PHYSICAL ACTIVITY AND ITS ASSOCIATION WITH PAIN-RELATED DISTRESS
AND PAIN PROCESSING BEFORE AND AFTER EXERCISE-INDUCED LOW BACK
PAIN

By
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To my mom and my Gainesville family
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LIST OF ABBREVIATIONS

ACSM  American college of sports medicine
AHA   American heart association
DOMS  Delayed onset muscle soreness
FPQ   Fear of pain questionnaire
ICF   International classification of functioning, disability and health
METs  Metabolic equivalent
NRS   Numeric rating scale
PCS   Pain catastrophizing scale
PPT   Pressure pain threshold
QST   Quantitative sensory testing
SPSS  Statistical package for the social sciences
TS    Temporal summation
VAS   Visual analogue scale
WHO   World health organization
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By

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Chair: Mark Bishop
Cochair: Steven Z. George
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Reduction in physical activity is a problem often reported by healthy individuals and those with chronic low back pain. Some studies have demonstrated that psychosocial factors may play a more important role in decreased physical activity rather than pain itself. Furthermore, human and animal research has suggested that vigorous physical activity is linked to increased pain sensitivity. However the protective effect of light activity on pain processing has not been investigated as much. Therefore, the purpose of this dissertation was threefold. First, we investigated the relationship between psychosocial factors using two measures of pain-related distress (fear of pain and pain catastrophizing) and physical activity before pain induction. Second, we examined what factors predicted the change in physical activity after exercise-induced low back pain, and third, we explored the role of physical activity in influencing experimental pain sensitivity. In particular we were interested in whether light physical activity was protective of pain processing.
In this dissertation, an acute muscle injury exercise protocol was used to induce delayed onset muscle soreness (DOMS) into 39 individuals who were pain-free in the first week of the study and reported low back pain in the second week after DOMS induction. Their participation in this study consisted of six sessions carried out in two weeks. Physical activity was monitored with an accelerometer throughout the time subjects were enrolled in the study. Pain processing was measured with static and dynamic quantitative sensory testing local and remote to the injury site.

Results from this study found that while self-report questionnaires of physical activity are appropriate instruments to capture vigorous activity, they fail to detect light activities in which case an accelerometer should be used because of its higher sensitivity to detect ordinary body movement. Moreover, light activity was negatively associated with pain-related fear before pain induction. Only light and moderate activity decreased after DOMS and it was found that pain-related fear was a factor influencing the reduction in light activity. Finally, light activity was associated with measures of pain processing before pain induction, additionally; higher amount of light activity pre-DOMS modulated increased pressure pain threshold after exercise-induced low back pain.
CHAPTER 1
INTRODUCTION

Background

Chronic low back pain and associated disability pose a growing burden characterized by great personal suffering and elevated health care cost [1], making this condition a public health priority in western industrialized societies [2]. Research has reported that 70 to 85% of all adults will experience low back pain at some moment in their lifetime. About 10% of these patients develop chronic low back pain, which is the cause of disability and high health care expenses [1, 3, 4]. The influence of psychosocial factors seems to play an important role in the transition from acute to chronic low back pain [5, 6]. In particular, emotional and cognitive factors such as fear and catastrophizing respectively have been found to be strongly associated with decline in physical activity and disability in patients with low back pain in the acute, sub-acute and chronic stage [7-9]. Reduction in physical activity is a problem often reported by patients with chronic low back pain [10-13]. This reduction in physical activity is often described as difficulty or less time spent in performance of recreational activities, occupational tasks, and activities of daily living that eventually may lead to pain-related disability [4].

Although disability and decreased physical activity have some similarities in their concepts, they are two different constructs. The World Health Organization (WHO) defines disability as “any restriction or lack of ability to perform an activity within a range considered normal for a human being”. The WHO also defines physical activity as “any bodily movement produced by skeletal muscle that results in a substantial increase over
the resting energy expenditure” [14] and it can occur during occupation, leisure time, sports, home and household activities, personal care and transportation [15].

Physical activity is an essential component in the International Classification of Functioning, Disability and Health (ICF) model. Physical activity plays a large role in the individual’s level of participation in social, work and recreational activities. Physical activity is a direct outcome measure of the person’s health condition. According to the ICF model, physical activity can be affected when body structures and/or functions are impaired. But also it can be affected by environmental and personal factors [16-18].

Physical activity can be important in the prevention of several chronic diseases such as diabetes, heart diseases and cancer [19-23]. For this reason, several guidelines for physical activity have been recommended. For example, The American College of Sports Medicine (ACSM) and the American Heart Association (AHA) recommends that to promote a healthy lifestyle, individuals between 18 and 65 years of age perform at least 30 minutes of moderate intensity physical activity, five days each week, or a minimum of 20 minutes of vigorous activity three days a week [24]. The national physical activity guidelines suggest that accumulating 10,000 steps per day when measured by a pedometer will meet the requirements in bout length recommended by the ACSM and the Centers for Disease Control and Prevention and the U.S. Surgeon General [25]. Additionally, 10,000 steps/day have been associated with indicators of good health, such as decreased body fat, blood pressure, and resting heart rate [26, 27]. However for some people meeting these guidelines can be quite challenging, for this reason, it has been suggested that performance of light intensity (non-exercise
physical activity) may be just as beneficial as meeting the guidelines proposed above [28].

Dissertation Focus

While pain catastrophizing and fear of pain are well known to influence the transition from acute to chronic pain and subsequent disability, it is not known if these pain-related psychosocial factors relate to regular physical activity in pain-free individuals. Moreover, the change in physical activity from health to a pain condition has been poorly documented due to not having the physical activity accurately measured prior to injury. Given that patients often self-report decreased physical activity in chronic low back pain, it becomes important to accurately measure this change early in the acute stage with performance based measures to clearly elucidate whether physical activity pattern changes in acute pain. Therefore, this dissertation work will focus on the performance of free-living activity and how physical activity performance type is associated with pain-related distress. These associations are explored as part of Aim 1 of this study. Since returning to normal physical activity is often viewed as a primary goal by physical therapists and patients with chronic low back pain, it is important to understand how people begin to change their activity pattern even in response to acute injury. Detectable changes in activity in the acute stage could provide physical therapists with the knowledge to intervene and potentially avoid the transition to a chronic stage. Patients with chronic low back pain often report that their decreased physical activity is caused by their pain intensity while some studies have found that pain-related fear is actually the driving factor of decreased physical activity in this population. Therefore, with Aim 2 of this study we explored these issues in acute exercise-induced low back pain using a muscle injury protocol to identify what factors
influence changes in physical activity. Finally, on a related topic, the evidence for a hypoalgesic effect of vigorous (i.e. protective) activity in human and animal models is overwhelming; however, little is known whether light physical activity has any protective effect on pain perception in humans. The protective effect of light activity has been identified for chronic conditions such as diabetes, heart diseases and cancer. Therefore, we need to know if the protective effect of light activity extends to pain processing, given that people spend the highest amount of their day in light activity. For this reason, with Aim 3 we explored whether light activity is associated with pain perception and the protective effect of light activity on pain processing after muscle injury to the low back region.
CHAPTER 2
LITERATURE REVIEW

Objective and Subjective Measures of Physical Activity

Traditionally, physical activity has been measured with self-report questionnaires, activity diaries, activity logs, and interviews [15]. These instruments are usually chosen because of their low cost, and they are easy to administer. Therefore, numerous questionnaires for assessing physical activity have been developed [29-31]. Some of these questionnaires have been validated for the population with low back pain, but they are the source for subjective interpretation [32, 33] and have several limitations. Some limitations that have been reported include reporting bias associated with social desirability [34], social approval, [35] and the cognitive challenge associated with estimating frequency and duration [36]. For example, a person may report an hour of moderate activity when cleaning, but most likely this person did not spend the whole hour in moderate intensity and the same is true for other activities such as gym classes, gardening, or home management. In this case self-report measures may yield to higher values when compared to objective measures of activity [37]. Additionally, some surveys on physical activity focus on performance of vigorous activity, and they may be very weak or inaccurate when reporting light or moderate activities [38]. This discrepancy can be attributed to the fact that it is easier to recall vigorous activities such as jogging or running but not unplanned activities such as walking and household activities [38, 39].

For example, a study conducted in patients with fibromyalgia found that physical activity intensity from self-report was greater than measures from accelerometer. Additionally, no relationship between these two measures (subjective and objective) of
physical activity was found [40], similar results were reported by van Weering et al. [41] in people with chronic low back pain. Collectively these findings suggest a greater variability in the way patients report activity. However, evidence of the relationship between objective and self-reported physical activity in acute low back pain is still lacking.

Quantifying and categorizing physical activity is difficult for the researcher which may yield to misinterpretations, if the appropriate measure is not chosen. For example, Linton SJ [42] found an association between pain intensity and self-reported physical activity in patients with chronic low back pain; however, this association disappeared when an observation measure of activity was used. Currently, activity monitors provide reliable and valid means for quantifying physical activity performance type and intensity which may help us better understand the relationship between physical activity and health compared to relying on self-report measures of activity [43].

Most self-report questionnaires try to capture how active a person has been for the past 7 days. This means that an individual has to accurately remember the amount of time, intensity, and frequency of their physical activity. Kremer et al. (1981) compared physical activity as reported by patients with low back pain and activity reported by their physical therapists. They found that patients underestimated their level of activity despite reporting less pain [44]. A reason for underreporting levels of physical activity may again be due to aforementioned recall bias [45]. For example, a person may have a hard time remembering physical activities that lasted for less than 10 minutes [46] or have more increased difficulty remembering previous day’s activities specially those activities that occurred 3 to 7 days ago. In this case because of limitations in memory,
reliability of the information provided in the questionnaire is going to decrease as the amount of time that is surveyed increases [47].

A difficulty presented by self-reported moderate or light activity is that, this type of physical activity is less structured than vigorous activity; therefore they are harder to recall. Measuring intensity by self-report becomes also difficult. For example, a person may perform a task such as raking leaves at a light intensity while another person can perform the same task at a vigorous intensity [48]. Another way to obtain activity information from a person is with the use of interviews, however when an interview is conducted, interviewers bias can be introduced [49].

Boon et al. [50] showed that self-reported physical activity has a small to moderate correlation with moderate and vigorous activity from the accelerometer, but they also found that self-report overestimated the amount of activity over what the activity monitor recorded. Moreover, a systematic review evaluated the extent of agreement between subjectively and objectively measured physical activity in adults. In this investigation, researchers found that the mean percent difference between self-report and objective measures increased with higher categories of physical activity, which may reflect a weakness of self-report trying to capture higher levels of physical activity or participant’s interpretation and recall [51]. Another systematic review reported that self-report measures of physical activity were higher and lower when compared to objective measures of physical activity [51]. Moreover, another study reported higher values for sedentary and vigorous activity when using a questionnaire compared with Actigraph (activity monitor) [37]. Similar results were found by Grimm et al. [52] in which they found that physical activity intensities were over-reported when a
questionnaire was used compared to when physical activity was measured by an accelerometer. Collectively, these findings demonstrate that measures of self-reported activity appear to underestimate short bouts of physical activity such as walking around the house and overestimate intensity of vigorous physical activity compared to moderate physical activity [53, 54]. Therefore, using measures of self-report of physical activity in people with low back pain may lead to false assumptions between activity and other important variables of low back pain.

Accurate quantification of activity levels using objective measures is necessary to establish the extent to which people with low back pain modify their levels of physical activity. Physical activity is one of the most important topics physical therapists target in their treatment interventions for patients with low back pain. However, we need to be careful with the way we recommend resuming or engaging in activity. High levels of physical activity have been reported to be associated with high pain intensity in patients with chronic low back pain [55, 56] and it has also been reported that those patients with chronic low back pain who engage in over activity tend to use more opioid medication [57]. Therefore, providers should provide education related to how much activity they need to perform, and activity monitors may be a means to accurately regulate the amount of desired activity.

