchi et al., 2012).

*Functional Movements*

To perform the step-down procedure, each participant was asked to step up on to a 20-centimeter-tall box using the leg not being assessed, and then when prompted, step down on to the leg being assessed (Childs et al., 2004). Regarding the assessed limb, those in the pain group had data gathered on the most painful leg (Childs et al., 2004; Wilson et al., 2017). Beyond the commonality of selecting the most painful leg for analyses, Davison et al. (2016) noted that the ICOAP is leg specific; therefore, if bilateral KOA participants were included, the relationship between physical function and the pain score of both legs would need to be assessed. In addition, according to researchers, adding both legs complicates interpretations, magnifies effect size, and negates independent observation (Menz, 2004; Radzak et al., 2017). Lastly, for accuracy of comparison, the control group had data gathered on a randomized leg (Wilson et al., 2017).

The walking trials were completed by having each participant walk over level ground for 6 meters, in normal shoe wear, at a comfortable self-selected pace (Hubley-Kozey et al., 2008; Hubley-Kozey et al., 2009; Wilson et al., 2017). This type of gait analysis is not only simple but has high day to day repeatability (Robbins et al., 2013). Lastly, walking at a self-selected pace and a step-down, at the above step height, are recommended by the Osteoarthritis Research Society International (OARSI) as valid

means of assessing movement in this population (Fitzgerald et al., 2015; McAlindon et al., 2015).

*Procedures*

Each participant was required to attend one data collection session. At this session, participants first read and signed the informed consent document followed by the physical activity readiness questionnaire (PAR-Q+; See Appendix C), which was meant to screen for health and medication related exclusion criteria. After applying exclusion criteria, participants were placed in either the pain or control group. Once participants were in a group, each participant's height was assessed to the nearest 0.1 cm using a stadiometer (SECA Corporation, Model 222, Hamburg, Germany) and body mass was measured to the nearest 0.1 kg using a digital scale (Tanita Corporation, Model BF-522, Arlington Heights, IL). Muscle activity was assessed, using the wireless Trigno electromyography system (Delsys, Trigno EMG, Natick, MA). This occurred during 5 trials of a self-paced 6-meter walk, and during 5 trials of a 20-centimeter step down (Childs et al., 2004; Hubley-Kozey et al., 2008; Wilson et al., 2017). There was at least one minute of rest between each walking and stepping trial to avoid the negative impact of fatigue.

Prior to placement of the electrodes, skin at the electrode sites was prepared by shaving (standard disposable safety razor), debriding (Redux), and cleansing (isopropyl alcohol). Surface EMG (sEMG) was placed over the vastus lateralis (VL), semitendinosus (ST), tibialis anterior (TA), and the medial gastrocnemius (MG) of the most painful knee or randomized knee in the control group (Childs et al., 2004). All

electrodes were positioned over the greatest proportion of the muscle belly according to the procedures and locations suggested by the SENIAM project (seniam.org).

Once signal verification was achieved, muscle activity during a 3 second maximal voluntary isometric contraction (MVIC) was performed and recorded across three trials. These MVIC attempts, gathered via a manual muscle test, were targeted for each muscle, and included knee flexion (ST), knee extension (VL), plantarflexion (MG) and dorsiflexion (TA) (Hubley-Kozey et al., 2008; Lee et al., 2012; Wilson et al., 2017). The manual muscle test used to illicit these MVICs has been validated to gather repeatable and reliable values for normalization (Halaki & Ginn, 2012; Lee et al., 2012). The highest of the MVIC trials was used to normalize muscle activity in the previously indicated muscles during the loading phase of the 20-centimeter step down and during stance phase of the 6-meter walk trials (Childs et al., 2004; Hubley-Kozey et al., 2008). In addition, to the MVICs, each participant was required to perform a 30-second sit-to-stand. This data was gathered as a precautionary measure in the circumstance that the MVIC data was not valid, which did not occur. This functional test is reliable as a performance-based test in this population (Holm et al., 2021).

Regarding the 11-item ICOAP (see Appendix D), this scale has been validated, has demonstrated high retest-reliability, and high internal consistency (Davison et al., 2016). Furthermore, this scale provides a valid means of gathering data on (KOA), in older individuals, cross-culturally, and across different languages, to assess intermittent or chronic pain separate, effectively and easily, from physical function and is even a recommendation by OARSI (Hawker et al., 2008a; Maillefert et al., 2009; McAlindon et al., 2015; Moreton et al., 2012).

The ICOAP score can range from 0 to 24 with zero being no pain and 24 being extreme pain (Hawker et al., 2008a). To meet study inclusion for the symptomatic group and given the novelty of using a scale like this one for an exploratory study, inclusion for the pain group included participants who reported greater than a 0 out of 24 on items 6-11 on the ICOAP (Hawker et al., 2008a). That would be consistent with selecting at least answer choice 1 to items 6 through 11 on the ICOAP, which is indicative of mild or rare impact of intermittent pain (Hawker et al., 2008a).

*Data Processing*

All sEMG data was normalized to the peak MVIC for each participant and represents each muscle, during both movements, as a percentage of peak muscle activity. Data was analyzed using EMGworks analysis software (Delsys, Model SC-S08-4.5.3, Natick, MA), and then exported to Microsoft Excel (2019). Within the analysis software, sEMG was processed via a Nyquist resampling equation at 1000 Hz. Data were then filtered with a Butterworth band-pass filter at 20Hz and 450Hz, and then filtered further with a 200-millisecond window root-meant-square algorithm. The sEMG data was processed according to the above specifications which included mean peak, and overall mean muscle activity gathered during the activities listed in the procedures section (Childs et al., 2004; Wilson et al., 2017).

*Statistical Analysis*

IBM© SPSS© Statistics (IBM Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp) was used for statistical analyses. Descriptive statistics included height, weight, age, and BMI which are listed as means ± standard deviations. Statistical analysis included an analysis of co-variance (ANCOVA) ($\alpha = .05$) to assess group differences

between mean peak, and overall mean of the VL, ST, MG, TA during both activities. The 5 walking trials and 5 step-down trials were averaged to reduce group variance as well as to reduce sample redundancy (Hubley-Kozey et al., 2008). Given the potential impact of BMI and age on outcomes, they were treated as covariates. Partial eta squared was used to calculate effect size. Co-activation ratios were calculated via the Rudolph equation $(EMG_L + EMG_M) * (EMG_L/EMG_M)$. This ultimately yielded values as a percent between the ST and VL, and TA and MG, where ST and TA were the less active muscles (Childs et al., 2004; Rudolph et al., 2000).

***Results***

Participant descriptive statistics are listed in Table 1, and as an observation, the pain group recorded higher mean age and BMI when compared to the control group. A one-way between groups analysis of covariance (ANCOVA) was conducted to assess the impact of reported intermittent pain on muscle activity and co-activation, above and below the knee, during a 6-meter walk. This relationship was also assessed during the load acceptance phase of the 20-centimeter step-down, only co-activation was not calculated for this activity. Load acceptance was when each participant contacted the ground and loaded her body mass onto the test leg. The severity of pain, in this case a higher or lesser score from person to person on the ICOAP, was not considered as there are no clinical endpoints suggesting the scale can be used that in that fashion. Age and BMI were considered co-variates.

Preliminary assessments, including Levene's test, Q-Q plot, and residual plot, were conducted to ensure no violations of homogeneity, normality, and linearity respectfully for all analyses described below. There were no violations. It was revealed

that there was no statistically significant difference between groups on the mean or mean peak activity of the SL, VL, TA, or MG during the 6-meter walk (see Tables 2 – 9). However, while controlling for the impacts of intermittent pain and BMI, there was a statistically significant difference between groups regarding mean ST activity during the 6-meter walk, $F$ (1,13) = 5.79, $p$ = .032, partial eta squared= .308. This means that Age explained 30.8% of the variance within the pain group, and this was a large effect size (Field, 2018). Furthermore, for every one unit increase in Age on average, there was a .006 (β = .006) or .6% higher mean ST activity during the 6-meter walk in the pain group. In addition, while controlling for the impacts of intermittent pain and BMI, there was a statistically significant difference between groups regarding mean peak ST activity during the 6-meter walk, $F$ (1,13) = 5.10, $p$ = .042, partial eta squared = .282. This means Age explained 28.2% of the variance in the pain group, and this was a large effect size (Field, 2018). When compared to the control group, on average, for every one unit increase in Age there was a .011 (β = .011) or 1.1% higher mean peak ST activity during the 6-meter walk in the pain group.

Furthermore, there was no statistically significant difference between groups regarding co-activation between the ST versus VL or MG versus TA (see tables 10 & 11). However, while controlling for the impacts of BMI and intermittent pain, there was a statistically significant difference between groups on co-activation between the ST versus VL during the 6-meter walk, $F$ (1,13) = 5.94, $p$ = .030, partial eta squared = .314. This means that Age explained 31.4% of the variance in the pain group, and this was a large effect size (Field, 2018). Furthermore, when compared to the control group, for everyone

one unit increased in Age, on average, those in the pain group yielded co-activation ratios that were .014 (β = .014) or 1.4% higher.

There was a statistically significant difference in mean ST muscle activity between groups, while controlling for covariates Age and BMI, during the 20-centimeter step down, $F$ (3,13) = 10.54, $p$ = .006, partial eta squared = .448. This means that intermittent pain explained 44.8% of the variance in the pain group, and this was a large effect size (Field, 2018). Additionally, those in the pain group yielded mean ST muscle activity that was .151 (β = .151) or 15.1% higher, on average, when compared to the control group. Regarding the mean VL, TA, and MG, (see Tables 13 - 15) there were no statistically significant differences between groups during the 20-centimeter step down.

While controlling for covariates Age and BMI, there was a statistically significant difference between groups in the mean peak ST during the 20-centimeter step-down, $F$ (3,13) = 17.42, $p$ = .001, partial eta squared = .572. This means intermittent pain explained 57.2% of the variance in the pain group, and this was a large effect size (Field, 2018). Furthermore, it was found that, on average, the pain group yielded mean peak muscle activity that was .299 (β = .299) or 29.9% higher when compared to the control group. In addition, while controlling for the impact of BMI and intermittent pain there was statistically significant difference between groups in the mean peak ST during the 20-centimeter step down, $F$ (1,13) = 9.94, $p$ = .008, partial eta squared = .433. Age, to a lesser degree, explained 43.3% of the variance in the pain group, and this was a large effect size (Field, 2018). Furthermore, when compared to the control group, for every one unit increase in Age on average, those in the pain

group yielded mean peak ST activity that was .008 (β = .008) or .8% higher. Lastly, there were no statistically significant differences between groups regarding mean peak VL, TA or MG activity during the 20-centimeter descent (see Tables 17 - 19).

