THE IMPACT OF A DYNAMIC TRUNK AXIAL TWISTING TASK TO FATIGUE ON MUSCULOSKELETAL RESPONSES

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Abstract

The purpose of this thesis was to examine pain developers' (PD) and non-pain developers' (NPD) musculoskeletal responses to a repetitive dynamic axial twisting exposure when performed to self-reported fatigue. Trunk/pelvis muscle activation & kinematics, self-reported transient pain, range of motion (ROM) tests, and a repetitive dynamic axial twisting exposure were collected on 13 female softball players. Seven participants developed transient pain. The PD had a decrease in mean muscle activation and spine segment angles in the ROM tasks and the axial twisting exposure. Yet, the PD reached the same maximum spine segment angle as the NPD during the exposure with lower muscle activation. This suggests that PD were using a different strategy to perform the exposure, one that could be the source of transient pain. More research needs to be conducted to better understand musculoskeletal responses to twisting, especially in PD, to identify the possible mechanisms that lead to LBP/injury.

Dedication

I want to dedicate this to my wonderful parents, Chris and Art. Through everything you both have been my number one fans and the best support system anyone could ask for. No matter what I set my mind to, or what challenges I take on, you guys are always there cheering me on. Whether it is traveling across North America to watch me play or coach softball. Or, listening to me vent or complain about the many struggles that presented itself over the last two years. Mom and Dad, you have been my rock, and I owe everything to you both.

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List of Abbreviations

LBP	Low back pain
MMH	Manual materials handling
MVC	Maximum voluntary contraction
EMG	Electromyography
VAS	Visual analog scale
IVD	Intervertebral disc
AHAbd	Active hip abduction
ROM	Range of motion
3D	Three-dimensional
PD	Pain developer
IREDs	Infrared emitting diodes
IPAQ	International Physical Activity Questionnaire
PARQ+	Physical Activity Readiness Questionnaire
RSES	Rosenberg Self-Esteem Scale
SPAS	Social Physique Anxiety Scale
BSQ	Body Shape Questionnaire
NPD	Non-pain developer
BIA	Bioelectrical impedance analysis
RRA	Right rectus abdominis muscle
LRA	Left rectus abdominis muscle
REO	Right external oblique muscle

LEO	Left external oblique muscle
RIO	Right internal oblique muscle
LIO	Left internal oblique muscle
RGM	Right glute medius muscle
LGM	Left glute medius muscle
RTES 4	Right Thoracic erector spinae muscle at the level of 4^{th} thoracic vertebra
LTES 4	Left Thoracic erector spinae muscle at the level of 4^{th} thoracic vertebra
RTES 12	Right Thoracic erector spinae muscle at the level of 12^{th} thoracic vertebra
LTES 12	Left Thoracic erector spinae muscle at the level of 12^{th} thoracic vertebra
RLES	Right Lumbar erector spinae muscle at the level of 5^{th} lumbar vertebra
LLES	Left Lumbar erector spinae muscle at the level of 5^{th} lumbar vertebra
UT	Upper thoracic spine segment
MT	Middle thoracic spine segment
LT	Lower thoracic spine segment
L	Lumbar spine segment
HR	Heart Rate
Bpm	Beats Per Minute
SD	Standard deviation

1. Introduction

Minimal research has examined repetitive dynamic axial twisting *in vivo* and the effect of axial twist on the spine. However, Manning *et al.* (1984) noted that axial twisting of the trunk was involved in over 60% of all back injuries reported in the workplace. Epidemiological studies evaluating workers in manufacturing settings have identified axial twisting of the trunk to be a risk factor associated with the development of low back pain (LBP; Kelsey *et al.*, 1984; Manning *et al.*, 1984; Marras *et al.*, 1993). Kelsey *et al.* (1984) examined the risk of the development of LBP in workers where lifting was a part of their job requirement. These researchers concluded that lifting over 11.3 kg, 25 times a day or more had a three times more likely risk of injury to the lumbar spine in comparison to those lifting less weight (Kelsey *et al.*, 1894). It was also identified that when workers performed a weighted lift multiple times throughout the day, there was an increased risk of injury to the lumbar spine (Kelsey *et al.*, 1894). But, the risk of injury from a twisted position was not quantified. Likewise, axial twisting appears to increase the risk of pain/injury on the spine, but the musculoskeletal responses to repetitive twisting may resist the motion or lead to injury are still unknown.