**Physical Activity and Psychosocial Factors in Low Back Pain**

Physical activity has been studied in people with chronic low back pain; nonetheless, the literature in physical activity in acute low back pain is very limited. It is well known that psychosocial factors such as pain-related fear and catastrophizing are present in acute low back pain, [58] as well as in pain-free individuals, and that these
factors potentially increase risk for future disability [59]. In a study of self-reported physical activity, low back pain was associated with low levels of physical activity [60].

Several studies have provided evidence that pain catastrophizing and fear-avoidance beliefs are associated with low levels of physical activity [61, 62]. Catastrophizing refers to the augmented interpretation of pain which might occur during actual pain or anticipation to pain [63] and it is measured with pain catastrophizing scale (PCS). The PCS was developed by Sullivan et al. [64] as a measure to assess exaggerated negative interpretation of pain with higher scores indicating higher levels of catastrophizing. Evidence has demonstrated that high scores in the PCS are associated with disability [65, 66]. This is in part, the reason for our special interest in PCS and physical activity in pain-free individuals. Researchers who have induced delayed onset muscle soreness (DOMS) to replicate the symptoms of acute low back pain have shown that the catastrophizing is associated with activity intolerance [67]. Moreover, pain-related fear during DOMS has been found to be associated with physical performance and perceived disability [68, 69]. Some researchers have explored the relationship between pain catastrophizing and pain-related fear with the performance of specific tasks in a laboratory setting [9, 70-72]. The primary limitation of these types of investigations, however, is that researchers are not able to capture the regular physical activity that occurs in a free-living environment during the acute stage of a low back pain episode.

Cognitive factors such as pain catastrophizing are considered essential in the study of pain behavior because they potentially determine who transitions from acute to a chronic stage of pain. Pain catastrophizing can best be conceived as the cognitive
element of the fear network, besides physiological reactivity and behavioral responses, and it refers to the process during which pain is interpreted as being extremely threatening. [65, 73]. Research has shown that elevated levels of pain catastrophizing are associated with pain intensity and disability [74, 75]. Therefore, it may be necessary to identify pain catastrophizing in order to provide early intervention and treatment [59].

In acute pain, pain-related fear also arises. Pain-related fear leads to avoidance behaviors and hypervigilance [76]. Patients with pain conditions, who tend to catastrophize, avoid movements that exacerbate the pain condition; therefore levels of physical activity are reduced which may lead to deconditioning [61, 62]. However some studies in patients with chronic low back pain have found that aerobic capacity is not adversely affected [77]. People who catastrophize usually develop expectancies of heightened pain experience [78]. These heightened pain expectancies have been found to be associated with emotions such as depression [79]. Additionally, Wade JB et al. (1990) found that depression is associated with pain-related emotional distress [80]. Individuals who present with all these type of psychological factors may not have the ability to cope with their painful condition and often fail to adapt leading to low levels of physical activity and potentially disability.

Fear is an emotional response that has been implicated in the maintenance of chronic pain behavior [81]. Some patients when they experience low back pain, develop fear of movement that may lead to decreased physical activity and disability [9, 62, 82]. Several studies have provided evidence that fear-avoidance beliefs are associated with low levels of physical activity [61, 62]. For example, Elfving et al. [62] found that low levels of self-reported physical activity were associated with high levels of fear and pain
catastrophizing in patients with chronic low back pain. Additionally, Buer and Linton [59] reported that high scores in fear-avoidance beliefs and catastrophizing were associated with low levels of activities of daily living in non-chronic spinal pain. However, one of the limitations of these studies, as in others that have measured physical activity, is that physical activity was evaluated with a self-report questionnaire.

People with higher levels of pain-related fear tend to withdraw from rewarding and recreational activities such as work, leisure, and family. The mechanism by which this happens may be explained because pain-related fear is associated with heightened body awareness and hypervigilance [6]. These adverse outcomes fuel the cycle of higher fear and avoidance. Therefore measuring fear of pain in patients with low back pain may be important to understand and individual’s beliefs and behavior about their pain. Fear of movement can be measured with the fear of pain questionnaire (FPQ) [83] with higher score representing higher pain-related fear [84, 85]. Pain catastrophizing and fear have been found to be predictors for pain intensity and disability, respectively, [86] which makes these two construct appropriate measurements for patients in the clinic. Additionally, in healthy individuals, fear of pain assessment has demonstrated to be a strong predictor for pain intensity reported from heat pain threshold and tolerance [87].

Wadell et al. (1993) developed the fear avoidance beliefs questionnaire which is based on the theory that fear of movement leads to avoidance behaviors and how physical activity and work affect low back pain [88, 89]. Wadell has also reported fear of movement was strongly correlated with disability in activities of daily living and work
loss. Additionally, Fritz and colleagues [90] found that fear of movement predicted disability after controlling for levels of pain and impairments.

Movement and behavior in people with chronic pain are influenced by fear of pain [91]. Numerous studies have explored the association between pain-related fear and variables of physical performance such as range of motion [92, 93], muscle activity [93], lifting tasks [9, 94], and subjective and objective measures of physical activity [10]. In every one of these studies a strong association between pain-related fear and physical performance has been found but not between physical performance and pain intensity. Taken together, these findings suggest that for patients with chronic pain physical performance maybe the result of pain-related fear more than pain intensity itself. Whether this is also true for acute low back pain is not well understood, and remains an important question to answer if we want to better understand the transition from acute to chronic low back pain.

**Physical Activity and Low Back Pain**

Low back pain from musculoskeletal origin is often described as mechanical pain; therefore, it is suspected that physical activity would be reduced as a result. Nilssen R.M. and colleagues [95] showed that in an experimental model of low back pain, accelerations of the trunk are diminished and that this reduction in trunk kinematics has a linear association with pain. Additionally, Linton, SJ. [42] reported a linear relationship between self-reported physical activity and pain intensity in chronic low back pain. Moreover, some subjects when they experience low back pain, they develop fear of movement, or they may interpret their pain as a threatening condition (catastrophizing) which may be another possible reason for patients to restrict their
physical activity [62]. If these behaviors outlast the pain condition, disability and disuse can occur [10].

In conditions such as chronic low back pain, physical activity may have a behavioral influence on fear/avoidance beliefs, as well as influence on neuromechanical pathways that modulate pain perception, which in turn, affects the person’s level of functioning [71]. Studies on physical activity in people with chronic low back pain have presented mixed results. Some studies have demonstrated that there is a reduction in physical activity in the chronic stage of low back pain compared to control subjects [4, 96-99], while in others investigations changes in physical activity have not been confirmed [100-104]. None-the-less, while the exact impact of reduced physical activity may differ in acute and/or chronic low back pain, low levels of physical activity are considered to be a risk factor for developing persistent pain [105].

Evidence has shown that intense physical activity and sedentary behaviors are associated with back pain. A study conducted by Hildebrandt and colleagues [106] found that people with many sedentary activities in leisure time and workers with sedentary tasks show higher prevalence of low back symptoms. On the other hand, a study found that at least in adolescents, high levels of leisure physical activity were associated with low back pain, upper and lower limb pain [107]. Similar results were found in another group of adolescents where both high levels of brisk physical activity (more than 6 hours a week) and low level of physical activity (high amount of sitting) were associated with self-reported low back pain [108]. Collectively, findings from these investigations agree with results found by Heneweer et al. [105] in which they found that both extremes of physical activity pattern (sedentary and strenuous) are associated with
chronic low back pain, suggesting that physical activity and low back pain may have a U-shaped relationship, and that not all patients with chronic low back pain exhibit low levels of physical activity [103].

Physical activity needs to be investigated in healthy people and people with non-painful chronic conditions in which increasing physical activity has been recommended. Regular physical activity is a modifiable factor that has been linked to a series of physical and mental health conditions. Therefore, increasing physical activity in healthy people could be used to prevent development of chronic conditions. The protective effect of physical activity for conditions of public health importance such as heart disease [109-111], hypertension [112, 113], diabetes [20, 111, 114], osteoporosis [115], colon cancer [116], depression and anxiety [117-119] has been demonstrated. However, the protective effect of regular physical activity in the development of musculoskeletal pain conditions requires further research. The longitudinal design of this investigation allows examination of whether different types of physical activity have a protective effect on pain processing in acute exercise-induced low back pain.

Delayed Onset Muscle Soreness to Study Low Back Pain

Exercise-induced DOMS has been used to study pain in several musculoskeletal structures, such as the shoulder [120, 121], Biceps [122-125], quadriceps [126, 127], trapezius [128, 129], and dorsal interosseous muscle [130]. These muscles are chosen because of the convenience to perform exercise and they are linked to sites that commonly have clinical conditions. In all of these studies PPT has been a consistent local pain sensitivity measure that changes after DOMS. However, the literature is very limited in low back DOMS [131] despite it being such a common site for clinical pain.
DOMS has the advantage that it reproduces the same signs and symptoms commonly seen in patients with acute musculoskeletal pain, such as inflammation, loss of range of motion, decreased muscle strength, pain that can range from muscle tenderness to severe pain that interfere with ADLs [132, 133] to the point that some people have reported disability resulting from DOMS [69]. Therefore, DOMS is ideal for prospective studies in which pain is induced in healthy participants [68] and the interest in the acute stage of pain.

However, this model is not perfect to study clinical pain. Several weaknesses have been reported in the literature. The fact that it dissipates within 5 days [134], makes it different from persistent clinical pain that is likely to transition to chronic pain. Moreover, George et al. [120] suggested that results from DOMS studies need to be carefully interpreted because DOMS often is induced in young individuals with no structural or physiological changes that are commonly seen in clinical pain. Nevertheless, a muscle injury model to induce DOMS is the best available method that allows researchers to examine the transition from health to acute pain. Observation of this transition is not typically available in clinical studies. Moreover, pain resulting from DOMS has a standard cause as opposed to the multiple etiologies in the clinical population [125]. Additionally, the time of the onset of pain is consistent across participants with a time-course that is predictable [135, 136], which is not the case in clinical samples. Specific to the low back, research from this lab has shown that DOMS can be induced in a controlled and safe manner using appropriate equipment [69, 131, 137].
Pain Processing

The transition of pain from acute to chronic seems to be the results of abnormalities in pain processing rather than direct physiologic changes from inflammation and pathological anatomical structures [138]. For example, Bishop et al. [137] found that after a muscle injury protocol, damage to the muscle fibers as measured by MRI was not associated with pain intensity, therefore, the source of pain is likely related to a neurologic mechanism. Quantitative sensory testing (QST) provides alternate methods to assessing tissue damage to evaluate alterations and reorganization of the nociceptive system [139]. QST measures have been classified as static and dynamic [140, 141]. Static measures include threshold (pain detection) or magnitude of pain intensity to a given stimulus (visual analogue scale) and they are considered unidimensional [139, 141]. Static measures cannot distinguish from peripheral or central sensitization unless they are applied in remote areas from the injury site. For example, in the case of low back pain, increased sensitivity to pressure in the paraspinal muscles indicate a peripheral sensitization mechanism [137], but increased sensitivity to pressure in remote areas such as the hand or foot may be indicative of central sensitization [142].

While static QST measures provide a potentially limited view of pain processing, dynamic tests evoke a more complex course of modulatory pain processing by measuring temporal and spatial summation and explore descending pain modulatory mechanisms [139]. Dynamic measures such as temporal summation explore increased excitability of the pain processing centers and it occurs when repetitive input from C-fibers produces an enhanced response in neurons of the dorsal horn of the spinal cord [143, 144]. It has been suggested that dynamic measures of pain sensitivity are more
indicative of clinical pain [145, 146]. Both, static and dynamic can unveil mechanisms of pain augmentation or descending inhibitory control [139, 147] and clinically, they can be used to assess therapeutic outcomes [147]. Practically, studies like the current dissertation that include both static and dynamic measures have the best potential to inform on how pain processing may be impacted by experimental methods.