Table 1

*Participant demographics*

| | Control | | Intermittent Pain | |
|---|---|---|---|---|
| | *n* (10) | | *n* (7) | |
| Sex (Female) | | | | |
| | ***M*** | **±*SD*** | ***M*** | **±*SD*** |
| Height (m) | 1.676 | 0.075 | 1.63 | 0.068 |
| Weight (kg) | 69.09 | 13.79 | 90.45 | 10.95 |
| Age (Years) | 59 | 9.17 | 62 | 8.71 |
| BMI ($kg/m^2$) | 24.47 | 3.5 | 34.51 | 5.99 |

*Note*: BMI is body mass index.

Table 2

*Analysis of Covariance for Mean sEMG Semitendinosus during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 4.36 | 0.025* | 0.502 | |
| Main Effect | | | | 13.00 | 2.19 | 0.163 | 0.144 | 0.094 |
| Pain group | 0.23 | 0.11 | 7 | | | | | |
| Control group (reference) | 0.12 | 0.08 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 5.79 | 0.032* | 0.308 | 0.006 |
| BMI ($kg/m^2$) | | | | | 0.05 | 0.829 | 0.004 | -0.001 |

*Note*: $F$ (3,13) = 4.36, $p$ = .025, partial eta squared = .502. Values were normalized to the highest attempt of three MVIC's. The symbol * denotes significance. BMI is body mass index.

Table 3

*Analysis of Covariance for Mean sEMG Vastus Lateralis during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.65 | 0.596 | 0.131 | |
| Main Effect | | | | 13.00 | 0.15 | 0.704 | 0.011 | -0.186 |
| Pain group | 0.57 | 0.66 | 7 | | | | | |
| Control group (reference) | 0.33 | 0.55 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.26 | 0.619 | 0.02 | 0.009 |
| BMI ($kg/m^2$) | | | | | 1.27 | 0.279 | 0.089 | 0.04 |

*Note*: $F$ (3,13) = 0.65, $p$ = .596, partial eta squared .0131. Values were normalized to the highest attempt of three MVIC's. BMI is body mass index.

Table 4

*Analysis of Covariance for Mean sEMG Tibialis Anterior during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 1.17 | 0.360 | 0.212 | |
| Main Effect | | | | 13.00 | 0.01 | 0.920 | 0.001 | -0.01 |
| Pain group | 0.30 | 0.08 | 7 | | | | | |
| Control group (reference) | 0.23 | 0.16 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 2.13 | 0.168 | 0.141 | 0.006 |
| BMI ($kg/m^2$) | | | | | 0.70 | 0.417 | 0.051 | 0.006 |

*Note*: $F$ (3,13) = 1.17, $p$ = .360, partial eta squared = .212. Values were normalized to the highest attempt of three MVIC's. BMI is body mass index.

Table 5

*Analysis of Covariance for Mean sEMG Medial Gastrocnemius during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.91 | 0.462 | 0.174 | |
| Main Effect | | | | 13.00 | 1.68 | 0.218 | 0.114 | -0.57 |
| Pain group | 0.85 | 0.58 | 7 | | | | | |
| Control group (reference) | 0.88 | 0.57 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 1.14 | 0.305 | 0.081 | 0.017 |
| BMI ($kg/m^2$) | | | | | 2.30 | 0.154 | 0.15 | 0.049 |

*Note*: $F$ (3,13) = .91, $p$ = .462, partial eta squared = .174. Values were normalized to the highest attempt of three MVIC's. BMI is body mass index.

Table 6

*Analysis of Covariance for Mean Peak sEMG Semitendinosus during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 3.15 | 0.061 | 0.421 | |
| Main Effect | | | | 13.00 | 1.35 | 0.267 | 0.094 | 0.153 |
| Pain group | 0.50 | 0.22 | 7 | | | | | |
| Control group (reference) | 0.35 | 0.17 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 5.10 | 0.042* | 0.282 | 0.011 |
| BMI ($kg/m^2$) | | | | | 0.17 | 0.686 | 0.013 | -0.004 |

*Note*: $F$ (3,13) = 3.15, $p$ = .061, partial eta squared = .0421. Values were normalized to the highest attempt of three MVIC's. The symbol * denotes significance. BMI is body mass index.

Table 7

*Analysis of Covariance for Mean Peak sEMG Vastus Lateralis during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.53 | 0.668 | 0.109 | |
| Main Effect | | | | 13.00 | 0.14 | 0.710 | 0.011 | -0.523 |
| Pain group | 1.49 | 2.02 | 7 | | | | | |
| Control group (reference) | 0.89 | 1.45 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.24 | 0.634 | 0.018 | 0.025 |
| BMI ($kg/m^2$) | | | | | 1.07 | 0.320 | 0.076 | 0.105 |

*Note*: $F$ (3,13) = .53, $p$ = .668, partial eta squared = .109. Values were normalized to the highest attempt of three MVIC's. BMI is body mass index.

Table 8

*Analysis of Covariance for Mean Peak sEMG Tibialis Anterior during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.59 | 0.635 | 0.119 | |
| Main Effect | | | | 13.00 | 0.10 | 0.758 | 0.008 | -0.074 |
| Pain group | 0.63 | 0.21 | 7 | | | | | |
| Control group (reference) | 0.55 | 0.34 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 1.30 | 0.275 | 0.091 | 0.01 |
| BMI ($kg/m^2$) | | | | | 0.51 | 0.487 | 0.038 | 0.012 |

*Note*: $F$ (3,13) = .59, $p$ = .635, partial eta squared = .119. Values were normalized to the highest attempt of three MVIC's. BMI is body mass index.

Table 9
*Analysis of Covariance for Mean Peak sEMG Medial Gastrocnemius during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.66 | 0.591 | 0.132 | |
| Main Effect | | | | 13.00 | 1.80 | 0.203 | 0.122 | -1.72 |
| Pain group | 1.98 | 1.47 | 7 | | | | | |
| Control group (reference) | 2.50 | 1.69 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.66 | 0.432 | 0.048 | 0.038 |
| BMI ($kg/m^2$) | | | | | 1.31 | 0.273 | 0.092 | 0.108 |

*Note*: $F$ (3,13) = .66, $p$ = .591, partial eta squared = .132. Values were normalized to the highest attempt of three MVIC's. BMI is body mass index.

Table 10

*Analysis of Covariance for Co-Activation Semitendinosus vs. Vastus Lateralis*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 3.27 | 0.056 | 0.43 | |
| Main Effect | | | | 13.00 | 0.99 | 0.336 | 0.071 | 0.152 |
| Pain group | 0.39 | 0.25 | 7 | | | | | |
| Control group (reference) | 0.23 | 0.21 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 5.94 | 0.030* | 0.314 | 0.014 |
| BMI ($kg/m^2$) | | | | | 0.10 | 0.755 | 0.008 | -0.004 |

*Note: F* (3,13) = 3.27, *p* = .056, partial eta squared = .43. Value in parenthesis is within-group error. Co-activation was calculated using the Rudolph equation (EMGL + EMGM) * (EMGL / EMGM) where, during ambulation, L is the less active muscle while M is the more active muscle. The symbol * denotes significance. BMI is body mass index.

Table 11
*Analysis of Covariance for Co-Activation Medial Gastrocnemius vs. Tibialis Anterior*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 1.87 | 0.185 | 0.301 | |
| Main Effect | | | | 13 | 0.77 | 0.397 | 0.056 | 0.15 |
| Pain group | 0.49 | 0.22 | 7 | | | | | |
| Control group (reference) | 0.30 | 0.22 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 2.29 | 0.154 | 0.15 | 0.01 |
| BMI ($kg/m^2$) | | | | | 0.01 | 0.921 | 0.001 | 0.001 |

*Note: F* (3,13) = 1.87, *p* = .185, partial eta squared = .301. Value is parenthesis is within-group error. Co-activation was calculated using the Rudolph equation (EMGL + EMGM) * (EMGL / EMGM) where, during ambulation, L is the less active muscle while M is the more active muscle. BMI is body mass index.

Table 12
*Analysis of Covariance for Mean sEMG Semitendinosus during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 8.72 | 0.002* | 0.668 | |
| Main Effect | | | | 13.00 | 10.54 | 0.006* | 0.448 | 0.151 |
| Pain group | 0.23 | 0.09 | 7 | | | | | |
| Control group (reference) | 0.10 | 0.05 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 3.85 | 0.072 | 0.228 | 0.003 |
| BMI ($kg/m^2$) | | | | | 0.81 | 0.384 | 0.059 | -0.003 |

*Note*: $F$ (3,13) = 8.72. $p$ = .002, partial eta squared = .668. Values were normalized to the highest attempt of three MVIC's. These values were gathered during the load acceptance phase of the step down. The symbol * denotes significance. BMI is body mass index.

Table 13
*Analysis of Covariance for Mean sEMG Vastus Lateralis during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.63 | 0.607 | 0.127 | |
| Main Effect | | | | 13.00 | 0.39 | 0.545 | 0.029 | -0.279 |
| Pain group | 0.65 | 0.36 | 7 | | | | | |
| Control group (reference) | 0.50 | 0.66 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.69 | 0.422 | 0.05 | 0.014 |
| BMI ($kg/m^2$) | | | | | 1.35 | 0.265 | 0.094 | 0.038 |

*Note*: $F$ (3,13) = .63, $p$ = .607, partial eta squared = .127. Values were normalized to the highest attempt of three MVIC's. These values were gathered during the load acceptance phase of the step down. BMI is body mass index.