Through *in vitro* research using porcine functional spine units (two adjacent vertebrae and intervening disc), small magnitudes of axial twist moments that are added to moderate compression and repetitive flexion-extension movements, were shown to reduce the number of cycles required to cause intervertebral disc (IVD) herniation (Drake *et al.*, 2005). During acute compressive strength testing of porcine functional spine units, Aultman *et al.* (2004) found that adding a 30Nm static axial twist moment decreased the spine unit's compression tolerance by roughly 54%. These acute and repetitive loading exposure results of Aultman *et al.* (2004) and Drake *et al.* (2005) research support the much earlier work on repetitive axial twist loading in

human cadaveric spines by Farfan *et al.* (1970). Farfan *et al.* (1970) observed disc herniation and disc delamination (termed degeneration in the paper) in human lumbar spines after axial twist loading in an otherwise neutral posture (no flexion or lateral bend applied to the spine), suggesting that repetitive axial twisting alone could damage the IVD. However, Pearcy and Hindle (1991) concluded from their *in vitro* work (and use of a different type of apparatus that did not have a fixed axis of rotation) that axial twisting, when applied in a neutral posture, was not sufficient enough to damage the IVD. Pearcy and Hindle (1991) commented that adding a twist to non-neutral movement (i.e. flexion/extension or lateral bend) would likely increase the specimen's ability to rotate, which may increase the risk of injury to the IVD (Pearcy and Hindle, 1991). Despite the strong *in vitro* evidence that identified possible mechanisms of injury from axial twisting that caused damage to an osteoligamentous spine, the role of muscles (mitigating, aggravating, or other) could not be considered. Further, the relatively limited human *in vivo* research that has included twisting exposures has involved only passive twisting (the participant was rotated and constrained in an apparatus; Drake and Callaghan, 2008) or focussed on range and the pattern of vertebral twisting motion along the spine (no muscle activation data; Pearcy and Tibrewal, 1984). Therefore, *in vivo* examination of the musculoskeletal response to twisting exposures is needed to understand possible manifestations of the possible *in vitro* mechanisms *in vivo.*

In addition to the structural damage that applied axial twisting can cause in an osteoligamentous spine, twisting imposes a considerable compression load from the substantial muscular involvement that is required to generate the twisting movement of the spine (Ng *et al.*, 2001). The anatomy of the trunk is important to consider when discussing axial twisting. The prime musculature that is involved during axial twisting of the trunk has been identified as the

contralateral external oblique and the ipsilateral internal oblique in addition to the latissimus dorsi (Kumar *et al.,* 1996). However, since the internal/external obliques and the latissimus dorsi muscles are large and have a sizeable area of attachment (with wide muscle fiber orientation), it causes contraction of these muscle to create moments in the three planes (twist, flexion/extension, and lateral bend; Dumas *et al*., 1991). Work done by Ng *et al.* (2001) also outlines the importance of the trunk muscles in stabilization of the spine. Since the rectus abdominus muscle spans the entire abdomen and attaches between the thoracic cage and pelvis, it provides stability of the anterior spine (Ng *et al.,* 2001). While the posterior spine can be protected or stabilized by the erector spinae muscles as it attaches to the vertebrae directly (Ng *et al.,* 2001). Therefore, inability to properly active the muscles of the trunk/back could lead to an instability of the spine and increasing the risk of injury/pain in the lower back.