QST has become increasingly used in clinical and research settings to study and monitor pain because it has been documented that it correlates with clinical pain reports. For example, research has found that mechanical and thermal hyperalgesia normalizes after pain-relieving treatment for hip osteoarthritis [148]. Similar results have been shown in patients with fibromyalgia who reported great reductions in clinical pain were reflected by a decrease in PPT and pain tolerance [149]. Staud et al. [145] demonstrated that abnormal temporal summation of second pain was the largest contributor to the variance in clinical pain intensity in patients with fibromyalgia syndrome. Lastly, decreased thermal deficit showed a moderate correlation with signs and symptoms in patients with symptomatic lumbar radiculopathy [150]. Additionally, the value of QST in predicting post-surgical clinical pain has also been documented. Granot et al. [151] reported that heat pain threshold evaluated 2 days before C-section predicted the amount of pain intensity reported the day after the surgery.

On the other hand, the usefulness of QST in assessing clinical pain has been questioned because of the short duration of the stimulus as opposed to the longer duration and unpredictable behavior of clinical pain. Additionally, participants in a laboratory setting have previous knowledge of the noxious stimulus that is going to be applied to their skin [152]. Moreover, psychological measures have been found to be
more strongly associated with pain intensity than QST. For instance, Gracely et al. [153] reported that in patients with fibromyalgia clinical pain was associated with pain catastrophizing but not with PPT. Similar results were reported by George et al. [154] in which a series of thermal sensitivity measures where employed in patients with chronic low back pain and none of these measures were associated with clinical pain intensity after controlling for depression.

Even though there is debate about the clinical significance of QST measures, it is the best available method we have to separate pain processing from pathology. In this dissertation project, both, static and dynamic measures of pain sensitivity were used because together they help differentiate peripheral from central mechanism that are commonly observed in chronic pain conditions. The muscle injury model employed in this dissertation will help elucidate changes that occur in pain processing from health to pain, which cannot be identified in a clinical population.
CHAPTER 3
SPECIFIC AIMS AND RATIONALE

Specific Aim 1: To explore the relationship between pain-related distress and physical activity before exercise induced low back pain induction

This aim investigated the relationship between physical activity performance type assessed with an accelerometer and level of physical activity obtained with self-report. Additionally we explored the extent to which pain associated distress is associated with performance and self-report of physical activity in pain free individuals.

Rationale

Research has shown that low levels of self-reported physical activity are associated with high levels of pain catastrophizing and pain-related fear in chronic low back pain [62]. However, these associations have been poorly investigated in a healthy state before experiencing low back pain. Traditionally, researchers of physical activity have used questionnaires of self-report. Nonetheless, questionnaires pose a series of limitations that may lead to misinterpretations, given that people tend to overestimate or underestimate their level of physical activity [37]. More recently, accelerometers have been used because they provide more accurate information about movement patterns of physical activity in a free-living environment. This technology allows for separation of physical activity performance types based on energy expenditure, which allow the researcher to draw more precise conclusions. Physical activity questionnaires have demonstrated that they are able to capture intense moderate and vigorous planned activities [155, 156] however; they are unable to capture the lower end of the continuum of physical activity such as unplanned, incidental body movement and walking [46, 157, 158]. Therefore, the method chosen should be dictated by the research question.
Pain-related fear and pain catastrophizing play an important role in the transition from acute pain to chronic pain in people with low back pain [6, 81, 159, 160]. These two measures of negative affect are usually studied in individuals who are already experiencing pain and for this reason are believed to be associated with pain [161]. A potential limitation in this type of research is the assumption that these patients did not have any pain-related fear or catastrophizing thoughts before their pain experience. Evidence of these two constructs being present in the healthy population is very limited. However given their role in the transition from acute to chronic pain conditions, it is necessary to identify how elevated pain-related fear and catastrophizing in healthy individuals relates to physical activity. The investigation of whether these associations are present in a pain-free state is important because reduction in physical activity is often reported in people with low back pain and it has been found to be associated with pain-related fear [9, 62]. Additionally, it is unknown if elevated pain related distress would place healthy populations at a higher risk of developing a pain conditions.

**Hypothesis 1**

Physical activity performance as measured by accelerometer would not be associated with self-reported physical activity in pain free participants, consistent with other research in this area.

**Hypothesis 2**

Physical activity performance as measured by an accelerometer and self-reported physical activity would be negatively associated with fear of pain and pain catastrophizing in healthy participants.
Specific aim 2: To examine changes in physical activity after exercise-induced low back pain

This aim investigated the extent to which acute exercise-induced low back pain affects physical activity performance assessed with an accelerometer and by self-report.

Rationale

Evidence showing that physical activity is affected in subjects suffering from acute, sub-acute and chronic low back pain has provided contradicting results [10, 98, 100]. While some studies have reported decreased physical activity in the chronic stage of low back pain compared to control participants [4, 96-99], others have failed to reach the same conclusions [100-104]. Limitations in these studies have included the cross-sectional design and the use of self-report questionnaire to obtain physical activity data. For many years, researchers have relied primarily on measures of self-reported physical activity. A disadvantage of using this measurement approach is that patients with low back pain may have a different perception on how they function on paper compared to how they actually function. Therefore, precise quantification of physical activity performance is paramount when the objective is to capture non-exercise activity and incidental movement. The reason for this could be due to the perception of physical activity is biased by recall and other pain-related factors [162]. It is believed that people with pain conditions have a lower level of physical activity because of their pain [53]. Nonetheless evidence has shown pain-related fear has a more important role in influencing reporting of activities of daily living than pain itself in both, acute [9] and chronic pain [7]. This aim will elucidate the extent to which physical activity is impaired after acute exercise-induced low back pain by using an objective and sensitive measure of physical activity performance (accelerometer) and also a self-report measure.
Traditionally, researchers have used a control group and low back pain group to compare levels of physical activity, which is a limitation that all have reported [98, 100, 163]. To our knowledge; no study has ever measured physical activity performance within the same participants before and after they develop pain by the use of a muscle-injury protocol. The design of this study in which healthy participants underwent a muscle-injury protocol to induce pain allowed us to obtain precise quantification of physical activity performance before and after the onset of pain. Additionally, the use of a performance measure will allow us to identify whether type of physical activity performance (light, moderate, vigorous) and intensity (peak activity counts and mean activity counts per minute) are decreased in this model of acute exercise-induced low back pain. Finally, because these participants are tested in a longitudinal design, this protocol will allow us to identify what factors from the pain experience influence physical activity reductions.

**Hypothesis 1**

Participants would display reduced levels of physical activity performance measured by an accelerometer and self-report of activity after induction of low back pain.

**Hypothesis 2**

Induced low back pain intensity and area of pain distribution would predict change in physical activity performance measured by an accelerometer and self-report of activity.
Specific aim 3: To determine the extent to which physical activity before exercise induced low back pain influences experimental pain sensitivity

This aim investigated the extent to which pre-muscle injury physical activity performance and self-report relate to local and remote pain sensitivity before and after acute exercise-induced low back pain.

Rationale

Very few studies have examined the association between physical activity and pain sensitivity in healthy individuals and individuals with musculoskeletal pain. The protective effect of regular physical activity on pain sensitivity during acute exercise-induced low back pain needs to be explored. In addition, the importance of light physical activity has recently been highlighted because the potential benefits on health outcomes and because individuals often find it challenging to achieve the recommended 150 min/week in moderate and vigorous activity [164]. Moreover, light activity is emerging as a new area of research interest and its impact on pain sensitivity measures is unknown. The value of physical activity performance type has not been well documented in the pain literature. Research has mainly focused on the protective effect of moderate and vigorous activity in a controlled environment such as treadmill and bicycle exercises. However, in this study we investigated physical activity performance in a free-living environment.

Regular physical activity involves mostly activities that are light and require energy expenditure under 3 METs such as body movement in the work place, performance of household chores, gardening, etc. Recently, research has found that even light-intensity physical activity is a practical strategy to decrease the risk of type 2 diabetes and cardiovascular disease [165] and therefore lower risk for early mortality.
Additionally, it has been reported that occupational physical activity (light) decreases the risk of developing chronic diseases [167]. Due to the impressions of self-report questionnaires, it is challenging to accurately measure light activity, such as domestic and occupational tasks [168]. Even with the development of newer methods to obtain precise profile of movement patterns with activity monitors, light activity has not been taken into appropriate consideration. Light activity should not be neglected since it involves the largest amount of time spent in activity throughout the day. Tremblay et al. [28] suggest that lifestyle-embedded activities, incidental movement and chores, all of which are considered light activities, may have a great promise in achieving health outcomes in the general population. Recently, Ekblom-Bak et al. [164] suggested that an active lifestyle, regardless of exercise, may be as important as prescribing exercises. In their study they found that non-exercise physical activity was associated with cardiovascular health and longevity in older adults. Over the years, research has made evident the positive effects of moderate and vigorous activities. Nonetheless, the evidence on the extent to which light physical activity relates to health outcomes is very limited. Therefore, given the benefits of light activity in health outcomes of other body systems, it becomes important to investigate whether these benefits extend to other areas including pain perception.

A study reported that healthy subjects with higher levels of physical activity exhibited higher mechanical pain threshold than subjects with lower activity levels [169]. In a different study, it was found that those subjects who reported more total and vigorous activity exhibited decreased temporal summation of pain [170]. Nonetheless, these investigations measured physical activity using self-report questionnaires.
Ellingson et al. [171] measured physical activity using an accelerometer in healthy women and found that meeting physical activity recommendations are associated with decreased thermal pain sensitivity.

The protocol used in this study allows us to perform some novel explorations on the effect of physical activity on experimental pain sensitivity. First of all, the use of a muscle-injury model is important to explore some associations between physical activity and pain sensitivity in a pain-free state. Additionally, the protective effect of physical activity performance on pain sensitivity after participants develop pain can be explored. Finally, the use of an activity monitor that provides us with measures of performance type allows for precise quantification of light, moderate and vigorous activities which in the end makes the results obtained from this analysis more robust.

**Hypothesis 1**

Physical activity performance and self-report of activity would be negatively associated with local and remote pain sensitivity before exercise-induced low back pain.

**Hypothesis 2**

Increased physical activity performance and self-report of activity before exercise-induced low back pain would be protective of local and remote pain sensitivity after pain induction.

**Hypothesis 3**

Physical activity performance and self-report of activity before pain induction would predict change in local and remote pain sensitivity measures after exercise-induced low back pain.
CHAPTER 4
METHODS

Participants

We recruited pain-free subjects aged 18 to 40 years of age. Subjects were excluded if they met the following criteria previously described in our lab [69, 137], and include:

- Current pack pain or chronic medical conditions.
- Participation in another ongoing study
- Previous participation in a conditioning program specific to trunk extensors in the past 6 months.
- Any report of back or leg pain in the past 3 months
- Any chronic medical conditions that may affect pain perception (e.g., diabetes, high blood pressure, fibromyalgia, headaches), kidney dysfunction, muscle damage, or major psychiatric disorder
- History of previous injury including surgery to the lumbar spine, renal malfunction, cardiac condition, high blood pressure, osteoporosis, or liver dysfunction
- Consumption of any drugs (e.g., caffeine, alcohol, theophyline, tranquilizers, antidepressants) that may affect pain perception or hydration status from 24 hr. before participation until completion of the investigation
- Performance of any intervention for symptoms induced by exercise and before the termination of their participation or the protocol
- Recent illness

Protocol Implementation and Randomization

Healthy subjects that met eligibility criteria and provided informed consent were enrolled. Based on our previous studies, subjects had two baseline QST assessments during the first week of their enrollment to ensure measurement stability and familiarity with the QST procedures. Following the third baseline assessment, subjects performed
a dynamic muscular fatigue protocol to induce DOMS. Table 4-1 shows research design.