Table 14
*Analysis of Covariance for Mean sEMG Tibialis Anterior during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 1.26 | 0.330 | 0.225 | |
| Main Effect | | | | 13.00 | 0.01 | 0.918 | 0.001 | 0.015 |
| Pain group | 0.33 | 0.20 | 7 | | | | | |
| Control group (reference) | 0.19 | 0.16 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.14 | 0.711 | 0.011 | 0.002 |
| BMI ($kg/m^2$) | | | | | 1.29 | 0.277 | 0.09 | 0.012 |

*Note: F (3,13) = 1.26, p = .330, partial eta squared = .225.* Values were normalized to the highest attempt of three MVIC's. These values were gathered during the load acceptance phase of the step down. BMI is body mass index.

Table 15
*Analysis of Covariance for Mean sEMG Medial Gastrocnemius during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 2.92 | 0.074 | 0.402 | |
| Main Effect | | | | 13.00 | 1.20 | 0.294 | 0.084 | -0.619 |
| Pain group | 1.28 | 1.47 | 7 | | | | | |
| Control group (reference) | 0.77 | 1.69 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.35 | 0.567 | 0.026 | 0.012 |
| BMI ($kg/m^2$) | | | | | 6.71 | 0.022* | 0.341 | 0.108 |

*Note*: $F$ (3,13) = 2.92, $p$ = .074, partial eta squared = .402. Values were normalized to the highest attempt of three MVIC's. These values were gathered during the load acceptance phase of the step down. The symbol * denotes significance. BMI is body mass index.

Table 16
*Analysis of Covariance for Mean Peak sEMG Semitendinosus during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Corrected Model** | | | | 3 | 17.42 | <.001* | 0.801 | |
| Main Effect | | | | 13 | 17.40 | 0.001* | 0.572 | 0.299 |
| Pain group | 0.523 | 0.157 | 7 | | | | | |
| Control group (reference) | 0.242 | 0.088 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 9.94 | 0.008* | 0.433 | 0.008 |
| BMI ($kg/m^2$) | | | | | 0.67 | 0.428 | 0.049 | 0.049 |

*Note*: $F$ (3,13) = 17.42, $p$ < .001, partial eta squared .801. Values were normalized to the highest attempt of three MVIC's. These values were gathered during the load acceptance phase of the step-down. The symbol * denotes significance. BMI is body mass index.

Table 17
*Analysis of Covariance for Mean Peak sEMG Vastus Lateralis during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.53 | 0.670 | 0.109 | |
| Main Effect | | | | 13.00 | 0.08 | 0.785 | 0.006 | -0.333 |
| Pain group | 1.60 | 1.56 | 7 | | | | | |
| Control group (reference) | 1.02 | 1.39 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.25 | 0.626 | 0.019 | 0.022 |
| BMI ($kg/m^2$) | | | | | 0.93 | 0.353 | 0.067 | 0.085 |

*Note*: $F$ (3,13) = .53, $p$ = .670, partial eta squared = .109. Values were normalized to the highest attempt of three MVIC's. These values were gathered during the load acceptance phase of the step-down. BMI is body mass index.

Table 18
*Analysis of Covariance for Mean Peak sEMG Tibialis Anterior during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 1.36 | 0.229 | 0.239 | |
| Main Effect | | | | 13.00 | 0.05 | 0.830 | 0.004 | 0.061 |
| Pain group | 0.77 | 0.42 | 7 | | | | | |
| Control group (reference) | 0.48 | 0.29 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.003 | 0.959 | <.001 | 0.001 |
| BMI ($kg/m^2$) | | | | | 1.23 | 0.288 | 0.086 | 0.023 |

*Note*: $F$ (3,13) = 1.36, $p$ = .229, partial eta squared = .239. Values were normalized to the highest attempt of three MVIC's. These values were gathered during the load acceptance phase of the step-down. BMI is body mass index.

Table 19
*Analysis of Covariance for Mean Peak sEMG Medial Gastrocnemius during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3.00 | 1.637 | 0.229 | 0.274 | |
| Main Effect | | | | 13.00 | 1.12 | 0.309 | 0.079 | -2.549 |
| Pain group | 4.35 | 4.11 | 7 | | | | | |
| Control group (reference) | 3.10 | 2.59 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.29 | 0.600 | 0.022 | 0.048 |
| BMI ($kg/m^2$) | | | | | 4.22 | 0.061 | 0.245 | 0.364 |

*Note*: $F$ (3,13) = 1.637, $p$ = .229, partial eta squared = .274. Values were normalized to the highest attempt of three MVIC's. These values were gathered during the load acceptance phase of the step-down. BMI is body mass index.

***Discussion***

The purpose of this study was to investigate the influence of self-reported intermittent pain on muscle activity, above and below the knee, during a 6-meter walk at a self-selected pace, and during a 20-centimeter step-down, in women with KOA. While no significant differences were found in group comparisons during walking, notable differences in the step-down task were revealed, where the pain group exhibited elevated mean and mean peak muscle activity in the semitendinosus. Previous research findings suggest that women particularly during the tasks mentioned, who report chronic pain linked to physical function, tend to demonstrate higher amplitude mean, mean peak, and duration of muscle activity both above and below the knee (Childs et al., 2004; Costello et al., 2021; Hatfield et al., 2021; Heiden et al., 2009; Hodges et al., 2016; Hortobágyi et al., 2005; Hubley-Kozey et al., 2009; Miyazaki et al., 2002; Wilson et al., 2017). Moreover, women with KOA have been observed to display abnormal co-activation patterns both above and below the knee while walking and navigating stairs (Childs et al., 2004; Hortobagyi et al., 2005; Lyytinen et al., 2016).

Although this study did not uncover significant group differences during walking and only observed two differences during the step-down task, variations in methodological parameters, beyond having larger sample sizes, across studies may reveal potential mechanisms of underlying disparities and similarities in findings. For example, a foundational study by Childs et al. (2004) investigated the influence of KOA on muscle activity, also encompassing co-activation, among individuals with unilateral KOA, both men and women, in comparison to a control group, where women constituted the majority in both sets. To be concise, Childs et al. (2004) found that individuals with KOA

exhibited earlier and prolonged muscle activation above and below the knee compared to those without KOA. Furthermore, abnormal co-activation was found between the hamstrings and vastus lateralis and tibialis anterior and gastrocnemius (Childs et al., 2004). These findings held true for both the step task and walking.

While the direct comparison of muscle activity duration to the findings of this study isn't applicable, the fundamental notion persists that changes in muscle activity above and below the knee during a step-down are associated with KOA. Therefore, the findings of this study seem to align with prior research findings. This also might serve as evidence of the new intrinsic neurological control described by Hortobagyi et al. (2005) and illustrate a mechanism in the pain group to alter muscle activity in response to intermittent pain. Nonetheless, there are some points of comparison to be addressed.

While Childs et al. (2004) matched participants, set a defined walking speed, and controlled for K-L grade severity, they did not directly analyze the influence of pain. It is plausible that the presence of these rigorous controls might have changed the findings and elucidated an influential mechanism. This study did not have these controls, and therefore, too much variability within groups may have existed for the other variables. For instance, the existing body of research establishes a direct correlation between the progression of knee joint deterioration, as measured by K-L grade, and the alteration of co-activation and muscle activity (Hatfield et al., 2021; Hodges et al., 2016; Hortobagyi et al., 2005; Hubley-Kozey et al., 2009; Rutherford et al., 2013). That is, as the knee joint worsens, so does the prevalence in atypical co-activation and increased muscle activity. Childs et al. (2004) was also able to assess knee joint alignment, which has been shown to impact the muscle activation results of the quadriceps (Lim et al., 2015). Additionally,

Hanlon and Anderson (2006) revealed that healthy participants ambulate at a higher preferred walking speed than those with KOA. With these items in mind, pain was not directly investigated in most of these studies. That is vital to discuss, as some researchers investigated the impact of pain, although not intermittent, with some of these controls in place.

Wilson et al. (2017) stratified participants as symptomatic and asymptomatic, while matching for K-L grade, to investigate the impact of pain on muscle activity. That study, unlike Childs et al. (2004) and the same as this research, used the same walkway distance of 6 meters, and allowed a self-selected pace across 5 trials (Wilson et al., 2017). Wilson et al. (2017) found that those with KOA and pain reported a higher mean activity in the vastus lateralis, but not the other muscles including the medial gastrocnemius, and semitendinosus. Wilson et al. (2017) did not assess the tibialis anterior. This difference is marginal, but controlling for K-L grade is clearly vital to accurately assess the impact of pain, of either type. Wilson et al. (2017) was also able perform motion analysis and therefore knee joint alignment, like Childs et al (2004). It could also be argued from these findings that walking speed, K-L grade, and knee joint alignment all need controlled or assessed, like in the Childs et al. (2004) study.

The covariates BMI and Age, both of which were higher in the pain group, yielded intriguing findings in this study. It is in line with expectations and, consequently, lends support to preceding research that age and BMI, while maintaining control over other variables, exert an influence on muscle activity during the 6-meter walk and 20-cm step-down tasks. That is, elevated age and greater BMI tend to correlate with heightened muscle activity and an increased likelihood of encountering aberrant coactivation patterns

(Clark et al., 2013; Hortobagyi et al., 2011; Rudolph et al., 2007; Rutherford et al., 2017; Schloemer et al., 2016; Sowers & Karvonen-Gutierrez, 2010). These findings also underscore the significance of regulating the impact of these variables, reinforcing the recommended need for their inclusion as controls.

Although statistical significance was not reached for the other muscles in the pain group, a discernible trend was consistently revealed across all muscle activity for the ST, VL, TA, and MG during both activities. Mean and mean peak muscle activity was higher in the pain group when compared to the control group in all but the MG. Abnormal co-activation above and below the knee followed the same trend. The previously discussed studies all found the same finding, including Wilson et al. (2017), who also found a lower mean MG muscle activity during walking. Including gathering data on a larger sample, which all the studies mentioned here had, several limitations likely influenced results.

*Limitations & Recommendations*

The absence of a requirement for disease severity assessment using a method such as the K-L scale (Kellgren and Lawrence, 1957) for study inclusion in the pain group introduced a limitation. While it is common in this type of research to control for severity (Childs et al., 2004; Hubley-Kozey et al., 2009; Wilson et al., 2017), this was considered potentially burdensome for participants, as some might not have had readily available access to this diagnostic criterion, necessitating a physician consultation for verification. Additionally, the current study lacked access to a hospital, or campus clinic, to offer a free of charge assessment.