Due to the large number of muscles involved in axial twisting, it is important to consider the role that muscle activation may play in the twisting movement and its association to an increased risk of injury. Marras *et al.* (1998) examined 12 men aged 20 to 30 years-old to document the trunk muscle activation during twisting in flexed and asymmetric trunk postures. Marras *et al.* (1998) noted the use of the internal and external oblique muscles (dependent on twist direction) during neutral axial twisting. As the participants were in a flexed position and performing an axial twist, Marras *et al.* (1998) observed an increase in the activity of the erector spinae muscles (about 10-15%) and a decreased activity of the external oblique muscles (about 3-5%). McGill (1991) examined the electromyography (EMG) of 6 trunk muscles during isometric and isokinetic torsion exertions and observed a significant increase in muscular activation in the latissimus dorsi muscle as they performed a twist. McGill's research then led to Marras and Granata (1995) observing the muscular activity of ten trunk muscles during twisting; and they found that, even though

participants were asked to perform a pure twisting movement, there was also movement in the lateral and sagittal planes. The coactivation of the trunk musculature during the 'pure twisting task' resulted in significant increases in compression and lateral shear forces on the spine, since the spine was not in a neutral position (Marras and Granata, 1995; Moreside *et al.*, 2007). *In vitro* research from Callaghan and McGill (2001) clearly demonstrated that increased compression with moderate motion (they used flexion-extension) significantly increased the occurrence and severity of disc injuries. Likewise, the increase in compression forces from the muscle activation required to perform axial twisting is of concern, especially as these compounds the risk associated with the axial twisting itself. Therefore, more dynamic *in vivo* research needs to be conducted to understand the muscle activation and kinematic responses associated with axial twisting.

The static and quasi-static *in vivo* studies have shown axial twisting to be a significant risk factor in developing LBP and/or injury (Aultman *et al.*, 2004; Drake *et al.*, 2005; Kelsey *et al.*, 1984; Marras *et al.*, 1993; Punnet *et al.*, 1991). However, repetitive dynamic *in vivo* studies of axial twisting of the trunk are lacking despite being the most commonly occurring type of twisting exposure in the MMH industry (Kelsey *et al.*, 1984). Studies examining axial twist are often conducted using a restrictive apparatus to isolate for the muscle of interest and limit cofounding factors (such as velocities, accelerations, etc.; Drake and Callaghan, 2008; Marras, 1998). It is important to examine the muscles of the participants without restriction (i.e. without the use of an apparatus), as participants do not typically twist their trunk with such restrictions in everyday life. A study conducted without spine and/or pelvis restrictions, enables researchers to better understand the 3D ROM of the spine and pelvis to comprehend the impact of twist rather than a check if a specific posture was maintained/obtained (Drake and Callaghan, 2008). Therefore, examining a repetitive dynamic axial twisting exposure without the use of a restrictive apparatus, could allow

researchers to have further knowledge of muscular activation and kinematic strategies that individuals use while performing repetitive dynamic axial twisting tasks.

Fatigue has been identified as a motor deficit, and it can be described as the gradual decrease in the force capacity of the muscle or the endpoint of a sustained activity (Enoka & Duchateau, 2008). Horton *et al.* (2014) quantified the effects of an axial twist and its parameters using a lifting and twisting task. Horton *et al.* (2014) noted that experienced individuals who participate in daily axial twists are likely to undergo the effects of fatigue due to the large muscular demand an axial twist requires. These researchers noted that performing an axial twist (while performing a lifting and twisting task) increased fatigue and cardiovascular demand during twisting with a higher load in comparison to a lighter load (~34% increase in discomfort; Horton *et al*., 2014). Likewise, a study performed by Gregory *et al*. (2008) examined the effect fatigue had on spinal postures and muscular activation in firefighters, while the firefighters performed physically demanding simulated job tasks. Gregory *et al*. (2008) noted that when fatigued, firefighters adapted higher spine flexion angles and a reduction in muscle activation of the abdominal muscles. As noted previously, the spine relies heavily on the abdominal and erector spinae muscles to work in concert to provide stability of the spine (Bonato *et al*., 2003; Ng *et al*., 2001). Therefore, if fatigue alters muscular activation in the muscles that provide stability of the spine and/or control trunk motion during twisting, this could be a mechanism by which twisting poses an increased risk of injury/pain.