Prior to DOMS protocol implementation subjects warmed up for five minutes on a stationary bicycle. Participants were seated in a MedX Lumbar Exercise machine, and stabilizing straps were attached across the pelvis and knees (Figure 4-1). Participant was moved through the range of motion of the machine in lumbar flexion and extension to determine their available range. Baseline trunk extensor torque was measured with isometric tests in the available trunk range of motion using the Medx machine. The device was locked into place in maximal trunk flexion, and the participant was instructed to build up force gradually against the pad in contact with the lower thoracic and upper lumbar spine. One peak force was achieved, the subject was instructed to relax, the device was released and participant returned to upright sitting for at least 10 seconds. Participants were tested at different angles, starting from maximum trunk flexion and every 12° until maximal trunk extension. To perform the muscle-injury protocol, participants then performed a trunk extension exercise at 80% of their maximum isometric peak torque measured during the isometric test. Each repetition was performed through the full range of motion until fatigue, which was indicated by a 50% reduction of their baseline isometric torque as previously described in our lab [69, 137, 172]. Participants were instructed not to take any pain-relieving medication or apply any palliative intervention to the lumbar spine.
Activity Monitoring

Subjects wore an accelerometer (ActiGraph GT1M) (Pensacola, FL, USA) for the duration of the study during waking hours. The GT1M is a lightweight device (27 g: 3.8 cm x 3.7 x 1.8 cm) that records movement of the subject. Subjects were instructed to remove the accelerometer for water activities such as showers and swimming. Subjects were also instructed to remove the ActiGraph during sleeping because of discomfort or risk of causing damage to the accelerometer. The device was worn over the right hip (on the waist band or belt) in line with the right axila. The device was set to record data continuously in 60 second epochs (sampling interval) [36, 173]. The subject wore the accelerometer a minimum of 12 hours per day throughout the length of the study. However, days containing at least 8 hours (480 epochs) were used for analysis [174]. Research has shown that at least 8 to 9 hours of wear time per day are needed to obtain a good estimate a subject’s level of physical activity [175, 176]. To ensure compliance, participants were reminded to keep wearing the activity monitor every time.
they came to the lab for testing. At the end of the last visit, subjects were asked to return the device to the research team.

Data was then downloaded into analysis software (Actilife 5) that reads and analyzes the data that was collected during wear time. Physical activity is expressed in counts per minute. Activity counts have been validated against energy expenditure [177] to identify sedentary (0 – 100), light (101 - 1,951), moderate (1,952 – 5,723) and vigorous (≥ 5,724) [175, 178]. Light activity is interpreted as activity that requires between 1 and 3 metabolic equivalents (METs), Moderate activity between 3 and 6 METs and vigorous activity more than 6 METs [179]. Physical activity output from the ActiGraph was calculated four days before DOMS and four days after DOMS (figure 6). Research has found that 3 to 5 days can be used to acquire reliability of 0.70 [180]. Peak activity counts before and after DOMS induction were determined by obtaining the highest level of activity achieved in a 5 min period [181].

Activity monitors can be worn in any part of the human body whose movement is being studied. When we are trying to measure physical activity of the whole body, a subject’s sternum, back or waist can be used. The common location for whole-body movement is the waist because it is closer to the center of mass; therefore, it is implied that acceleration measured at this point represents major human motion, and discomfort is also minimized at this location [182, 183]. Moreover, placement at this location has shown to be the best prediction of energy expenditure [184]. For these reasons, this study required the device to be worn over the right hip (on the waist band or belt) in line with the right axilla. Figure 4-2.
Physical activity is expressed in counts per minute, and they are a measure of intensity and frequency of body accelerations and decelerations. Counts are dimensionless units that are derived from the force and frequency of displacements. Because accelerometers have an internal clock, it is possible to obtain reliable measurement of time spent in each category of physical activity [185]. Physical activity measures derived from the data were: type and duration spent in each activity category (light, moderate, vigorous), Intensity (mean activity counts per minute, peak activity counts, and mean step count).

Figure 4-2: Placement of accelerometer

Photo courtesy of Fredy Solis
Quantitative Sensory Testing (QST)

A research assistant administered all QST measures. Study participants underwent QST to determine pain sensitivity to thermal and pressure stimuli. Study participants underwent standard psychophysical pain testing using a contact thermode to deliver the evoked, thermal pain stimuli to assess both first pulse response (primarily A-delta fiber mediated function) and second pain (primarily C-fiber mediated function). The stimuli were applied by a research assistant who ensured proper thermode application. In order to standardize the scaling instructions and to clarify the distinction between the sensory intensity and affective dimensions of pain, a standardized instructional set was used for all subjects. The research assistant recorded visual analog scale (VAS) response to each stimulus. The VAS consisted of a scale whose endpoints are designated as '0 - no pain sensation' and '100 - the most intense pain sensation imaginable'. In order to standardize the scaling instructions, standard instructions were for all subjects. Both, static and dynamic measures of pain sensitivity were used in this study because it has been demonstrated that pain sensitivity to these stimuli is elevated in patients with fibromyalgia, osteoarthritis and chronic neck and back pain. QST measures used in this study are described as follows.

**Pressure Pain Threshold (PPT)**

PPT was assessed bilaterally at T12, L5 and S2. Pressure was applied at a rate of 1 kg/s, until the subject reported change from pressure to pain. Lower values of PPT indicate increased pain sensitivity. Values obtained from the 6 sites at the lumbar spine were averaged together for analysis, and represented local sensitivity. During testing subjects were asked to rate any pain they experience using the NRS. Both, pressure and pain rating were recorded.
Heat pain Threshold and Tolerance

A continuous heat stimulus was delivered to the subjects' dominant arm. The stimulus started at 35°C and increased at a rate of 0.5°C with subjects terminating the stimulus when the temperature reached pain threshold (“when the sensation first transitions from heat to pain”) and tolerance (“when the sensation becomes so strong you want to remove it from your skin”). In addition to familiarizing the subjects to thermal stimuli, these threshold and tolerance data allowed us to investigate general aspects of pain sensitivity and compare to other reports in the literature.

First Pain

First pain was evaluated on the calf or each participant through the application of heat stimuli of 3 s duration. The thermode was applied with a baseline temperature of 35°C, and it increased rapidly (10°C/s) to a peak of 45°C, 47°C, 49°C and 50°C. The sequence of these temperatures were determined randomly to prevent an order effect. First pain is believed to be primarily mediated by Aδ fibers [186]. Subjects rated their first pain using the 101 NPR as described in our lab [187-189]

Temporal Summation

A train of 10 heat pulses was applied to the glabrous skin of the foot. To ensure temporal summation, an inter-stimulus interval of 2 seconds was used with temperatures starting at 39°C and increasing to 50°C (the TSA medoc maintains 10°C/sec rate in this range which is sufficient for maintaining the desired inter-stimulus interval). The participants were asked to rate the magnitude of their delayed (second) pain sensation following each heat pulse. These response ratings are believed to be primarily C-fiber mediated [186].
Self-reported Measures

Pain Catastrophizing Scale (PCS)

The PCS is a 13-item measure that evaluates the extent to which participants focus heavily on their sensation of pain through feelings of rumination, magnification, and helplessness. The score on this measure ranges from 0 to 52 with higher score indicating higher levels of catastrophizing. Appendix B

Fear of Pain Questionnaire (FPQ)

The short form of the FPQ consists of 9 items that measure pain-related fear. Individual items are scored ranging from 1 (not at all) to 5 (extreme), therefore the highest the score the highest the amount of pain-related fear. Appendix A

Physical Activity Scale

Participants were asked to rate their level of physical activity using a six-scale level that ranges from “hardly any physical activity” to “hard or very hard exercise regularly and several times a week, where physical exertion is great, such as jogging or running”. The scale includes domestic as well as recreational activities and it has been validated in people with low back pain [62, 190]. Appendix C

Body Area of Pain Distribution

The subjects were instructed to shade all parts of the body that were painful at the time of their visit by using a drawing depicting the front and back of the human body. Shaded areas were measured by overlaying a transparency grid on the pain locations. The areas that participants indicated having pain were calculated based on the number of squares that were on top of the shaded areas. Each square represented 25 mm$^2$. Therefore the number of squares was multiplied by 25 to obtain the total area of pain distribution. Appendix D
Statistical Analysis

All statistical analyses were conducted on IBM SPSS Statistics, Version 22.0 (Armonk, NY). Significance level was set at \( p < 0.05 \). Descriptive statistics (mean, standard deviation, standard error, range) were generated for all variables.

**Specific Aim 1**

Pearson correlation was used to examine the associations between physical activity performance and self-reported physical activity (hypothesis 1). Pearson correlation was also used to investigate the relationship between physical activity performance and fear of pain and pain catastrophizing. Moreover, regression models were conducted including age and gender as potential confounders (hypothesis 2).

**Specific Aim 2**

Physical activity performance types and self-report were compared with paired sample t-tests pre and post injury (Hypothesis 1). Repeated measures ANOVAs with low back pain intensity, and area of pain distribution as covariates, were calculated to determine which of these variables influenced the change in physical activity performance and self-report (Hypothesis 2).

**Specific Aim 3**

Pearson correlation was used to examine the associations between mechanical and thermal pain sensitivity, physical activity performance type and self-report. Additionally, stepwise regression models were conducted to identify what pain sensitivity measures were associated with physical activity performance before exercise-induced low back pain. Individual categories of physical activity (light, moderate and vigorous) were entered as dependent variables and local and remote pain sensitivity measures that were found to be associated in the correlation matrix
were entered as independent variables (Hypothesis 1). Separate stepwise regression models were then used in which local and remote pain sensitivity measures after exercise-induced low back pain were entered as dependent variables, and categories of physical activity performance (light, moderate and vigorous) obtained before pain induction, were entered as independent variables (Hypothesis 2). Separate stepwise regression models were also used in which the change in local and remote pain sensitivity measures after exercise-induced low back pain were entered as dependent variable and categories of physical activity performance were entered as independent variables (Hypothesis 3). All regression models in this aim included age and gender to control for potentially confounding factors.
### Table 4-1: Protocol implementation

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CHAPTER 5
RESULTS

Subjects

Results were obtained from 39 participants who underwent a DOMS protocol protocol to induce low back pain. Descriptive statistics for demographic and pain-related distress are summarized in Table 5-1. Pain intensity and area of pain distribution elicited by DOMS are also reported on Table 5-1.

Specific Aim 1 - To Explore the Relationship between Pain-related Distress and Physical Activity before Exercise-induced low Back Pain Induction

Results from this analysis did not fully support hypothesis 1. The Pearson correlation matrix showed that moderate and vigorous activity were positively correlated with self-reported physical activity ($r = 0.325, p = 0.046$; $r = 0.376, p = 0.20$, respectively). However, light activity, which represents the highest amount of time spent in activity throughout the day was not significantly associated with self-reported physical activity ($r = 0.140, p = 0.401$). Table 5-2

Results from these analyses partially support hypothesis 2. Pearson correlation matrix showed that only light activity was significantly and negatively associated with fear of pain ($r = -0.377, p = 0.18$). Pain catastrophizing did not show any significant association with physical activity performance. Regression analysis showed that after controlling for age and gender, pain-related fear was responsible for 11.6% of the variability in light activity ($r^2 = 0.116, p = 0.021$). Finally, self-reported physical activity was not significantly associated with either, pain-related fear or pain catastrophizing before pain induction (Table 5-3).
Specific Aim 2 - To Examine Changes in Physical Activity after Exercise-induced low Back Pain

This aim described the change in physical activity after exercise-induced low back pain. Results from this analysis were able to confirm that physical activity performance type was reduced after exercise-induced low back pain. However, self-reported physical activity remained unchanged.