For various reasons, it could be recommended that participants be stratified by severity level even if the impact of pain is included in analyses. As discussed in the

review of literature, pain can progress independent of disease progression, and vice versa (Neogi et al., 2013; Sharma, 2021). Regarding classification severity independently, Rutherford et al. (2013) noted that a more severe classification led to greater alteration in knee joint muscle activation. A similar observation was made by Hubley-Kozey et al. (2009) with respect to co-activation. This means that severity may have influenced results and introduced variability into the sample. That variability could be why there was such a large range of effect sizes as well. Therefore, it is highly recommended that future researchers stratify based on disease severity.

In addition, not setting a speed window could have introduced variability within and between groups, as walking speed can vary greatly between those with and without KOA (Astephen, 2012; Na et al., 2018; Zeni & Higginson, 2009). Although setting a window is not necessarily ecologically valid, setting a speed window, like in Childs et al. (2004), could aid in more accurately defining the impact of intermittent pain while accounting for potential outside influence. Lastly, although using an MVIC to normalize muscle activity values is valid, there is the ubiquitous concern that each pain group participant yielded an absolute MVIC. Therefore, there is a slight potential that the normalized activity values in that group were overestimated, which would limit the significance of the findings. It could therefore be recommended to normalize to a functional task.

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# APPENDICES FOR CHAPTER III

# APPENDIX A

Date: 7-20-2023

**IRB #:** IRB-FY2023-44
**Title:** The Impact of Intermittent Pain in Women with Osteoarthritis of the Knee on Biomechanics and Muscle Activation Patterns during Level Walking and Stair Descent
**Creation Date:** 1-23-2023
**End Date:**
**Status:** Approved
**Principal Investigator:** Conor Theiss
**Review Board:** MTSU Institutional Review Board
**Sponsor:**

## Study History

| | | |
|---|---|---|
| **Submission Type** Initial | **Review Type** Expedited | **Decision** Approved |

## Key Study Contacts

| | | |
|---|---|---|
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# APPENDIX B



## [EXTERNAL] IRB-FY2023-44 - Initial: Initial Expedited Protocol Approval Letter

do-not-reply@cayuse.com <do-not-reply@cayuse.com>
Mon 2/27/2023 11:22 AM
To:Conor Theiss <clt6m@mtmail.mtsu.edu>;John Coons <John.Coons@mtsu.edu>

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Date: February 27, 2023
PI: Conor Theiss
Department: Middle Tennessee State University, Health and Human Performance
Re: Initial - IRB-FY2023-44
The Impact of Intermittent Pain in Women with Osteoarthritis of the Knee on Biomechanics and Muscle Activation Patterns during Level Walking and Stair Descent

The Middle Tennessee State University Institutional Review Board has rendered the decision below for The Impact of Intermittent Pain in Women with Osteoarthritis of the Knee on Biomechanics and Muscle Activation Patterns during Level Walking and Stair Descent. The approval is effective starting February 27, 2023.

Decision: Approved
Category: 4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.)

Findings:
Research Notes:

**Please note:**

Any **modifications to the approved study must be submitted for review through Cayuse IRB.** Please note, as well, that according to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to complete the required training. If you add researchers to an approved project, please add them to the project within Cayuse IRB for approval **before** they begin to work on the project.

**Any unanticipated harm to participants or adverse events must be reported to the Office of Compliance,** and any subsequent changes to the protocol must be submitted to the IRB for review before implementing this change.

**You must submit an end-of-project form to the Office of Compliance upon completion of your research.** Completed research means that you have finished collecting data.

All research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion and then destroyed in a manner that maintains confidentiality and anonymity.

All approval letters and study documents are located within the Study Details in Cayuse IRB.

We wish you a successful research project,

*Middle Tennessee State University Institutional Review Board*

APPENDIX C

# 2021 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.



01-11-2020

# 2021 PAR-Q+

## 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 chemotherapy 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 ☐ |

# 2021 PAR-Q+

**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.**

 

01-11-2020

# 2021 PAR-Q+

**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+**
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

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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PRINT FORM RESET FORM

 4/ 4

01-11-2020

# APPENDIX D

**A Measure of Intermittent and Constant Osteoarthritis Pain, ICOAP: KNEE Version**

People have told us that they experience different kinds of pain (including aching or discomfort) in their knee. To get a better sense of the different types of knee pain you may experience, we would like to ask you about any "constant pain" (pain you have all the time) separately from any pain that you may experience less often, that is, "pain that comes and goes". The following questions will ask you about the pain that you have experienced in your knee in the PAST WEEK. Please answer ALL questions.

## A) CONSTANT PAIN

For each of the following questions, please select the response that best describes, on average, your *constant knee pain* in the PAST WEEK.

1. In the past week, how intense has your *constant knee pain* been?

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

2. In the past week, how much has your *constant knee pain* affected your sleep?

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

3. In the past week, how much has your *constant knee pain* affected your overall quality of life?

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

4. In the past week, how frustrated or annoyed have you been by your *constant knee pain?*

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

5. In the past week, how upset or worried have you been by your *constant knee pain*?

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

**B) PAIN THAT COMES AND GOES**

**For each of the following questions, please select the response that best describes your *knee pain that comes and goes*, *on average*, in the PAST WEEK.**

**6. In the past week, how intense has your most severe *knee pain that comes and goes* been?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**7. In the past week, how frequently has this *knee pain that comes and goes* occurred?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Never/ No knee pain that comes and goes | Rarely | Sometimes | Often | Very Often |

**8. In the past week, how much has your *knee pain that comes and goes* affected your sleep?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**9. In the past week, how much has your *knee pain that comes and goes* affected your overall quality of life?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**10. In the past week, how frustrated or annoyed have you been by your *knee pain that comes and goes*?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**11. In the past week, how upset or worried have you been by your *knee pain that comes and goes*?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**THANK YOU!**

# CHAPTER IV: THE IMPACT OF INTERMITTENT PAIN IN WOMEN WITH OSTEOARTHRITIS OF THE KNEE ON FOOT PRESSURE DISTRIBUTION AND GAIT PARAMETERS DURING LEVEL WALKING AND STEP DOWN

## *Introduction*

In addition to other definitions, osteoarthritis is a disease characterized by failed repair of joint damage caused either by stress or certain tissue abnormalities, which usually yields a combination of cartilage loss, joint change, and pain (Sharma, 2021). Although diagnosed in many parts of the body, osteoarthritis of the knee (KOA) is the most common form of OA impacting over 30 million individuals in the United States (Arthritis Foundation, 2020; Centers for Disease Control, 2020; Mobasheri & Batt, 2016; Sharma, 2021). The most common demographic impacted by this disease is the elderly, as those that are 55 to 64 years of age have the highest lifetime risk of developing this disease (Losina et al., 2013; Sharma, 2021). While KOA is common in both sexes, females are 2 to 3 times likely to develop KOA, and experience more intense symptoms than males (Hame et al., 2013; McKean et al., 2007; Phinyomark et al., 2016; Sharma et al., 2021; Sims et al., 2009).

For instance, pain experienced by females is more severe than males, which has led to higher rates of reported pain in clinical trials (Hame et al., 2013; McKean et al., 2007; Phinyomark et al., 2016; Sims et al., 2009; Zajdman et al., 2022). Females, most likely due to pain, have also yielded severely altered knee biomechanics during ambulation, while males appear to demonstrate much less change when compared to healthy controls (McKean et al., 2007; Phinyomark et al., 2016).

Osteoarthritis of the knee (KOA) is considered the leading cause of walking difficulty in participants when combined with comorbidities such as aging (Fritz & Mitchell, 2009; Guccione et al., 1994; Munoz-Organero et al., 2017; Na et al., 2018; Nuesch et al., 2011; Sharma, 2021). For instance, researchers have demonstrated during walking and stair descent that participants with KOA and pain, exhibited less knee adduction, excursion, extension moments, loaded weight on the center of the foot, used both legs when bearing weight, and transitioned force from his or her heal to the midfoot faster (Costello et al., 2021; Igawa & Katusuhira, 2014; Munoz-Organero et al., 2017; Na et al., 2018; Wilson et al., 2017). This is indicative of a stiff knee joint, flat foot walking, and favoring, which all abnormally load the knee (Costello et al., 2021).

Recently, Costello et al. (2021) confirmed these findings, as those who had KOA and reported pain, and those who just had pain, produced lower peak force production, flatter curves, and higher mid-stance forces. However, these findings were discovered only after controlling for sex, BMI, age, and race, which suggests that these altered pressure distribution and gait patterns could be indicative of favoring or guarding due to the impact of pain (Costello et al., 2021). Such findings are common as pain is the most limiting factor of this disease, especially in older individuals (Gay et al., 2019; Guccione, 1994; Sharma, 2021). The impact of severity of pain is also important to note, as it was demonstrated that as pain worsens, so do outcomes, such as walking pressure distribution (Munoz-Organero et al, 2017).

Although findings like these are important, none of these studies accounted for intermittent pain, which has been found to be distressing and limiting, as this type of pain has been correlated with a decrease in physical activity over time (Hawker et al., 2008a;

Hawker et al., 2008b; Davison et al., 2016). Given the impact of intermittent pain, the intermittent and constant osteoarthritis pain index (ICOAP) was created to track not only intermittent pain, but the severity of it (Hawker et al., 2008a). This scale is even recommended for use in this population, to gather pain data (McAlindon et al., 2015).

To date, there is no description of how intermittent pain in those with KOA impacts pressure distribution of the foot, and knee joint angle during functional tasks. This gap in literature also includes how different severity levels of intermittent pain impact outcomes. Describing the negative impact of intermittent pain on gait parameters and pressure distribution during gait would be impactful for clinicians and those with KOA alike, as it could provide the knowledge necessary to intervene earlier in disease course, which has been described as highly difficult (Wilson et al., 2017).

Therefore, the purpose of this study is to evaluate and describe the impact of reported intermittent pain on kinetics and kinematics during level walking at a self-selected pace, and during a 20-centimeter stair descent, in those with KOA. Given the findings described here, those with reported intermittent pain should yield severely altered pressure distribution consistent with flat foot walking, favoring, or transitioning from the heal to forefoot faster in the most painful leg, and have less knee excursion during the above tasks, when compared to healthy controls.