Previous biomechanical research has shown that unaffected participants (i.e. preclinical or unaffected or "injury free" population) can be stratified by low and high risk of future injury using self-reported transient pain levels (Nelson-Wong & Callaghan, 2014). Nelson-Wong and Callaghan (2014) followed participants for three years that were classified as either "more/less

likely to develop LBP in in their life". Those who were identified as having an increased risk of developing LBP (identified by the >10mm levels of self-reported transient pain during an exposure) had significantly higher rates of the development of clinical LPB after a three-year follow up (Nelson-Wong & Callaghan, 2014). Researchers, including Hoang (2016), Nairn *et al.*, (2013) and Schinkel-Ivy *et al.*, (2013), have successfully applied the pain developer model developed and validated by Dr. Nelson-Wong and colleagues (2008, 2009, 2010, 2014) to group participants based off transient pain levels. In addition, Babiolakis *et al.* (2015) applied the transient pain developer model in their examination of female nurses with and without low back pain, to assess if lumbopelvic control could attribute to the prevalence of LBP in nurses. The self-reported transient pain levels in this study were taken during targeted-performance based physical fitness and biomechanical tests and tasks (Babiolakis et al., 2015). Grouping the participants as either a transient pain developer (PD) or a non-transient pain developer (NPD) allows researchers to determine where there are common or divergent muscle activation and kinematic responses both within and between groups. An exposure (standing in the case of Nelson-Wong & Callaghan, 2014) can induce transient pain in 40-70% of individuals who were previously heathy and asymptomatic (Marshall *et al.*, 2011; Nelson-Wong and Callaghan, 2010; Nelson-Wong *et al*., 2008; Babiolakis *et al.*, 2005; Schinkel-Ivy *et al.*, 2013). Therefore, using the transient pain developer model could allow researchers to identify which musculoskeletal responses to a repetitive dynamic twisting exposure are associated with a greater and/or lesser risk of future injury.

Again, there is little known of the musculoskeletal responses to twisting despite strong epidemiological and *in vitro* evidence associating twisting to an increased risk of injury to the spine. Further, it is known that twisting requires a large number of muscles working in concert

(exactly how in dynamic twisting is not well understood), and depending on the activation magnitudes may raise spine compression values to unsafe levels and/or lead to fatigue. Fatigue has been shown to have the potential to increase risk of injury, but again little is known about fatigue from a twisting exposure. If participants can be grouped NPD and PD, the differences/similarities between pain groups could lead researchers toward better foundational understanding of the above issues. Therefore, the purpose of this thesis is to examine the musculoskeletal responses to a repetitive dynamic axial twisting exposure when performed to a limit of self-reported fatigue.

2. Research Questions

The primary purpose of this thesis was to examine the musculoskeletal responses to a repetitive dynamic axial twisting exposure when performed to a limit of self-reported fatigue. The following research questions were addressed:

1. Will some participants report clinically relevant levels of transient pain during the repetitive twisting exposure?
2. Does performing repetitive dynamic axial twisting affect the trunk kinematic responses during and/or following the exposure?
3. Does performing repetitive dynamic axial twisting affect the trunk muscle activation responses during and/or following the exposure?
4. If participants do report transient pain during the exposure, will they fatigue more quickly and/or will they have different musculoskeletal responses?

3. Hypotheses

To address the purpose of the study, trunk muscle activation and kinematics, self-reported transient pain, and three-dimensional (3D) range of motion (ROM) tasks (upright stand, lateral bend, flexion/extension, and upright axial twist) were collected. Considering the design of this thesis, the following hypotheses were tested:

1. Participants who are PD will have a larger twist, flexion, and lateral bend angles in the spine while:
    a) Performing the repetitive dynamic axial twisting task.
    b) Performing the pre/post-ROM tasks.
2. Participants who are PD will have a higher mean and max muscle activation while:
    a) Performing the repetitive dynamic axial twisting task.
    b) Performing the pre/post-ROM tasks.
3. Fatigue will increase twist, lateral bend, and flexion angles in the spine segments in all participants regardless of pain group classification while:
    a) Performing the repetitive dynamic axial twisting task.
    b) Performing the pre/post-ROM tasks.
4. Fatigue will increase the mean and max muscle activation regardless of pain group classification while:
    a) Performing the repetitive dynamic axial twisting task.
    b) Performing the pre/post-ROM tasks.