Change in Physical Activity Performance Type

Time spent in light activity decreased significantly after pain induction from 191.4 ± 74.5 to 165 ± 60 minutes (p = 0.004). Similarly, time spent in moderate activity was also reduced after exercise-induced low back pain from 48 ± 24.1 to 42 ± 21.8 minutes (p = 0.029). Time spent in vigorous activity before pain induction was 4.8 ± 8.1 minutes and after pain induction it was 5.6 ± 13.3 minutes (p > 0.05). Table 5-4

Change in Physical Activity Performance Intensity

Both measures of physical activity intensity employed in this study were significantly reduced after exercise-induced low back pain. Peak activity count decreased from 9489.2 ± 5223.8 to 7696.1 ± 4504.3 (p < 0.001). Mean activity count per minutes was reduced from 458.6 ± 209.3 to 396.3 ± 168.9 (p = 0.002). Table 5-4

Change in Self-reported Physical Activity

Self-reported physical activity was not different after exercise-induced low back pain (p = 0.700). Participants reported activity of 4.45 ± 1.24 before pain induction and 4.39 ± 1.24 after pain induction on a 6 point scale. Table 5-4

Figure 5-1 shows the discrepancy between self-reported physical activity and light activity from the accelerometer.
Results from repeated measures analysis failed to support our hypothesis. Induced low back pain intensity and area of pain distribution did not influence the change observed in physical activity performance type. Repeated measure ANOVAs were used to compare light and moderate physical activity before and after induction of pain. Only models for light and moderate activity were conducted because they were they only two measures that had a statistical change. Results from this analysis revealed that for light activity, low back pain intensity and body area of pain distribution did not predict this change in activity as initially hypothesized ($F = 0.234, p = 0.631$, $\eta^2 = 0.007$; $F = 0.227, p = 0.637$, $\eta^2 = 0.007$, respectively) (Table 5-5). Similar results were identified for moderate activity. Low back pain intensity and area of pain distribution did not predict the change in moderate physical activity ($F = 0.013, p = 0.908$, $\eta^2 = 0.000$; $F = 0.470, p = 0.498$, $\eta^2 = 0.014$, respectively). (Table 5-6)

Given that pain-related fear was associated with light physical activity before pain induction, and the pain literature has reported that pain-related fear influences ADL in acute and chronic low back pain, we decided to perform an additional exploratory analysis. In this new model, low back pain intensity and body area of pain distribution remained in the model, and pain-related fear was added as an additional covariate. This additional model showed that pain-related fear predicted the change in light physical activity but not in moderate activity after pain induction ($F = 5.524, p = 0.025$, $\eta^2 = 0.147$). See Table 5-7.

**Specific Aim 3 - To Determine the Extent to which Physical Activity before Exercise-induced low Back Pain Influences Experimental Pain Sensitivity**

Results from these analyses confirmed our hypothesis that physical activity performance type would be associated with local and remote pain sensitivity before
exercise-induced low back pain. Nevertheless, self-reported physical activity was not associated with pain sensitivity.

**Association between Physical Activity and Measures of Pain Sensitivity before Pain Induction**

Light physical activity was found to be positively associated with PPT \( (r = 0.422, p = 0.007) \), heat pain threshold \( (r = 0.386, p = 0.015) \). Light physical activity was also negatively associated with first pain rating at 47 and 49 C \( (r = -0.350, p = 0.029; r = -0.383, p = 0.018, \text{ respectively}) \). Table 5-8

Moderate activity was positively associated with PPT \( (r = 0.577, p < 0.001) \), heat pain threshold \( (r = 0.472, p = 0.002) \), and heat pain tolerance \( (r = 0.362, p = 0.023) \). Vigorous activity did not correlate with any of the pain sensitivity measures assessed in this study. Additionally, self-reported physical activity was only associated with heat pain tolerance \( (r = 0.480, p = 0.002) \), and first pain rating reported at 49 C \( (r = -0.409, p = 0.012) \). Table 5-8

Further analyses were performed using separate stepwise regression models for light and moderate activity. Only measures that were found to be associated with each type of activity were entered as independent variables, potentially confounder factors such as age and gender were also added. Only PPT explained 15.2% of the variance in light activity \( (r^2 = 0.152, p = 0.010) \) Table 5-9. Both, PPT and age explained the variance in moderated physical activity \( (r^2 = 0.391, p = 0.027) \). See Table 5-10

**Association between Physical Activity and Measures of Pain Sensitivity after Pain Induction**

Results from these analyses were able to support our hypothesis that physical activity performance and self-report of activity before exercise-induced low back pain would be protective of local and remote pain sensitivity after pain induction. Separate
regression models were conducted in which PPT and heat pain threshold were entered as dependent variables, given that these two measures were associated with physical activity before induction of pain. Physical activity performance and self-report were entered as independent variables. Our first model showed that gender and moderate activity before pain induction were predictive of PPT after exercise-induced low back pain ($r^2 = 0.505$, $p = 0.005$) Table 5-12. The second model showed that light activity before pain induction predicted heat pain threshold after exercise-induced low back pain ($r^2 = 0.109$, $p = 0.024$). Table 5-13

Stepwise regression model was able to partially confirm our hypothesis that physical activity performance and self-report of activity before pain induction would predict change in local and remote pain sensitivity measures after exercise-induced low back pain. Only change in local pain sensitivity was predicted by light activity (Figure 5-2). We only conducted one regression model with PPT as dependent variable, since it was the only measure that had a statistically significant change after exercise-induced low back pain (Table 5-11). This model showed that after accounting for age and gender, light activity alone predicted the change in PPT after pain induction ($r^2 = 0.142$, $p = 0.012$). Table 5-14
Table 5-1: Characteristics of participants

<table>
<thead>
<tr>
<th>Variable</th>
<th>Participants (n = 39)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>24.9 ± 5.1</td>
</tr>
<tr>
<td>Sex (% female)</td>
<td>23% ± 59%</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>27% ± 69%</td>
</tr>
<tr>
<td>African American</td>
<td>2% ± 5%</td>
</tr>
<tr>
<td>Asian</td>
<td>2% ± 5%</td>
</tr>
<tr>
<td>Native American</td>
<td>0% ± 0%</td>
</tr>
<tr>
<td>Hawaiian/Pacific Islander</td>
<td>0% ± 0%</td>
</tr>
<tr>
<td>Indian</td>
<td>5% ± 13%</td>
</tr>
<tr>
<td>More than one race</td>
<td>3% ± 8%</td>
</tr>
<tr>
<td>Fear of pain (FPQ) (9–45)</td>
<td>21.4 ± 7.3</td>
</tr>
<tr>
<td>Pain Catastrophizing (PCS) (0-52)</td>
<td>14.4 ± 11.5</td>
</tr>
</tbody>
</table>

Table 5-2: Associations between physical activity performance type and self-report

<table>
<thead>
<tr>
<th>Light</th>
<th>Moderate</th>
<th>Vigorous</th>
<th>PAQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>1</td>
<td>0.223</td>
<td>0.087</td>
</tr>
<tr>
<td>Moderate</td>
<td>1</td>
<td>0.268</td>
<td>0.325*</td>
</tr>
<tr>
<td>Vigorous</td>
<td>1</td>
<td>0.376*</td>
<td>0.032</td>
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<td>PAQ</td>
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</tbody>
</table>

Table 5-3: Associations between physical activity performance types, self-report and fear of pain and pain catastrophizing.

<table>
<thead>
<tr>
<th>Light</th>
<th>Moderate</th>
<th>Vigorous</th>
<th>PAQ</th>
<th>FPQ</th>
<th>PCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>1</td>
<td>0.223</td>
<td>0.087</td>
<td>0.140</td>
<td>-0.377*</td>
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<tr>
<td>Moderate</td>
<td>1</td>
<td>0.268</td>
<td>0.325*</td>
<td>-0.225</td>
<td>-0.055</td>
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<tr>
<td>Vigorous</td>
<td>1</td>
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<td>-0.155</td>
<td>0.032</td>
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</tr>
<tr>
<td>PAQ</td>
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<td>-0.272</td>
<td>-0.200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPQ</td>
<td>1</td>
<td>0.373*</td>
<td>1</td>
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</tr>
<tr>
<td>PCS</td>
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<td>1</td>
<td>1</td>
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Table 5-4: Physical activity measures before and after exercise-induced low back pain

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<th>Post-DOMS</th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>p-value</td>
<td>Cohen’s d</td>
<td></td>
</tr>
<tr>
<td>Light activity (min)</td>
<td>191.4</td>
<td>74.5</td>
<td>165</td>
<td>60</td>
<td>0.004</td>
<td>0.39</td>
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<tr>
<td>Moderate activity (min)</td>
<td>48</td>
<td>24.1</td>
<td>42</td>
<td>21.8</td>
<td>0.029</td>
<td>0.26</td>
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<tr>
<td>Vigorous activity (min)</td>
<td>4.8</td>
<td>8.1</td>
<td>5.6</td>
<td>13.3</td>
<td>0.744</td>
<td>0.07</td>
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<tr>
<td>Self-report (1 – 6)</td>
<td>4.45</td>
<td>1.24</td>
<td>4.39</td>
<td>1.24</td>
<td>0.700</td>
<td>0.05</td>
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</tr>
<tr>
<td>Peak activity count</td>
<td>9489.2</td>
<td>5223.8</td>
<td>7696.1</td>
<td>4504.3</td>
<td>0.001</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>Mean activity count per min</td>
<td>458.6</td>
<td>209.3</td>
<td>396.3</td>
<td>168.9</td>
<td>0.002</td>
<td>0.33</td>
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Table 5-5: Change in light physical activity was not predicted by pain intensity or area of pain distribution

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<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
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</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>991159</td>
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<td>991159</td>
<td>119.723</td>
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<td>0.784</td>
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<td>Pain intensity</td>
<td>1940.514</td>
<td>1</td>
<td>1940.514</td>
<td>0.234</td>
<td>0.631</td>
<td>0.007</td>
</tr>
<tr>
<td>Area of pain distribution</td>
<td>1878.42</td>
<td>1</td>
<td>1878.42</td>
<td>0.227</td>
<td>0.637</td>
<td>0.007</td>
</tr>
<tr>
<td>Error</td>
<td>273199.2</td>
<td>33</td>
<td>8278.765</td>
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</tr>
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</table>
Table 5-6: Change in moderate physical activity was not predicted by pain intensity or area of pain distribution

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>73599.46</td>
<td>1</td>
<td>73599.46</td>
<td>76.192</td>
<td>0.000</td>
<td>0.698</td>
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<td>Pain intensity</td>
<td>13.011</td>
<td>1</td>
<td>13.011</td>
<td>0.013</td>
<td>0.908</td>
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<td>Area of pain distribution</td>
<td>453.734</td>
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<td>0.470</td>
<td>0.498</td>
<td>0.014</td>
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<td>Error</td>
<td>31877.14</td>
<td>33</td>
<td>965.974</td>
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</table>

Table 5-7: Pain-related fear predicted the change in light physical activity

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<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
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<tbody>
<tr>
<td>Intercept</td>
<td>376441.9</td>
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<td>376441.9</td>
<td>51.704</td>
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<td>0.618</td>
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<tr>
<td>Pain intensity</td>
<td>16630.98</td>
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<td>16630.98</td>
<td>2.284</td>
<td>0.141</td>
<td>0.067</td>
</tr>
<tr>
<td>Area of pain distribution</td>
<td>10871.55</td>
<td>1</td>
<td>10871.55</td>
<td>1.493</td>
<td>0.231</td>
<td>0.045</td>
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<tr>
<td>Pain-related fear</td>
<td>40216.24</td>
<td>1</td>
<td>40216.24</td>
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<td>Error</td>
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<td>32</td>
<td>7280.719</td>
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Table 5-8: Correlations between physical activity performance type, self-report and local and remote pain sensitivity

<table>
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<tr>
<th></th>
<th>Light</th>
<th>Moderate</th>
<th>Vigorous</th>
<th>PAQ</th>
<th>PPT</th>
<th>Threshold</th>
<th>Tolerance</th>
<th>First-pain-47</th>
<th>Fist-pain-49</th>
<th>TS-1</th>
<th>TS-2</th>
<th>TS-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>1</td>
<td>0.223</td>
<td>0.087</td>
<td>0.140</td>
<td>0.422**</td>
<td>0.386*</td>
<td>0.290</td>
<td>-0.035*</td>
<td>-0.383*</td>
<td>-0.200</td>
<td>-0.185</td>
<td>-0.235</td>
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<tr>
<td>Moderate</td>
<td>1</td>
<td>0.268</td>
<td>0.325</td>
<td>0.577**</td>
<td>0.472**</td>
<td>0.362*</td>
<td>0.197</td>
<td>-0.201</td>
<td>-0.114</td>
<td>-0.365*</td>
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<td>0.376</td>
<td>0.071</td>
<td>0.047</td>
<td>0.104</td>
<td>-0.062</td>
<td>-0.113</td>
<td>-0.061</td>
<td>-0.147</td>
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<tr>
<td>PAQ</td>
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<td>0.248</td>
<td>0.218</td>
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<td>-0.409*</td>
<td>-0.065</td>
<td>-0.065</td>
<td>-0.043</td>
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<td>PPT</td>
<td>1</td>
<td>0.611**</td>
<td>0.507**</td>
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<td>-0.506**</td>
<td>-0.592**</td>
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<td>-0.573**</td>
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<td>Threshold</td>
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<td>-0.577**</td>
<td>-0.592**</td>
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<td>Tolerance</td>
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<td>-0.527**</td>
<td>-0.439**</td>
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<td>First-pain-47</td>
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<td>1</td>
<td>0.496**</td>
<td>0.383*</td>
<td>0.401*</td>
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<td>Fist-pain-49</td>
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<td>1</td>
<td>0.684**</td>
<td>0.775**</td>
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</tr>
</tbody>
</table>