## ***Materials and Methods***

### *Study Design*

This was a non-randomized case-control study. This design ensured that the impact of intermittent pain on outcomes during a 6-meter walk and 20-centimeter step-down in those in a pain group can be compared to those in a control group. The

Institutional Review Board at Middle Tennessee State University approved this study and the procedures herein (see Appendices A & B).

*Participants*

Participants in the pain group included women ($n$ = 7), that had a clinical diagnosis of KOA, and self-reported intermittent pain as obtained by the intermittent and constant osteoarthritis pain index (ICOAP; see Appendix C) (Childs et al, 2004; Hawker et al., 2008a; Kessler et al., 2011; Wilson et al., 2017). Those in the control group included women ($n$ = 10) who had no diagnosed KOA or reported intermittent pain. Participants were excluded from either group if they were unable to demonstrate, at the data collection session, the ability to safely walk distances greater than 200 ft without the use of assistive devices, had a history of ligament injury to the diagnosed knee, had undergone total knee arthroplasty, or had any neurological disease(s) that impacted walking (Childs et al., 2004; Hortobagyi et al., 2005; Wilson et al., 2017).

In addition, participants were excluded from either group if they were unable to walk upstairs in a reciprocal manner (Childs et al., 2004; Wilson et al., 2017). Given the complexity of including both sexes discussed in the introduction, men were excluded from participation. In this population, age and BMI have been shown to directly influence and alter walking mechanics and joint load (Costello et al., 2021; Harding et al., 2012; McKean et al., 2007). Therefore, these variables were treated as covariates. Body mass index (BMI) is simply a ratio of mass in kilograms to height in meters squared ($kg/m^2$; *ACSM's Guidelines for Exercise Testing and Prescription*, 2022, p. 63).

Furthermore, interarticular injection is a common pain management strategy for those diagnosed with KOA (Mora et al., 2018). The duration of pain relief experienced

by an individual using this type of pain management is dependent on the dosage and type of medication administered, which can range from 2 weeks to 6 months (Arroll & Goodyear-Smith, 2004; Bellamy et al., 2006; Buyuk et al., 2017; Da Costa et al., 2021; Hirsch et al., 2013; Law et al., 2015; Mora et al., 2018; Yavuz et al., 2012). To avoid introducing variability, any participant in the pain group who reported having had an interarticular injection within 6-months of the data collection session was excluded (Deyle et al., 2020; Fransen et al., 2015; Sinusas, 2012). Given the commonality, and small impact of some oral and topical pain medications, it was not requested that participants cease oral pain medication use (Da Costa et al., 2021; Deyle et al., 2020; Fransen et al., 2015; Hmamouchi et al., 2012; Sinusas, 2012).

*Functional Movements*

During the movements described here, those in the pain group had data gathered on the most painful leg. (Childs et al., 2004; Wilson et al., 2017). The control group had data gathered on a randomized leg (Wilson et al., 2017). This limb selection is common, and according to research, is mainly due to lack of limb kinetic or kinematic congruence during gait in healthy or unhealthy populations (Radzak et al., 2017). Even if dominance and function are controlled, there is still a potential to artificially introduce differences, and therefore artificially inflate effect size, between groups simply due to abnormalities between limbs regardless of the impact of an independent variable (Menz et al., 2004; Radzak et al., 2017).

To perform the step-down procedure, each participant was asked to step up on a 20-centimeter-tall box using the asymptomatic leg, and then when prompted, step down on to the most painful leg or randomized leg in the control group (Childs et al., 2004).

The walking trials were completed by having each participant walk over level ground for 6 meters, in normal shoe wear, at a comfortable self-selected pace (Wilson et al., 2017). This type of gait analysis is not only simple but has high day to day repeatability (Robbins et al., 2013). Walking at a self-selected pace and step navigation, at the height proposed above, has been recommended by Osteoarthritis Research Society International (OARSI) as valid means of gathering data on movement capacity in those with KOA (Fitzgerald et al., 2017; McAlindon et al., 2015).

*Procedures*

Each participant attended one data collection session. At this session, participants read and signed the informed consent document and were assessed for physical activity readiness and medication use via the physical activity readiness questionnaire (PAR-Q+, see Appendix C). After applying inclusion criteria, participants were placed in either the pain or control group. Once participants were in a group, each participant's height was assessed to the nearest 0.1 cm using a stadiometer (SECA Corporation, Model 222, Hamburg, Germany) and body mass was measured to the nearest 0.1 kg using a digital scale (Tanita Corporation, Model BF-522, Arlington Heights, IL).

Pressure mapping was gathered via a wireless F-scan sport model 3001 E shoe insert (Tekscan, Incorporated, Norwood, MA). These thin and lightweight (0.152 millimeters) sensors were placed in each participant's shoe and fitted over any orthotic worn by the participant, as these sensors can be trimmed with scissors from a men's size 14 (US) to an infant size. Each participant was also given a moister wicking nylon sock to protect the sensor, as per recommendations by Tekscan. Once placed in the shoe, a portion of the sensor was left out of the shoe and attached to the lateral ankle via a cuff.

This remaining portion of the sensor, now attached to the ankle, was then connected to a battery pack worn around the waist of each participant via a waist band. This equipment has been validated for use in this population (Isao et al., 2013).

Once the system was attached to the participant, a brief walking calibration test occurred. This will be completed as per the recommendation provided by Tekscan and include having each participant walk back and forth at her normal pace for 200 meters. That was roughly 10 laps on the 6-meter walkway. This calibration is also adequate to calibrate the system for the step-down, according to Tekscan. To ensure no upward drift occurred, the sensor was also zeroed. Not doing so could have created pressure readings that were artificially high. This required each participant to lift her leg off the ground while the principal investigator initiated the zero button on the Tekscan software. This is not only recommended by Tekscan but has also been used previously in gait analysis (Lugade & Kaufman, 2014).

Following the above, pressure mapping data was then gathered during five trials of a 6-meter walk, and during five trials of a 20-centimeter step-down (Childs et al., 2004; Wilson et al., 2017). There was at least one minute of rest between trials to avoid any detrimental impact of fatigue (Wilson et al., 2017). Lastly, knee excursion was tracked via electronic bi-axial goniometers (Biometrics Ltd., Newport, United Kingdom) attached to the lateral aspect of the leg. This system is integrated into the Delsys system mentioned in chapter 3, but this is technically a kinematic measure.

Regarding the 11-item ICOAP (see Appendix D), this scale has been validated, has demonstrated high retest-reliability, and high internal consistency (Davison et al., 2016). Furthermore, this scale provided a valid means of gathering data on (KOA), in

older individuals, cross-culturally, and across different languages, as a means to effectively and easily assess intermittent pain or chronic pain separate from physical function, and is even a recommendation by OARSI to track pain in this population (Hawker et al., 2008a; Maillefert et al., 2009; McAlindon et al., 2015; Moreton et al., 2012).

The ICOAP score can range from 0 to 24 with zero being no pain and 24 being extreme pain (Hawker et al., 2008a). To meet study inclusion for the pain group and given the novel nature of using a scale like this one for an observational study, inclusion in the pain group was those who scored greater than 0 out of 24 on items 6 - 11 on the ICOAP (Hawker et al., 2008a). That was consistent with selecting at least answer choice 1 to items 6 through 11 on the ICOAP, which is indicative of mild or rare impact of intermittent pain (Hawker et al., 2008a).

*Data Processing*

Data gathered via the F-scan 3001 E sport sensors were gathered at 15 frames per second, calculated in the F-scan system version 7.5X, and then exported to Microsoft Excel (2019). This data included pressure in pounds loaded on the heel, midfoot and metatarsal, percentage of body mass loaded on the heel, midfoot, and metatarsal, time spent loading the heel, midfoot, and metatarsals, stance time, swing time, stride time, cadence, and center of force trajectory. During gait analysis in this population, these measures have been gathered previously (Childs et al., 2004; Igawa & Katusuhira, 2014; Munoz-Organero et al., 2017; Saito et al., 2013; Wilson et al., 2017).

Lastly, knee excursion, gathered via the wireless goniometer, mentioned in the procedure section, was processed in the Delsys software to gather the amount of knee

flexion in degrees during the stance phase of gait and during the load acceptance phase of the step-down. Unlike the Delsys electrodes used in chapter three, this wireless goniometer was not filtered or smoothed rather left in unfiltered degrees range of motion to assess knee excursion more accurately. Of note, The F-scan sensor output data was used to assess where the stance phases and weight acceptance phases were for each participant during the walking and step-down respectively. This ensured synchronous data gathering between the goniometer and F-scan.

*Statistical Analysis*

IBM© SPSS© Statistics (IBM Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp). was used for statistical analyses. Descriptive statistics included height, weight, age, and BMI, which are listed as means ± standard deviations. Given the questions posed here, a between groups one-way analysis of covariance (ANCOVA) ($\alpha = .05$) was selected, for the walking trials, to assess group differences on center of force trajectory (COF), pressure mapping along the bottom of the foot (time spent loading, peak force in pounds, and percentage of body weight loaded on heel, midfoot, and metatarsals), stance time, swing time, stride time, and cadence.

Data gathered for the step-down included pressure mapping along the bottom of the foot consistent with force in pounds on the heel, midfoot and metatarsals and percentage of body mass loaded on the heel, midfoot, and metatarsals. All data were averaged across 5 trials to reduce group variance, as well as to reduce sample redundancy (Hubley-Kozey et al., 2008). Lastly, knee excursion data were assessed for group differences during the stance phase of gate and the load acceptance phase of the 20-centimeter step down. Given the potential for impact on outcomes, age in years and body

mass index (BMI) were considered confounding variables in the analyses. Partial eta squared was calculated for effect size.

***Results***

Participant demographics are listed in Table 1. A one-way between groups analysis of covariance was conducted to assess the impact of reported intermittent pain on gait parameters and foot pressure distribution during the stance phase of a 6-meter walk and during the load acceptance phase of 20-centimeter step-down. Load acceptance occurred when each participant contacted the ground and loaded her body mass onto the test leg. Given the purpose of the ICOAP, the severity of pain, in this case a higher reported score from person to person on the ICOAP, was not considered. Age and BMI were considered co-variates.