4. Literature Review

4.1 Suspected Mechanisms of Injury with Twist

The mechanism of injury causing LBP is still up for debate as nearly 85% of LBP cases are classified as 'non-specific' according to Ebrahimi *et al.* (2017). The importance of joint stabilization in a neutral posture has been demonstrated, while instability of the spine has been proposed as a possible mechanism in the development of LBP (Henriksen *et al.*, 2007). It is well documented that introducing forward flexion to an axial twist has been associated with pain/injury of the lower back through increasing rotational stiffness (Drake and Callaghan, 2008) or by increasing the risk of injury to the annulus fibrosus (Pearcy and Hindle, 1991; Schmidt *et al.*, 2007). Drake et al. (2005) noted that the increased risk of injury to the annulus fibrosus could be due to the annulus fibrosus having to resist the axial twist due to the increase in facet joint separation from the flexed position. Pearcy and Hindle's (1991) *in vitro* work saw an increased ability for a specimen to rotate when flexion was introduced to an axial twist, which could damage the annulus fibrosis and lead to pain and/or injury. Therefore, having the spine in a non-neutral position during twisting could be a mechanism of low back pain and/or injury.

It is possible that poor lumbopelvic control plays a role in the twist mechanism of injury *in vivo*. Gluteus medius dysfunction during prolonged sitting and standing in a preclinical population has been shown to be associated with LBP (Nelson-Wong and Callaghan, 2010; Nelson-Wong *et al.*, 2008; Marshall *et al.*, 2011; Schinkel-Ivy *et al.*, 2013). The Active Hip Abduction (AHAbd) test was developed to examine postural control in the frontal plane in an unstable position (Nelson-Wong *et al*. 2009). The purpose of the AHAbd test is to predict asymptomatic individuals who are at risk for LBP development during a prolonged standing task (Nelson-Wong *et al.*, 2009). The AHAbd test has been used as a tool to provide a general understanding of an individual's ability

to maintain trunk and pelvis alignment as they hold an unstable position. The AHAbd test requires the participant to lie on their side while performing a controlled side lying leg raise to predict the development of occupational LBP (Nelson-Wong *et al.*, 2009). The AHAbd test is performed using an ordinal scale from zero (no loss of frontal plane position) to three (severe loss of frontal plane position; Nelson-Wong *et al.*, 2009). Although, the AHAbd test has been used vigorously in prolonged standing research, it has yet to be used in a repetitive dynamic axial twisting exposure. Researchers should examine if poor lumbopelvic control is related to the musculoskeletal responses and self-reported transient pain reports of the participants from the axial twisting exposure as a potential mechanism of pain/injury of the spine.

4.2 Fatigue

Fatigue can be defined as a decrease in maximal force and/or power that is produced by the muscles involved (Enoka & Duchateau, 2008). When a task requires a submaximal muscle contraction, the onset of fatigue is not likely associated with the termination of the task, but instead with a change in muscular activity of the primary to the secondary muscles involved in the task (Enoka & Duchateau, 2008). Ng *et al.* (2003) concluded that during the fatigue process, abnormal changes in EMG amplitude and frequency parameters had been found in the abdominal and back muscles of LBP patients, which could be due to the motor control variability of participants in response to pain. Moffroid (1997) discusses that some participants might describe muscular fatigue after a task despite the lack of physiological evidence of muscular fatigue. She also notes that muscular fatigue could be due to cardiovascular fitness level, muscle force capability, motivation, self-image, and perceptual acuity even when the task is designed to measure muscular fatigue (Moffroid, 1997). Moffroid (1997) used the assessment of EMG during trunk muscular endurance tasks, for example the Biering-Sorensen test, to quantify fatigue offline. Analyzing the data offline

using a frequency analysis of the muscle activation would then conducted to assess whether muscular fatigue has taken place, however this is not a real time solution for immediate feedback in the assessment (Sadoyama and Miyano, 1981). Others have used HR for a real time assessment of fatigue and exercise intensity during bouts of physical activity during an assessment (Hunt and Saengsuwan, 2018). Muscular fatigue could be a large risk factor of low back injury/pain due to the fact the spine is prone to the effects of reactive forces as a result of its multi-segmental structure and the spine's reliance on muscles to actively support and provide stability for the spine (Bonato *et al.*, 2003). Hence, examining fatigue during an exposure that requires a large muscular demand could give insight into similar/different musculoskeletal responses that participant's experience.