Table 5-9: PPT explain variability in light activity before pain induction

Model summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
<th>F Change</th>
<th>df1</th>
<th>df2</th>
<th>Sig. F Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.419*</td>
<td>0.176</td>
<td>0.152</td>
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<td>7.463</td>
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<td>5</td>
<td>0.01</td>
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</table>

a Predictors: (Constant), PPT
Table 5-10: PPT and age explain variability in moderate activity before pain induction

Model summary

<table>
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<tr>
<th>Model</th>
<th>R</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig. F Change</th>
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<td>.579a</td>
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<td>0.316</td>
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<td>35</td>
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<td>2</td>
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</table>

a Predictors: (Constant), PPT
b Predictors: (Constant), PPT, Age

Table 5-11: Change in pain sensitivity measures after pain induction

<table>
<thead>
<tr>
<th></th>
<th>Pre Mean</th>
<th>DOMS SD</th>
<th>post Mean</th>
<th>DOMS SD</th>
<th>Change</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPT (Kg/s)</td>
<td>31.4</td>
<td>14.3</td>
<td>25.9</td>
<td>13.1</td>
<td>5.5</td>
<td>0.0001*</td>
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<td>Heat pain threshold (Degrees C)</td>
<td>45</td>
<td>2.6</td>
<td>45</td>
<td>2.8</td>
<td>0.02</td>
<td>0.945</td>
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<tr>
<td>Heat pain tolerance (Degrees C)</td>
<td>48</td>
<td>1.3</td>
<td>48</td>
<td>1.5</td>
<td>0.02</td>
<td>0.835</td>
</tr>
<tr>
<td>First pain at 47° C (0-100)</td>
<td>10</td>
<td>10.3</td>
<td>9.3</td>
<td>12.2</td>
<td>0.74</td>
<td>0.594</td>
</tr>
<tr>
<td>First pain at 49° C (0-100)</td>
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<td>21.1</td>
<td>20.0</td>
<td>20.3</td>
<td>0.82</td>
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<tr>
<td>Temporal summation (0-100) trial 1</td>
<td>15.9</td>
<td>16.2</td>
<td>14.6</td>
<td>14.9</td>
<td>1.13</td>
<td>0.545</td>
</tr>
<tr>
<td>Temporal summation (0-100) trial 2</td>
<td>20.3</td>
<td>18.1</td>
<td>22.5</td>
<td>19.9</td>
<td>2.16</td>
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<tr>
<td>Temporal summation (0-100) trial 3</td>
<td>21.3</td>
<td>18.4</td>
<td>19.5</td>
<td>17.1</td>
<td>1.86</td>
<td>0.370</td>
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Table 5-12: Gender and moderate activity before pain induction predicts PPT after exercise-induced low back pain

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
<th>df1</th>
<th>df2</th>
<th>Sig. F Change</th>
</tr>
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<td>9.188</td>
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a Predictors: (Constant), Gender  
b Predictors: (Constant), Gender, Moderate

Table 5-13: Light activity before pain induction predicts heat pain threshold after exercise-induced low back pain

<table>
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<th>Model</th>
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<th>R²</th>
<th>Adjusted R²</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
<th>F Change</th>
<th>df1</th>
<th>df2</th>
<th>Sig. F Change</th>
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<tr>
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<td>1</td>
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</table>

a Predictors: (Constant), Light

Table 5-14: Light activity before induction of pain predicted the change PPT after exercise-induced low back pain

<table>
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<tr>
<th>Model</th>
<th>R</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
<th>F Change</th>
<th>df1</th>
<th>df2</th>
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<td>6.948</td>
<td>1</td>
<td>35</td>
<td>0.012</td>
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</tbody>
</table>

a Predictors: (Constant), Light
Figure 5-1: Comparison between self-reported physical activity and light activity from the accelerometer

Figure 5-2: Light activity predicted change in PPT after pain induction
CHAPTER 6
DISCUSSION

Specific Aim 1: To explore the relationship between pain-related distress and physical activity before exercise induced low back pain induction

Our first aim was to investigate the extent to which pain associated distress is associated with performance and self-report of physical activity in healthy pain free individuals. First, we investigated the relationship between physical activity performance types and self-report. Given that research has shown inconsistent results [51-54] we hypothesized that physical activity performance would not be associated with self-reported physical activity. Correlation analyses demonstrated that self-reported physical activity was not associated with light activity recorded by the accelerometer. However, self-reported activity was statistically associated with moderate and vigorous activity, although the strength of the relationship was moderate. This data suggest that this measure of self-report is better if the goal is to obtain estimates of moderate and vigorous activity from people, however when the objective is to capture all forms of activity, an activity monitor should be used. Research has found that when reporting physical activity participants tend to leave out light activity, which represent the highest amount of time spent in activity in a day [167]. The reason for the lack of self-reported light activity could be because, light activities are less structured than vigorous activity and often involves unplanned body movement that become harder to recall. Donahoo et al. [191] reported that the predominant determinant in the variability of total daily energy expenditure is derived from nonexercise activities such as domestic or occupational tasks. Moreover, recent investigations have highlighted the importance of light activity in health [165, 192]. Therefore, precise identification of physical activity performance it’s
becoming increasingly important in physical activity research because of its known benefits in physical and psychological well-being.

Second we investigated if physical activity performance and self-reported physical activity would be negatively associated with fear of pain and pain catastrophizing. It has been reported that pain-related fear and pain catastrophizing are present in the general population [6, 59, 193]. However, little is known about the relationship of these two constructs on objectively measured physical activity in a healthy population.

We were able to partially confirm our hypothesis that high levels of physical activity were associated with lower scores in pain-related fear. However, an association between physical activity and pain catastrophizing was not found. Pain-related fear and pain catastrophizing were both analyzed in a pain-free state because of their role in the transition from acute to chronic pain. A meaningful cut off value in pain catastrophizing is considered to be higher than 24 [194] in people with a pain condition. The mean score in pain catastrophizing from participants in this study was under 15, which is consistent with previous reports in healthy participants. This low mean score likely occurred because participants in this study were pain-free. Similar to these results, Sullivan et al. [67] found in a group of healthy subjects that pain catastrophizing did not affect physical capacity. Another potential explanation for the lack of association between physical activity and catastrophizing in healthy individuals may be related to the timing of the assessment. A study by Dixon, K.E. et al. [195] found that PCS scores are higher after induction of pain. It has been demonstrated that pain catastrophizing is a construct that emerges with the presence of a painful stimulus and has been
consistently associated with a heightened pain experience [63] in which case, it begins to show a relationship with ADL [59]. Moreover, catastrophizing is a cognitive factor that can be associated with anxiety and depressions brought in by a painful condition [196]. In the present study these associations were examined in the absence of pain, which could explain why we were unable to fully confirm our hypothesis for pain catastrophizing.

Findings from this study suggest that pain-related fear, but not pain catastrophizing, may be a better predictor of physical activity in healthy people. Similar findings have been found in people with acute low back pain [9] and chronic low back pain [7]. Collectively, these results indicate that fear of pain shows consistency as a predictor of physical activity in healthy individuals and individuals with low back pain and therefore it could be considered as a standard screening tool in healthy individuals whose goal is to increase their level of physical activity. Physical therapists who work in primary prevention programs encourage people with non-pain conditions, such as diabetes and heart diseases, to increase their level of physical activity. Therefore, fear of pain questionnaires at these levels of prevention could be used to identify those people whose low level of activity may be associated with their fear of pain.

The present study offers the advantage that a physical activity monitor was used instead of a questionnaire. Technology from the activity monitor and software allow for precise identification of different activity categories based on accelerations of the body. The correlation matrix of the association between pain-related fear and physical activity using the different categories provided by the software revealed that specifically light activity is negatively associated with pain-related fear. Light activity essentially refers to
the performance of activities of daily living such as household chores or any body movement that requires energy expenditure under 3 METs. This finding suggests that in people without any pain condition, elevated scores in pain-related fear have a negative influence in the performance of activities of daily living. Elevated pain-related fear may be one of the reasons why people with no chronic pain, but chronic conditions such as diabetes and heart diseases are not as active as they should be. Recently, research in light activity has increased because of the potential health benefits of increasing light activity for individuals with diabetes, heart diseases, cancer, among others.

Physical activity is one of the most important health promotion topics physical therapists address in their clinical practice. The APTA states that physical therapists need to “provide prevention and promote health, wellness and fitness” (Guide to Physical Therapist Practice. 2nd ed. Phys Ther. 2001;81; page 40); therefore, PT education programs across the United States have incorporated “Promotion and Wellness in Physical Therapy Practice” into their curriculum. The goal is that physical therapists get involved in the prevention of disease and address health promotion topics informing the general population about the benefits of enhancing physical health. Increasing physical activity seems to be at the top of the list of health promotion issues, given the increasing evidence of the protective effect of physical activity against chronic diseases [197] such as type 2 diabetes, obesity, cardiovascular diseases, and many types of cancers [198]. These aforementioned diseases are chronic conditions that physical therapists treat in their clinical practice. A study by Rea et al. showed that over 50% of physical therapists surveyed across 3 states thought physical activity was the number one topic they addressed in their clinical practice [199]. Therefore, we suggest
that physical therapists, as part of health promotion and wellness programs, include fear of pain-related questionnaires to identify people who have elevated fear of pain, and implement appropriate interventions to increase physical activity. Interventions such as education, fear-reducing information, and intervention aimed at reducing pain-related fear could be implemented.

Specific aim 2: To examine changes in physical activity after exercise-induced low back pain

Our second aim was to determine the extent to which acute exercise-induced low back pain affected physical activity. We hypothesized that participants would display reduced levels of physical activity performance type and self-report after induction of low back pain. Typically, physical activity in people with acute or chronic pain has always been compared to a control group. The use of a muscle-injury protocol, like the one used in this study, offered the opportunity to observe direct changes in physical activity measures as participants transitioned from health to a pain condition.

In this study, data from the activity monitor demonstrated that physical activity performance was diminished after pain induction. These changes were identified as decreased in parameters of physical activity performance type and intensity. However these changes were not reflected in the way people reported their level of physical activity when they filled out the self-report questionnaire on perceived physical activity. This finding indicates that for more precise identification of physical activity performance in people with acute low back pain activity monitors may need to be used in order to create appropriate interventions.

An analysis of physical activity performance type revealed that there was no difference in the amount of time spent in vigorous activity as reported in previous
research [200]. This may be attributed to our eligibility criteria to participate in this study. We recruited participants that were not very physically active in order for the muscle-injury protocol to be successful. Therefore, their baseline average time spent in vigorous activity was already low and there may have been a floor effect for additional decreases. Another potential explanation could be that pain elicited from our muscle-injury protocol may not have been intense enough for people to withdraw from vigorous activity. Moreover, this finding was already expected because in Aim 1 we found that vigorous activity was highly correlated with self-report and we previously reported that self-report did not change after pain induction (results from Aim 2). Nonetheless, a significant decrease in light and moderate activity by accelerometer was noted after pain induction.