Preliminary assessments, including Levene's test, Q-Q plot, and residual plot, were conducted to ensure no violations of homogeneity, normality, and linearity respectfully for all analyses described below. A one-way between groups analysis of covariance (ANCOVA) revealed, regarding the gait parameters, there was no statistically significant difference between groups, regarding center of force trajectory, cadence in steps per minute, stride time in seconds, stance time in seconds, swing time in seconds, and knee joint excursion in degrees during the 6-meter walk (see Tables 2 - 7). There was also no statistically significant difference between groups in degrees of knee excursion during the load acceptance phase of the 20-centimeter step down (see Table 8).

Regarding foot pressure distribution during the 6-meter walk, there were no statistically significant differences between groups in force in pounds loaded on the heel, midfoot, or metatarsals (see Tables 9 - 11). This was also true for the percentage of body

weight loaded on the heel, midfoot or metatarsals (see Tables 12 - 14). In addition, there was no statistically significant difference between groups in time spent loading the heel, midfoot, or metatarsals (see Tables 15 - 17).

Regarding the 20-centimeter stepdown, there was no statistically significant difference between groups in force in pounds loaded on the heel, midfoot, or metatarsals (see Tables 18 - 20). However, while controlling for intermittent pain and Age, there was a statistically significant difference between groups in force in pounds loaded on the metatarsals, $F(1,13) = 5.33$, $p = .038$, partial eta squared = .291. This means BMI explained 29.1% of the variance in the pain group, and this was a large effect size (Field, 2018). Furthermore, for every one unit increase in BMI, those in the pain group loaded, on average, 4.015 ($\beta = 4.015$) more pounds on the metatarsals when compared to the control group. In addition, while controlling for intermittent pain and Age, there was a significant difference between groups on pounds loaded on the midfoot, $F(1,13) = 6.60$, $p = .023$, partial eta squared = .337. This means BMI explained 33.7% of the variance in the pain group, and this was a large effect size (Field, 2018). Furthermore, it was found that those in the pain group, on average, for every one unit increase in BMI, loaded 1.79 ($\beta = 1.79$) more pounds on the midfoot compared to the control group. There was no statistically significant difference in the percentage of body weight loaded on the heel, midfoot, or metatarsals during the 20-centimeter step down (see Tables 21 - 23). Lastly, although not directly impactful on group differences, the intercept regarding cadence, stride time, stance time, and swing time was significant. This means a factor not assessed in the analysis impacted variables in the pain and control group.

Table 1

*Participant demographics*

| | Control | | Intermittent Pain | |
|---|---|---|---|---|
| | *n* (10) | | *n* (7) | |
| Sex (Female) | | | | |
| | ***M*** | ***±SD*** | ***M*** | ***±SD*** |
| Height (m) | 1.676 | 0.075 | 1.63 | 0.068 |
| Weight (kg) | 69.09 | 13.79 | 90.45 | 10.95 |
| Age (Years) | 59 | 9.17 | 62 | 8.71 |
| BMI ($kg/m^2$) | 24.47 | 3.5 | 34.51 | 5.99 |

*Note*: BMI is body mass index.

Table 2
*Analysis of Covariance for Center of Force Trajectory Percentage during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 1.55 | 0.249 | 0.264 | |
| Main Effect | | | | 13.00 | 0.09 | 0.768 | 0.007 | 1.22 |
| Pain group | 17.71 | 6.58 | 7 | | | | | |
| Control group (reference) | 14.80 | 4.39 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 1.85 | 0.196 | 0.125 | -0.204 |
| BMI ($kg/m^2$) | | | | | 0.59 | 0.455 | 0.044 | 0.229 |

*Note: F*(3,13) = 1.55, *p* = .249, partial eta squared = .264. BMI is body mass index.

Table 3

*Analysis of Covariance for Cadence in steps per minute during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 1.36 | 0.298 | 0.239 | |
| Main Effect | | | | 13.00 | 0.83 | 0.378 | 0.06 | -2.96 |
| Pain group | 54.29 | 2.69 | 7 | | | | | |
| Control group (reference) | 58.20 | 4.51 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.35 | 0.566 | 0.026 | -0.071 |
| BMI ($kg/m^2$) | | | | | 0.09 | 0.760 | 0.007 | -0.074 |

*Note: F* (3,13) = 1.36, *p* = .298, partial eta squared = .239. Cadence was the average steps per minute across 5 trials. BMI is body mass index.

Table 4

*Analysis of Covariance for Stride Time in seconds during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 1.35 | 0.303 | 0.237 | |
| Main Effect | | | | 13.00 | 0.82 | 0.382 | 0.059 | 0.054 |
| Pain group | 1.11 | 0.05 | 7 | | | | | |
| Control group (reference) | 1.04 | 0.08 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.17 | 0.686 | 0.013 | 0.001 |
| BMI ($kg/m^2$) | | | | | 0.13 | 0.720 | 0.01 | 0.002 |

*Note: F* (3,13) = 1.35, *p* = .303, partial eta squared = .237. Stride time was the average in seconds across 5 trials. BMI is body mass index.

Table 5

*Analysis of Covariance for Stance time in seconds during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 1.99 | 0.165 | 0.315 | |
| Main Effect | | | | 13.00 | 1.25 | 0.284 | 0.088 | 0.051 |
| Pain group | 0.72 | 0.05 | 7 | | | | | |
| Control group (reference) | 0.66 | 0.06 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.10 | 0.762 | 0.007 | -0.001 |
| BMI ($kg/m^2$) | | | | | 0.27 | 0.613 | 0.02 | 0.002 |

*Note: F* (3,13) = 1.99, *p* = .165, partial eta squared = .315. Stance time was the average in seconds across 5 trials. BMI is body mass index.

Table 6

*Analysis of Covariance for Swing Time in seconds during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.44 | 0.731 | 0.09 | |
| Main Effect | | | | 13.00 | 0.01 | 0.917 | 0.001 | 0.004 |
| Pain group | 0.39 | 0.03 | 7 | | | | | |
| Control group (reference) | 0.38 | 0.05 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 1.08 | 0.317 | 0.07 | 0.001 |
| BMI ($kg/m^2$) | | | | | 0.01 | 0.936 | 0.001 | <.001 |

*Note: F* (3,13) = .44, *p* = .731, partial eta squared = .09. Swing time was the average in seconds across 5 trials. BMI is body mass index.

Table 7

*Analysis of Covariance for Knee Excursion in Degrees during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.66 | 0.591 | 0.132 | |
| Main Effect | | | | 13.00 | 0.22 | 0.646 | 0.017 | 2.21 |
| Pain group | 13.25 | 2.47 | 7 | | | | | |
| Control group (reference) | 15.43 | 7.29 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.24 | 0.630 | 0.018 | -0.086 |
| BMI ($kg/m^2$) | | | | | 1.41 | 0.256 | 0.098 | -0.411 |

*Note: F*(3,13) = .66, *p* = .591, partial eta squared = .132. Knee Excursion is the amount of knee flexion during the stance phase of gait. BMI is body mass index.

Table 8
*Analysis of Covariance for Knee Excursion in degrees during a 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.44 | 0.731 | 0.091 | |
| Main Effect | | | | 13.00 | 0.69 | 0.421 | 0.051 | 4.368 |
| Pain group | 18.53 | 4.48 | 7 | | | | | |
| Control group (reference) | 18.56 | 7.58 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.65 | 0.435 | 0.048 | -0.157 |
| BMI ($kg/m^2$) | | | | | 1.02 | 0.331 | 0.073 | -0.391 |

*Note: F*(3,13) = .44, *p* = .731, partial eta squared = .091. Knee excursion is the amount of knee flexion during the load acceptance phase of the step-down. BMI is body mass index.

Table 9

*Analysis of Covariance for Force in pounds loaded on Heel during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.46 | 0.717 | 0.095 | |
| Main Effect | | | | 13.00 | 0.18 | 0.680 | 0.014 | -12.436 |
| Pain group | 105.31 | 35.40 | 7 | | | | | |
| Control group (reference) | 103.66 | 37.52 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.42 | 0.529 | 0.031 | -0.705 |
| BMI ($kg/m^2$) | | | | | 0.55 | 0.471 | 0.041 | 1.613 |

*Note: F*(3,13) = .46, *p* = .717, partial eta squared = .095. BMI is body mass index.

Table 10

*Analysis of Covariance for Force in pounds loaded on Midfoot during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 4.33 | 0.025 | 0.50 | |
| Main Effect | | | | 13.00 | 0.09 | 0.764 | 0.007 | 3.551 |
| Pain group | 47.23 | 20.05 | 7 | | | | | |
| Control group (reference) | 27.88 | 13.62 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.62 | 0.445 | 0.046 | -0.337 |
| BMI ($kg/m^2$) | | | | | 3.86 | 0.071 | 0.229 | 1.673 |

*Note: F*(3,13) = 4.33, *p* = .025, partial eta squared = 0.5. BMI is body mass index.

Table 11
*Analysis of Covariance for Force in pounds loaded on Metatarsals during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 2.22 | 0.135 | 0.339 | |
| Main Effect | | | | 13.00 | 0.05 | 0.824 | 0.004 | 6.458 |
| Pain group | 163.60 | 47.61 | 7 | | | | | |
| Control group (reference) | 129.72 | 28.82 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.37 | 0.554 | 0.028 | -0.641 |
| BMI ($kg/m^2$) | | | | | 1.94 | 0.187 | 0.13 | 2.921 |

*Note: F*(3,13) = 2.22, *p* = .135, partial eta squared = .339. BMI is body mass index.

Table 12
*Analysis of Covariance for Percentage of Body weight loaded on Heel during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.70 | 0.569 | 0.139 | |
| Main Effect | | | | 13.00 | 0.31 | 0.586 | 0.023 | -9.964 |
| Pain group | 53.69 | 18.49 | 7 | | | | | |
| Control group (reference) | 68.76 | 23.11 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.26 | 0.619 | 0.02 | -0.337 |
| BMI ($kg/m^2$) | | | | | 0.10 | 0.761 | 0.007 | -0.408 |

*Note: F*(3,13) = .70, *p* = .569, partial eta squared = .139. BMI is body mass index.