Few studies have reported a change in self-reported moderate activity in chronic pain [200]. However, to our knowledge no study has reported a specific change in light activity in acute low back pain. The reason for this may be attributed to the type of measurements used in other studies. Many self-report questionnaires of activity are more sensitive to changes in activities that are likely to be highly correlated with self-report measures, such as moderate and vigorous activity. Therefore, all the reductions in unplanned and incidental body movements are likely under-reported. However, the highest amount of time spent in activity during an ordinary day is mostly light activity. Results from this study suggest that performance of light activities such as activities of daily living are in fact reduced in an episode of exercise-induced acute low back pain. This impact on light activity would not have been identified if only a self-report measure was used. Therefore this category of activity could be an important target to address in
physical therapy interventions. Encouraging people with low back pain to continue performing light activities around the house and workplace can be a good short term goal that physical therapists and patients can agree on, and it is a good start before moving on towards increasing moderate activities.

Very few studies have compared peak activity counts between people with chronic pain conditions (CLBP and fibromyalgia) and healthy participants. In these studies peak activity counts has been found to be decreased [181, 200, 201]. Results from the current study showed similar results when peak activity counts where compared from before to after pain induction. Peak activity counts reflects the highest level of activity achieved during one minute epoch within a bout of physical activity and we need to mention that it is not a measured of sustained activity. Peak activity count as a measure by itself, it is not a strong measure to identify changes in physical activity intensity and needs to be reported with mean activity counts per minute.

Both measures employed in this study to estimate movement intensity (peak activity counts and mean activity counts per minute) were reduced, therefore, we can provide stronger evidence that body movement intensity is decreased in the presence of exercise-induced low back pain. These results indicate that people with acute pain may move slower in their free-living environment. In contrast to our results, Kop et al. [181] did not find differences in mean activity counts between patients and controls and one of the reasons for this discrepancy may be because in our study, activity levels were measured within the same subjects before and after they experienced pain from the muscle injury protocol, which is one of the strengths of this research project.
Participants from this study did not demonstrate change in physical activity in the self-report questionnaire. Only mean activity counts and time spent in vigorous activity were associated with self-reported physical activity. This association suggests that participants when they report activity, they are likely to be influenced by activities that involve high intensity movement rather than amount of time spent in activity. These results are in line with previous findings that reported that it is easier to remember those activities that are vigorous but not those that are light such as moving around the house performing household chores or moving around the workplace [43, 202].

Results from repeated measures failed to confirm our second hypothesis for Aim 2. Low back pain intensity and area of pain distribution did not influence the change in physical activity performance type. Separate repeated measures ANOVA with pain intensity, and area of pain distribution, as covariates were calculated for light and moderate activity. We did not create a model for self-report because there was no change reported by this population. Results from this analysis revealed that the amount of pain experienced from the exercise induced injury did not predict a decrease of light or moderate physical activity observed in these participants. Results from this study are in line with previous research in which muscle damage from DOMS [137] was not associated with pain intensity [203]. To further investigate what additional factors may have had an influence in the change in physical activity performance, we added pain-related fear to the model because of its moderate association with light activity before pain induction and pain-related fear has been found to influence ADLs in acute [9] and chronic pain conditions [7]. We were able to identify that the amount of pain-related fear that these participants reported at baseline had an influence on the change in light
physical activity after exercise-induced low back pain. Our results are in agreement with Crombez et al.[7] who found that in people with chronic pain, pain-related fear was a better predictor of performance than pain intensity or pain catastrophizing. These results are comparable to studies in which pain-related fear has been found to be the strongest predictor for the performance of functional tasks [9] in people with acute pain such as straight leg raising test [81], range of motion and muscle strength [7]. Nonetheless, these studies used measures of controlled physical performance and not free-living physical activity. Therefore, results from our study extend beyond laboratory measures of physical performance, and we can speculate that the reduction of light physical activity observed in these participants was influenced primarily by pain-related fear.

Collectively, these findings from Aim 1 and Aim 2 continue to imply that fear of pain is an important construct to evaluate and address during interventions in patients with acute low back pain. Even when pain intensity was included in the model, fear of pain was the only measure that emerged as a significant predictor. These results are consistent with previous research that has identified fear of pain to be more disabling than pain itself [7]. Change in moderate activity did not seem to be influenced by any of the variables included in the model. The reason for this could be because at baseline only light activity showed a strong association with fear of pain while moderate activities did not.

**Specific aim 3: To determine the extent to which physical activity before exercise induced low back pain influences experimental pain sensitivity**

Our first hypothesis stated that physical activity performance and self-report would be positively associated with local and remote pain sensitivity before exercise-induced low back pain. Results from this study showed a moderate correlation between the light physical activity recorded by the accelerometer before induction of DOMS with
PPT, heat pain threshold, and a-fiber mediated pain (first pain reported at 47 and 49 C). The direction of these correlations were expected based on previous research in which self-reported moderate physical activity was associated with some measures of pain sensitivity [170]. Further exploration of these associations using a regression model showed that after accounting for age and gender only PPT accounted for 15.2% of the variability in light activity. To our knowledge, this is the first investigation that suggests that a higher amount of time spent in light activity has a positive effect on pain sensitivity measures.

Correlation analysis revealed that moderate physical activity was associated with PPT, heat pain threshold and heat pain tolerance. A regression model demonstrated that PPT alone explained 31.6% of the variability in moderate activity. In this model, age also emerged as a significant factor explaining an additional 8% of the variability in moderate activity. This finding is not surprising because the literature has reported that deep tissue nociception is affected by age, and the age range in the present study was smaller than in previous studies [204, 205]. Unlike previous research, in this study, vigorous activity was not associated with local or remote pain sensitivity measures. Ellingson et al. [171] found a significant relationship between time spent in vigorous physical activity and pain sensitivity measures. However, this study was not able to confirm those results. Even though they used the same model of accelerometer we did, they only included for their analysis, participants who were very active. Time spent in vigorous activity in Ellingson’s study was nearly 4 times higher than the time our participants spent in vigorous activity [171]. This discrepancy may be the result of our
recruitment process. For this study we were recruiting participants who were not extremely active in order for the muscle-injury protocol to be successful.

Previous research has found that there is an association between moderate and vigorous physical activity and PPT; however, self-report questionnaires have been used to obtain physical activity data [169]. Associations between vigorous activity and PPT have been studied in a controlled laboratory environment where research participants were asked to perform aerobic exercises either on a treadmill or a stationary bicycle for about 20 to 30 min [206-208] [209]. Results from these investigations suggested that the explanation for these associations is the result of elevated circulating and release of endogenous opioids. Nonetheless, in the present investigation we studied how much physical activity these subjects performed in their free-living environment.

Heat pain threshold was positively correlated with light and moderate activity before pain induction. Results from this study differ from results reported by Naugle and Riley [170]. In their study no relationship was found between total activity and heat pain threshold and tolerance [170]. A couple of methodological differences could explain why their results are not consistent with our findings. In Naugle’s study, a questionnaire to obtain physical activity data was used as opposed to the accelerometer used in this study. Moreover, their sample size consisted of a wider age range. It is well documented that age is a factor that influences pain sensitivity [204, 205, 210]. Finally, they used total activity as their physical activity measure, while in this study we used performance type based on the cut off points provided by the activity monitor software.

Results from this study support previous research that has suggested a strong relationship between physical activity and pain processing in the central nervous system.
Previous research on healthy women found that participation in vigorous activity seems to be responsible for decreased pain sensitivity to heat stimuli with temperatures ranging from 43° C to 49° C [171]. Even though Ellingson et al. [171] measured physical activity by the same method used in our lab, we were not able to identify an association between vigorous physical activity with pain ratings at 47° and 49° C. The discrepancy in findings could be explained by their smaller sample size (21 subjects) and the fact that their sample size consisted of women only. Sex differences in pain perception have been widely documented in the literature [211-214].

Self-reported physical activity from this study was not correlated with measures pain sensitivity, but physical activity performance was correlated with these measures. Using a measure of self-report in this study would have led us to believe that there is no relationship between physical activity and measures of pain sensitivity. Many physical activity scales have been developed and finding one that is appropriate for the population to be studied poses a big challenge. The physical activity scale used in this study was good only for capturing vigorous activities. As reported in this study most of the robust associations between physical activity and pain sensitivity derive from light physical activity. Therefore, we suggest that in order to avoid misleading results, activity monitors should be used because they are more sensitive to detect body movement that people would never report because their low intensity and low energy expenditure required such as the performance of ADL.

Our second hypothesis stated that physical activity performance and self-report before exercise-induced low back pain would be predictors of local and remote pain sensitivity after pain induction. Before conducting regression models, we needed to
know whether there was a change in pain sensitivity measures after exercise-induced low back pain. In this study, pressure pain threshold was the only measure that was statistically different. Research has shown that in people with chronic low back pain responses to pressure and thermal pain are heightened, which is indicative of central sensitization [138, 215-219]. However, in this study all the thermal modalities employed to evaluate pain sensitivity in regions away from the lumbar spine remained unchanged (Table 12). This augmented response to noxious stimuli in the lumbar spine during acute pain, but not in areas away from the painful region indicated a peripheral mechanism rather than central mechanism commonly observed in chronic pain conditions.

The muscle injury model used in this study allows for immediate assessment of experimental pain sensitivity measures at the onset of exercise-induced low back pain. It is not surprising that thermal pain sensitivity did not change after pain induction since it has been suggested that these measures are only altered in the presence of chronic pain conditions [143, 220]. The mechanisms behind this heightened perception to experimental pain in chronic conditions may be due to ongoing input from nociceptors, which was not the case in this study. These data suggest that PPT may be a more meaningful measure to use in clinical practice when assessing a patient with acute low back pain over the use of thermal pain assessment.

Once we established that PPT was the only pain sensitivity measured that changed after pain induction, we needed to investigate if pre muscle injury levels of physical activity was predictive of PPT after pain induction. Numerous studies on healthy animal and human subjects have found that acute exercise induces hypoalgesia
However, the effect of regular physical activity in a free-living environment on pain sensitivity after exercised-induced pain has not been investigated. Because PPT was the only measure that changed after exercise-induced low back pain, and heat pain threshold was consistently correlated with light and moderate activity, we only conducted two regression models for these two measures. This analysis demonstrated that moderate and light activity before pain induction were significant predictors in the variability of PPT and heat pain threshold after exercise-induced low back pain. Results from this analysis are supported by Andrzejewski, et al. [169] who found that physical activity has a positive influence on PPT. Additionally, animal studies have reported regular physical activity has a protective effect on the development of hyperalgesia in pain induction models [227, 228]. Moreover, human studies in teenagers have shown the protective effect of high physical activity in the development of back pain [229]. Similar results have been reported in the elderly population [230], however sensitivity to pressure pain was not tested in these studies. Pressure pain is an important assessment in acute pain because of the neurological and physiological changes that occur in acute and chronic pain conditions. This study demonstrated that the amount of moderate and light activity performed by these research participants before pain induction predicted significant variability in PPT during acute exercise-induced low back pain, which is suggestive of a protective effect on the peripheral mechanism of low back pain.

Our third hypothesis stated that change in local and remote pain sensitivity after exercise-induced low back pain would be predicted by physical activity performance and self-report measures recorded before pain induction. A few mechanisms have been
described to explain how regular physical activity in a free-living environment has a positive effect on pain modulation. One of these mechanisms that has been suggested is central release of endogenous opioids [209]. Stagg et al. [228] found that in mice, regular physical activity increases β-endorphins in the periaqueductal gray area, which is an area that has been well recognized for its role in pain modulation [231-233]. Similar results have been reported in humans, McLoughlin [175] found that in healthy and fibromyalgia patients, physical activity plays an important role in pain modulation in the periaqueductal gray. Another explanation on how physical activity influences pain sensitivity is that regular physical activity decreases proinflammatory cytokines such as TNF-alpha and IL-6, and increases anti-inflammatory cytokines such as IL-10. IL-10 is known for reducing nociceptor sensitization [234]. However, these changes brought in by regular physical activity are temporary if physical activity is not maintained [227].