Table 13
*Analysis of Covariance for Percentage of Body weight loaded on Midfoot during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.97 | 0.438 | 0.182 | |
| Main Effect | | | | 13.00 | 0.09 | 0.769 | 0.007 | 1.995 |
| Pain group | 23.34 | 7.88 | 7 | | | | | |
| Control group (reference) | 18.26 | 8.57 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.47 | 0.505 | 0.035 | -0.169 |
| BMI ($kg/m^2$) | | | | | 0.53 | 0.478 | 0.039 | 0.358 |

*Note: F*(3,13) = .97, *p* = .438, partial eta squared = .182. BMI is body mass index.

Table 14
*Analysis of Covariance for Percentage of Body weight loaded on Metatarsals during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3.00 | 0.193 | 0.90 | 0.043 | |
| Main Effect | | | | 13.00 | 0.018 | 0.90 | 0.001 | 2.227 |
| Pain group | 82.43 | 21.39 | 7 | | | | | |
| Control group (reference) | 86.82 | 19.28 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.31 | 0.585 | 0.024 | -0.347 |
| BMI ($kg/m^2$) | | | | | 0.202 | 0.660 | 0.015 | -0.555 |

*Note: F*(3,13) = .193, *p* = .899, partial eta squared = .043. BMI is body mass index.

Table 15

*Analysis of Covariance for Time in seconds Loading the Heel during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.40 | 0.757 | 0.084 | |
| Main Effect | | | | 13.00 | 0.46 | 0.508 | 0.034 | 0.046 |
| Pain group | 0.54 | 0.10 | 7 | | | | | |
| Control group (reference) | 0.52 | 0.07 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.33 | 0.576 | 0.025 | 0.001 |
| BMI ($kg/m^2$) | | | | | 0.35 | 0.565 | 0.026 | -0.003 |

*Note: F*(3,13) = .40, *p* = .757, partial eta squared = .084. BMI is body mass index.

Table 16
*Analysis of Covariance for Time in seconds Loading the Midfoot during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.80 | 0.518 | 0.155 | |
| Main Effect | | | | 13.00 | 1.52 | 0.239 | 0.105 | 0.068 |
| Pain group | 0.64 | 0.08 | 7 | | | | | |
| Control group (reference) | 0.59 | 0.06 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.10 | 0.756 | 0.008 | 0.001 |
| BMI ($kg/m^2$) | | | | | 0.34 | 0.570 | 0.025 | -0.002 |

*Note: F*(3,13) = .80, *p* = 518, partial eta squared = .155. BMI is body mass index.

Table 17
*Analysis of Covariance for Time in Seconds Loading the Metatarsals during 6-meter walk*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 2.61 | 0.096 | 0.375 | |
| Main Effect | | | | 13.00 | 2.64 | 0.128 | 0.169 | 0.088 |
| Pain group | 0.64 | 0.07 | 7 | | | | | |
| Control group (reference) | 0.55 | 0.06 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.63 | 0.442 | 0.046 | 0.002 |
| BMI ($kg/m^2$) | | | | | 0.003 | 0.955 | <.001 | <.001 |

*Note*: $F(3,13) = 2.61$, $p = .096$, partial eta squared = .375. BMI is body mass index.

Table 18
*Analysis of Covariance for Force in Pounds loaded on Heel during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.27 | 0.847 | 0.058 | |
| Main Effect | | | | 13.00 | 0.21 | 0.652 | 0.016 | 11.28 |
| Pain group | 88.54 | 36.21 | 7 | | | | | |
| Control group (reference) | 76.50 | 23.34 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.14 | 0.713 | 0.011 | -0.34 |
| BMI ($kg/m^2$) | | | | | 0.01 | 0.924 | 0.001 | 0.176 |

*Note: F*(3,13) = .27, *p* = .847, partial eta squared = .058. These values were gathered during the load acceptance phase of the step-down. BMI is body mass index.

Table 19
*Analysis of Covariance for Force in Pounds loaded on Midfoot during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 6.90 | 0.005 | 0.614 | |
| Main Effect | | | | 13.00 | 0.07 | 0.797 | 0.005 | 2.474 |
| Pain group | 58.34 | 15.07 | 7 | | | | | |
| Control group (reference) | 39.02 | 14.74 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 1.06 | 0.321 | 0.076 | -0.36 |
| BMI ($kg/m^2$) | | | | | 6.60 | 0.023 | 0.337 | 1.785 |

*Note: F*(3,13) = 6.90, *p* = .005, partial eta squared = .614. These values were gathered during the load acceptance phase of the step-down. BMI is body mass index.

Table 20
*Analysis of Covariance for Force in Pounds loaded on Metatarsals during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 3.04 | 0.067 | 0.412 | |
| Main Effect | | | | 13.00 | 0.32 | 0.582 | 0.024 | -13.316 |
| Pain group | 119.84 | 33.64 | 7 | | | | | |
| Control group (reference) | 92.64 | 33.50 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.00 | 0.949 | < .001 | 0.057 |
| BMI ($kg/m^2$) | | | | | 5.33 | 0.038 | 0.291 | 4.015 |

*Note: F*(3,13) = 3.04, *p* = .067, partial eta squared = .412. These values were gathered during the load acceptance phase of the step-down. BMI is body mass index.

Table 21
*Analysis of Covariance for Percent of Body Weight Loaded on Heel during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.52 | 0.674 | 0.108 | |
| Main Effect | | | | 13.00 | 0.24 | 0.634 | 0.018 | 6.615 |
| Pain group | 45.55 | 20.52 | 7 | | | | | |
| Control group (reference) | 50.58 | 13.73 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.20 | 0.659 | 0.015 | -0.227 |
| BMI ($kg/m^2$) | | | | | 1.20 | 0.294 | 0.084 | -1.091 |

*Note: F*(3,13) = .70, *p* = .569, partial eta squared = .139. These values were gathered during the weight acceptance phase of the step-down. BMI is body mass index.

Table 22
*Analysis of Covariance for Percent of Body Weight Loaded on Midfoot during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.92 | 0.459 | 0.175 | |
| Main Effect | | | | 13.00 | 0.04 | 0.852 | 0.003 | 1.122 |
| Pain group | 29.04 | 4.62 | 7 | | | | | |
| Control group (reference) | 25.76 | 8.92 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 1.01 | 0.333 | 0.072 | -0.22 |
| BMI ($kg/m^2$) | | | | | 0.42 | 0.531 | 0.031 | 0.28 |

*Note: F*(3,13) = .97, *p* = .438, partial eta squared = .182. These values were gathered during the load acceptance phase of the step-down. BMI is body mass index.

Table 23
*Analysis of Covariance for Percent of Body Weight Loaded on Metatarsals during 20-centimeter step-down*

| **Source** | ***M*** | **±*SD*** | ***n*** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ | **β** |
|---|---|---|---|---|---|---|---|---|
| | | | | Between subjects | | | | |
| **Source: Reduced Model** | | | | 3 | 0.12 | 0.948 | 0.027 | |
| Main Effect | | | | 13.00 | 0.33 | 0.577 | 0.024 | -9.726 |
| Pain group | 60.13 | 14.81 | 7 | | | | | |
| Control group (reference) | 62.60 | 23.37 | 10 | | | | | |
| Main Effect (covariates) | | | | | | | | |
| Age (Years) | | | | | 0.07 | 0.800 | 0.005 | 0.163 |
| BMI ($kg/m^2$) | | | | | 0.29 | 0.600 | 0.022 | 0.673 |

*Note: F*(3,13) = .19, *p* = .899, partial eta squared = .043. These values were gathered during the load acceptance phase of the step-down. BMI is body mass index.

***Discussion***

The purpose of this exploratory study was to evaluate the effect of intermittent pain on gait parameters, and the distribution of foot pressure during a self-paced 6-meter walk and a 20-centimeter step-down task, in women diagnosed with KOA. However, the presence of intermittent pain did not lead to statistically significant effects on the observed outcomes. In accordance with previous research, women who report experiencing intermittent pain typically exhibit a series of distinct alterations in their gait during both walking and stair descent tasks. These alterations encompass shifts in foot pressure distribution to avoid loading the heel, reduced heel contact duration in comparison to the midfoot and metatarsals, diminished knee flexion or excursion, and an overall altered duration of loading on the foot of the most painful knee. These cumulative alterations consequently bring about modifications in cadence, stride, stance, and swing time (Costello et al., 2021; Davison et al., 2016; Hame & Alexander, 2013; Hodges et al., 2016; Hunt et al., 2010; Igawa & Katusuhira, 2014; Munoz-Organero et al., 2017; Na et al., 2018; Saito et al., 2013).

While no significant findings were found in this study, it is worth noting that there are still several comparable trends that allow us to draw upon previous research to reveal potential mechanisms that may have led to these findings. Specifically, it was observed that the pain group exhibited a higher percentage of body weight loaded on the midfoot and lower percentages on the heel and metatarsals during both the self-paced 6 m walk and the 20-cm. step-down task. These results are like the findings of Childs et al. (2004) and Saito et al. (2013) during walking and step-down tasks. Childs et al. (2004) reported a reduced percentage of overall body mass loading on the most painful or tested leg in

persons with KOA. Similarly, Saito et al. (2013) described that KOA patients exhibited a higher percentage of body weight distributed to the midfoot, as opposed to the heel or metatarsals. Notably, the Saito et al. (2013) study did not incorporate a step down. However, their use of the F-scan system strengthens the relevance of their findings to the findings of the current study. This could be evidence of the abnormal gait pattern known as midfoot walking and favoring as an adaptation to pain described by Munoz-Organero et al. (2017); however, further explorations with different controls are needed to confirm this assertion.

In addition to the above findings, knee excursion during both the self-paced 6 m walk and 20 cm step-down also exhibited trends with previous studies. Specifically, the pain group presented less knee flexion compared to the control group, which aligns with the findings of Astephen et al. (2008), Childs et al. (2004), Igawa & Katsuhira (2014), and Wilson et al. (2017). It is important to recognize that there are some notable differences between the methods used in the studies mentioned and the current study, other than larger sample sizes, which are likely to have impacted findings.

Childs et al. (2004) selected strict controls including a window for walking speed, and joint severity, measured via the K-L grade. It is well established that joint severity directly impacts the biomechanics of walking and stair descent (Astephen et al., 2008; Costello et al., 2021; Hall et al., 2017; Igawa & Katsuhira, 2014; Saito et al., 2013). That is, as joint severity worsens, so do gait parameters, such as knee joint excursion, stance time, swing time, stride time, cadence, and pressure distribution. This is important for several reasons. Chronic pain is known to elicit biomechanical changes independent of K-L grade, as shown by Wilson et al. (2017). Conversely, the worsening of severity (K-L

grade) may also alter biomechanics in the absence of pain, as shown by Hunt et al. (2010). While not directly comparable to the current study, it is certainly an issue to consider when deciding whether to control walking speed or disease severity. In this instance, not controlling these variables likely introduced excessive variability within pain group for the foot and gait parameters, which is indicative of no significant findings and a wide range of effect sizes.

Lastly, it is important to note that none of these studies assessed the impact of intermittent pain, and other than Saito et al. (2013), used different methods to gather gait parameters such as force plates, and motion analysis systems. Also, there was likely an outside factor that influenced results regarding cadence, stance, swing, and stride time. Combining these controls with the current study parameters may yield a more precise description of how the pathology of KOA impacts those diagnosed. Beyond the differences between the methods of this study and past research, there were some notable limitations.

*Limitations & Recommendations*

Disease severity, commonly tracked by K-L grade (Childs et al, 2004; Hubley-Kozey et al., 2009; Kellgren and Lawrence, 1957; Wilson et al., 2017), was not a requirement for study inclusion into the pain group and could be considered a limitation. Given the lack of access to a hospital or capable campus clinic, requiring K-L radiographic grade was considered a potential burden to participants. Some participants would have had to request information like this from a physician, which requires time and, in some cases, financial responsibility. For several reasons, it could be a general recommendation to control or stratify participants with this variable in the future.

Regarding just disease progression, which can progress independently of pain (Neogi et al., 2013; Sharma, 2021), and vice versa, it is well documented that KOA severity is significantly and negatively impactful on walking mechanics and function (Astephen et al., 2008; Hall et al., 2017; Hunt et al., 2010). However, it is important to note that these studies did not account for the impact of intermittent pain, used different activities, and assessed a wide array of gait parameters. As a result, this limitation and recommendation should be regarded as factors for consideration.

There was lack of access to visual recording and motion analysis software and was therefore a limitation. This study included several components of gait and foot parameter analysis, but it has been considered most beneficial to analyze KOA in three dimensions to assess the impact of the disease more precisely (Chambers & Sutherland, 2002). In addition, collecting an arch index could be recommended (Kaufman et al., 1999; Lugade & Kaufman, 2014). If sensors like the ones used in this research are selected to collect gait and foot parameters, foot arch height can impact the reliability of gathered data (Lugade & Kaufman, 2014).

Walking speed was also not controlled in this study and is a limitation. Although there are criticisms of using a speed window in which each participant walks, not controlling walking speed could have introduced too much variability into the sample given those with KOA will often walk slower to compensate for gait abnormalities and pain (Childs et al., 2004; Hunt et al., 2010; Radzak et al., 2017). Given the importance of walking speed as a measure of health (Fritz & Michelle 2009), and the potential variability present without controlling it, it is recommended that future methods employ a window, match speed like that used in Childs et al. (2004) and Rutherford et al. (2013) or

include walking speed as a covariate. Including these additional controls, if applicable, could lead to a more complete description of the etiology and pathology of KOA, and therefore are strong recommendations for future studies.

Lastly, although joint injection was considered exclusion criteria, it is likely, given the commonality of oral pain medication use in this population, that a variable amount of the pain group participants was consuming medication for pain on the day of testing (Sharma, 2021; Smith et al., 2017; Smith et al., 2018). Although the impact of oral pain medication wasn't assessed, a lower pain level due to pain medication consumption could have impacted gait parameters and foot pressure distribution and was a limitation. Similarly, although the F-scan insert was worn in between the foot and insert of the shoe of each participant, differing insole softness may have impacted foot pressure distribution and gait parameters and led to a high degree of variability. This was therefore a limitation. It could be recommended to control for show insert type.

# Chapter IV: References

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# APPENDIX FOR CHAPTER IV

# APPENDIX A

Date: 7-20-2023

**IRB #:** IRB-FY2023-44
**Title:** The Impact of Intermittent Pain in Women with Osteoarthritis of the Knee on Biomechanics and Muscle Activation Patterns during Level Walking and Stair Descent
**Creation Date:** 1-23-2023
**End Date:**
**Status:** Approved
**Principal Investigator:** Conor Theiss
**Review Board:** MTSU Institutional Review Board
**Sponsor:**

## Study History

| | | |
|---|---|---|
| **Submission Type** Initial | **Review Type** Expedited | **Decision** Approved |

## Key Study Contacts

| | | |
|---|---|---|
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# APPENDIX B



## [EXTERNAL] IRB-FY2023-44 - Initial: Initial Expedited Protocol Approval Letter

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Mon 2/27/2023 11:22 AM
To:Conor Theiss <clt6m@mtmail.mtsu.edu>;John Coons <John.Coons@mtsu.edu>

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Date: February 27, 2023
PI: Conor Theiss
Department: Middle Tennessee State University, Health and Human Performance
Re: Initial - IRB-FY2023-44
The Impact of Intermittent Pain in Women with Osteoarthritis of the Knee on Biomechanics and Muscle Activation Patterns during Level Walking and Stair Descent

The Middle Tennessee State University Institutional Review Board has rendered the decision below for The Impact of Intermittent Pain in Women with Osteoarthritis of the Knee on Biomechanics and Muscle Activation Patterns during Level Walking and Stair Descent. The approval is effective starting February 27, 2023.

Decision: Approved
Category: 4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.)

Findings:
Research Notes:

**Please note:**

Any **modifications to the approved study must be submitted for review through Cayuse IRB.** Please note, as well, that according to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to complete the required training. If you add researchers to an approved project, please add them to the project within Cayuse IRB for approval **before** they begin to work on the project.

**Any unanticipated harm to participants or adverse events must be reported to the Office of Compliance,** and any subsequent changes to the protocol must be submitted to the IRB for review before implementing this change.

**You must submit an end-of-project form to the Office of Compliance upon completion of your research.** Completed research means that you have finished collecting data.

All research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion and then destroyed in a manner that maintains confidentiality and anonymity.

All approval letters and study documents are located within the Study Details in Cayuse IRB.

We wish you a successful research project,

*Middle Tennessee State University Institutional Review Board*

APPENDIX C

# 2021 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.



01-11-2020

# 2021 PAR-Q+

## 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 ☐ |

 
01-11-2020

# 2021 PAR-Q+

**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.**

 

01-11-2020

# 2021 PAR-Q+

**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.epermedx.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.epermedx.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.epermedx.com
Email: epermedx@gmail.com

**Citation for PAR-Q+**
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PRINT FORM RESET FORM

 4/ 4
01-11-2020

# APPENDIX D

## A Measure of Intermittent and Constant Osteoarthritis Pain, ICOAP: KNEE Version

**People have told us that they experience different kinds of pain (including aching or discomfort) in their knee. To get a better sense of the different types of knee pain you may experience, we would like to ask you about any "constant pain" (pain you have all the time) separately from any pain that you may experience less often, that is, "pain that comes and goes". The following questions will ask you about the pain that you have experienced in your knee in the PAST WEEK. Please answer ALL questions.**

### A) CONSTANT PAIN

**For each of the following questions, please select the response that best describes, on average, your *constant knee pain* in the PAST WEEK.**

1. **In the past week, how intense has your *constant knee pain* been?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

2. **In the past week, how much has your *constant knee pain* affected your sleep?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

3. **In the past week, how much has your *constant knee pain* affected your overall quality of life?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

4. **In the past week, how frustrated or annoyed have you been by your *constant knee pain?***

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

5. **In the past week, how upset or worried have you been by your *constant knee pain*?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No constant knee pain | Mildly | Moderately | Severely | Extremely |

## B) PAIN THAT COMES AND GOES

**For each of the following questions, please select the response that best describes your *knee pain that comes and goes*, *on average*, in the PAST WEEK.**

**6. In the past week, how intense has your most severe *knee pain that comes and goes* been?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**7. In the past week, how frequently has this *knee pain that comes and goes* occurred?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Never/ No knee pain that comes and goes | Rarely | Sometimes | Often | Very Often |

**8. In the past week, how much has your *knee pain that comes and goes* affected your sleep?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**9. In the past week, how much has your *knee pain that comes and goes* affected your overall quality of life?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**10. In the past week, how frustrated or annoyed have you been by your *knee pain that comes and goes*?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**11. In the past week, how upset or worried have you been by your *knee pain that comes and goes*?**

| ☐0 | ☐1 | ☐2 | ☐3 | ☐4 |
|---|---|---|---|---|
| Not at all/ No knee pain that comes and goes | Mildly | Moderately | Severely | Extremely |

**THANK YOU!**

# CHAPTER V: OVERALL CONCLUSIONS

Based on the findings of this research, there is a significant impact of intermittent pain on muscle activity during a step-down. Therefore, this type of pain is detrimental to the function of skeletal muscle around the knee joint, as the muscle of the thigh, in this case the semitendinosus, was overactive during the load acceptance phase of stair navigation. This overactivity, according to Hodges et al. (2016), could lead to detrimental joint load and ultimately worsen symptoms, such as cartilage degradation and increased pain. Given the trends described here, it is possible that intermittent pain also impacts other muscles above and below the joint, including leading to atypical co-activation, but further research with precise controls would need gathered to make clear the true impact of this pain type on skeletal muscle.

Lastly, given the trends described in this research surrounding the foot and gait parameters, it could be that intermittent pain impacted pressure distribution and gait. Likely, that would have been due to altered muscle function because of intermittent pain, but with the lack of any visual assessment or motion analysis software to rule out confounding issues, such as knee joint frontal plane angle, ankle mobility, hip mobility, and preexisting gait abnormalities, that relationship and its mechanism(s) is unclear. Future research should continue to probe for the magnitude of impact intermittent pain has on movement and function in three dimensions. Providing that information would be invaluable to the clinician and diagnosed alike, as, according to Sharma (2021), it is often difficult to quantify KOA symptom impact and ultimately describe how those symptoms relate to disease progression.

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