PPT was the only measure that had a significant change after pain induction and therefore it was the only measure analyzed to test this hypothesis. This result shows that after controlling for potentially confounding factors, light activity before pain induction predicted the change in PPT, which indicates that light activity potentially plays an important role in the modulation of peripheral pain processing. Similar results have been observed in animal models [228, 235], in which a slow-moving treadmill was used. In human research, Mcloughlin et al. [175] reported that the amount of time spent in light activity had a negative relationship to brain responses to painful stimuli. Ellingson et al. [173] found that in patients with fibromyalgia, physical activity is related to pain modulation in the periaqueductal gray. However, in another study [236] PPT modulation did not occur in fibromyalgia patients. The difference in results could be
attributed to the use of isometric contraction, which is muscle performance, and not sustained activity. Unlike animal studies in which physical activity has been manipulated, our results demonstrated that just having an active lifestyle around the home or workplace has great benefits in pressure pain modulation. This is an important finding because pressure pain correlates well with clinical status in individuals with low back pain [215, 237]. For this study we did not investigate what pathways may be affected by physical activity. However, based on these results, we speculate that light physical activity influences sensitization of the mechanoreceptors located in the lumbar spine.

**Limitations**

Several limitations are present in this study. An objective assessment of physical activity was the main outcome measure of this investigation; nonetheless, the activity monitor itself presented a couple of limitations. The device is not water proof; therefore participants had to remove the activity monitor for water activities, meaning that time spent in activities such as swimming is not included in the study. Moreover, while newer models record activity in 3 axes, the activity monitor used in this study only allowed recordings in 2 axes. Another limitation from this study is that physical activity scores after induction of DOMS may not truly represent physical activity in a population with low back pain. The reason for this is because values of physical activity variables presented in this study were averages across 4 days post-DOMS. Once muscle soreness from DOMS peaks at 24 to 48 hours, symptoms begin to subside, which allows participants to be more active. Additionally, participants from this study received manual interventions to decrease their pain 2 days after pain induction and at the end of the 4 day period the majority of participants reported that they were pain-free. Though
this is a good model to examine the transition from a pain-free state to acute pain via peripheral mechanism, this muscle injury protocol does not allow us to look at the transition from acute to chronic pain, and for this reason, no measurable changes in central sensitization were generated. Furthermore, in the current study DOMS was induced in a fairly young population. Implementing this model in an older cohort may help better understand pain behavior in a wider age range. Findings from this study cannot extend to adults over 40, who normally have changes in the anatomical structures spine which could make for a different pain experience from the sample analyzed in this dissertation. Finally, the modest sample size from the present study poses a limitation to the type of multivariate analyses that could be conducted.

**Future Directions**

This dissertation is the first study that investigates physical activity using objective and self-report measures in a muscle injury protocol. Thus, it forms the foundations for future research in the following ways. First, future studies could expand on these findings by adding a group who performs high vigorous activity before DOMS to compare their results with the results from this study that focuses on light activity. It is necessary to investigate if light and vigorous activities have the same protective effects on pain processing. Additionally, physical activity in an older cohort needs to be assessed, since this population may have anatomic and structural changes that may affect their pain processing. Finally, the associations of light activity with biomarkers of pain processing need to be investigated. Physical activity seems to have a chronic effect on cytokine profiles in animal models, such as IL-10 which is believed to decrease nociceptor sensitization [231]. However, these associations need to be explored in human models. Another biomarker that could be explored is Catechol-O-
methyltransferase (COMT). COMT is an enzyme that metabolized catecholamines involved in pain modulation. George et al. [238, 239] reported that COMT genotype predicts clinical pain ratings; therefore it is necessary to investigate if there is a link between light physical activity and COMT genotype activity. These types of investigations would provide the foundations for newer physical activity guidelines and their relationship to pain.

**Conclusions**

This study investigated whether physical activity is associated with pain-related distress and pain sensitivity before and after exercise-induced low back pain. Key findings from each study aim are summarized as follows. First, when measuring physical activity, it is important to carefully consider which component we are trying to capture. If moderate and/or vigorous activity is the main outcome, then a self-report questionnaire may be sufficient. However, if quantification of light activity is the main outcome, then an accelerometer should be employed. Second, light physical activity was negatively associated with pain-related fear before induction of pain. This finding is relevant because this association is often found in individuals with chronic pain conditions. However, this result is seldom reported in pain-free individuals, and it deserves attention in a pain free state because it seems to be a factor that influences regular physical activity. Third, light and moderate physical activity decreased after pain induction. Pain induction models have been shown to be successful because they replicate signs and symptoms from acute low back pain, such as pain, inflammation, decreased muscle strength, and range of motion. However, to our knowledge, this is the first study that shows that light physical activity performance type and intensity are reduced after exercise-induced low back pain. This finding adds strength to the use of
the pain induction model, not only for the low back but also for other joints. Moreover, the reduction in light physical activity in this population was driven by pain-related fear and not catastrophizing or post-DOMS pain measures as initially hypothesized. Fourth, only local pain sensitivity changed after pain induction, which suggests a peripheral sensitization mechanism with DOMS. Because pain from this model usually peaks within 48 hours and tends to disappear 2 days later, this model does not seem appropriate to study central sensitization, which was confirmed by the lack of change in remote sensitivity. Therefore the link to chronic pain may be tenable for DOMS model given that central sensitization is believed to be an integral part of the chronic pain experience. Finally, light physical activity was associated with pain sensitivity measures before pain induction, additionally; higher amount of light activity was associated with more modulation of PPT after exercise-induced low back pain. This is an important finding because physical activity recommendations often focus on moderate and vigorous activity. Nonetheless, a novel finding of this study is that it demonstrated that light activity performance may have a positive influence on peripheral sensitization. Whether there is a protective effect of light activity on central sensitization, however, should be further explored and future studies should try to differentiate between light and vigorous activity to determine if there is differential protective effect on peripheral and central sensitization. Studies like that would provide important foundational information for subsequent physical activity recommendations as they relate to prevention of chronic musculoskeletal pain.
APPENDIX A
FEAR OF PAIN QUESTIONNAIRE

Instructions: The items below describe painful experiences. Please look at each item and think about how fearful you are of experiencing the pain associated with each item. If you have never experienced the pain of a particular item, please answer on the basis of how fearful you expect you would be if you had such an experience. Fill in one circle for each item below to rate your

<table>
<thead>
<tr>
<th>Not at All</th>
<th>A little</th>
<th>A Fair Amount</th>
<th>Very Much</th>
<th>Extreme</th>
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<td>1</td>
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</table>

1. Being in an automobile accident
2. Biting your tongue while eating
3. Breaking your arm
4. Cutting your tongue licking an envelope
5. Having a heavy object hit you in the head
6. Breaking your leg
7. Hitting a sensitive bone in your elbow-your “funny bone”
8. Having a blood sample drawn with a hypodermic needle
9. Having someone slam a heavy car door on your hand
10. Falling down a flight of concrete stairs
11. Receiving an injection in your arm
12. Burning your fingers with a match
13. Breaking your neck
14. Receiving an injection in your hip/buttocks
15. Having a deep splinter in the sole of your foot probed and removed with tweezers
16. Having an eye doctor remove a foreign particle stuck in your eye
17. Receiving an injection in your mouth
18. Being burned on your face by a lit cigarette
19. Getting a paper-cut on your finger
20. Receiving stitches in your lip
21. Having a foot doctor remove a wart from your foot with a sharp instrument
22. Cutting yourself while shaving with a sharp razor
23. Gulping a hot drink before it has cooled
24. Getting strong soap in both your eyes while bathing or showering
25. Having a terminal illness that causes you daily pain
26. Having a tooth pulled
27. Vomiting repeatedly because of food poisoning
28. Having sand or dust blow into your eyes
29. Having one of your teeth drilled
30. Having a muscle cramp
**APPENDIX B**

**PAIN CATASTROPHIZING SCALE**

**Pain Catastrophizing Scale**

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

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

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>To a slight degree</th>
<th>To a moderate degree</th>
<th>To a great degree</th>
<th>All the time</th>
</tr>
</thead>
<tbody>
<tr>
<td>I worry all the time about whether the pain will end</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I feel I can’t go on</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>It’s terrible and I think it’s never going to get any better</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>It’s awful and I feel that it overwhelms me</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I feel I can’t stand it anymore</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I become afraid that the pain will get worse</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I keep thinking of other painful events</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I anxiously want the pain to go away</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I can’t seem to keep it out of my mind</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I keep thinking about how much it hurts</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I keep thinking about how badly I want the pain to stop</td>
<td>0</td>
<td>1</td>
<td>2</td>
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<td>4</td>
</tr>
<tr>
<td>There’s nothing I can do to reduce the intensity of the pain</td>
<td>0</td>
<td>1</td>
<td>2</td>
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<td>4</td>
</tr>
<tr>
<td>I wonder whether something serious may happen</td>
<td>0</td>
<td>1</td>
<td>2</td>
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</table>
APPENDIX C
PHYSICAL ACTIVITY QUESTIONNAIRE

PHYSICAL ACTIVITY QUESTIONNAIRE

_____ 1 Hardly any physical activity

_____ 2 Mostly sitting, sometimes a walk, light gardening or similar tasks, sometimes light household activities, such as heating up food, dusting or ‘clearing away’

_____ 3 Light physical exercise for 2–4 hours a week, such as walks, fishing, dancing, ordinary gardening, etc., including walks to and from shops; main responsibility for light domestic work such as cooking, dusting, ‘clearing away’ and making beds; performs or takes part in weekly cleaning

_____ 4 Moderate exercise for 1–2 hours a week, such as jogging, swimming, gymastics, heavy gardening, home repair or light physical activities for more than 4 hours a week; responsibility for all domestic activities, light as well as heavy; weekly cleaning with vacuum, washing floors and window cleaning

_____ 5 Moderate exercise for 3 hours a week, such as tennis, swimming, jogging, etc.

_____ 6 Hard or very hard exercise regularly and several times a week, where the physical exertion is great, such as jogging, running or skiing

Would you have been more physically active if you didn’t have low back pain?
Yes______ No______
PAIN EXPERIENCE VAS   Session#:   Subject#:   Date:

Mark a hash on the lines below to indicate how your pain makes you feel.

PAIN INTENSITY NOW (How much pain you currently have today)
none  worst imaginable

WORST IN THE LAST WEEK (Rate the greatest level of pain you have experienced starting this study)
none  worst imaginable

BEST IN THE LAST WEEK (Rate the least level of pain you have experienced since starting this study)
none  worst imaginable

DEPRESSION
none  worst imaginable

ANXIETY
none  worst imaginable

FRUSTRATION
none  worst imaginable

FEAR
none  worst imaginable

ANGRY
none  worst imaginable

PLEASANTNESS
none  worst imaginable

Use these diagrams to indicate the location of your pain that you are experiencing right now. Shade in the AMOUNT AND AREA OF PAIN YOUR ARE FEELING.
LIST OF REFERENCES


BIOGRAPHICAL SKETCH

Fredy Mora Solis was born in the city of Rivas, Nicaragua. He received his bachelor’s degree in physical therapy in 1999 from the National Autonomous University of Nicaragua (UNAN-Managua). He worked in a private practice for 9 years. In 2003, he joined the Physical Therapy Department at UNAN as adjunct faculty. In 2007, he became full time faculty. His responsibilities included teaching Anatomy, Therapeutic exercise, and Orthopedics.

In 2008, Fredy was awarded a Fulbright scholarship to study his Master’s degree in an American Institution. The Fulbright board placed him at the University of Florida where he completed his Master of Science in Applied Physiology and Kinesiology with concentration in exercise physiology, which he finished in the summer of 2011.

In the fall of 2011, Fredy began his PhD in Rehabilitation Science in the Physical Therapy Department at the University of Florida. During his PhD training, Fredy presented at national conferences including the Combined Sections Meeting of the American Physical Therapy Association (APTA), and the world congress of Osteoarthritis (OARSI). Mr. Solis was awarded the Frederick Family Scholarship in 2015 for excellence in academics, teaching and research and received his Ph.D. from the University of Florida in the spring of 2016.