Examining muscle activation while discussing fatigue is extremely important, as the human body attempts to reduce the effects of both pain and fatigue by changing muscular activation (Li *et al.*, 2007). Given the sizeable muscular demand required to perform repetitive axial twists, it is likely that if fatigue were to occur, a participant would adapt by altering their muscle activation and body position. Previous researchers have noted that core and back muscles are essential in performing trunk axial twists, which would lead to the core and back muscles being subjected to fatigue (Wasser *et al.*, 2017). Although analyzing these muscles during the repetitive dynamic axial twisting exposure is important for understanding the role of fatigue, examining the muscular responses to fatigue with pre/post-tasks may also be of value. Park (2012) identified that a decreased trunk ROM could result from passive structure stiffness during an upright axial trunk-twisting task. Passive structure stiffness could occur in the improper timing of segments during a high velocity coordinated task and could lead to injury (Wasser *et al.*, 2017). Based on current research, examining an upright standing static task, a dynamic lateral bend, a dynamic upright axial twist, and a dynamic flexion/extension task have not yet been completed after performing

repetitive dynamic axial twisting of the trunk. Therefore, experiencing fatigue could alter muscle activation and could increase the risk of pain/injury from passive structure stiffness.

It is not only a participant's muscle activation that can display adaptations during fatigue, but a change in kinematics can also be observed as fatigue takes place (Li *et al.*, 2007). A shift in kinematics during a repetitive dynamic axial twisting exposure and during the ROM tasks could lead to deviating from a safe and neutral spine position due to fatigue. The importance of stabilization of a joint in its neutral posture has been demonstrated, and an instability of that joint has been proposed as a possible contributing factor in the development of LBP (Henriksen *et al.*, 2007). Multiple *in vitro* and *in vivo* studies have shown an increased risk to the spine when an axial twist is associated with other movements like flexion (Pearcy and Hindle, 1991; Drake *et al.*, 2005; Farfan *et al.*, 1973). By examining participants during the repetitive dynamic axial twisting exposure and comparing the pre/post-ROM tests, researchers can assess if fatigue causes an individual to put themselves at risk by being in a non-neutral position.

4.3 Transient Pain Development

The development of clinically relevant transient pain in an asymptomatic population during exposure protocols has been linked to an increased risk of developing a future injury (Nelson-Wong and Callaghan, 2014). Research with protocols examining a preclinical population observed the exposure to induce transient pain in 40-70% of individuals who were previously asymptomatic (Marshall *et al*., 2011; Nelson-Wong and Callaghan, 2010; Nelson-Wong *et al*., 2008; Babiolakis *et al.*, 2005; Schinkel-Ivy *et al.*, 2013). The visual analog scale (VAS) is a blank 100-mm line that has been established as effective and is reliably used as a tool to evaluate self-reported pain. For many years, VAS has been used to measure pain on a 100-mm scale with 'no pain' listed on one end, and 'worst pain imaginable' on the other (Summers, 2001; Maxwell, 1978). High-risk

individuals are identified by the development of clinically relevant transient pain during relatively low-level pain inducing exposures/stimulus (Nairn *et al.*, 2013; Schinkel-Ivy *et al.*, 2013; Nelson-Wong & Callaghan, 2010). Participants record a tick or a mark somewhere on the 100-mm line where they feel their pain is best represented on a continuous scale. Common practice measures the distance of the line in mm from the tick made by the participant to the start of the 100-mm line for analysis of perceived pain during the exposure (Maxwell, 1978). Researchers in biomechanics use a VAS threshold of 10-mm to define someone as a PD but, if their rating remains under 10-mm, they are deemed an NPD (Nelson-Wong & Callaghan, 2010). Grouping the participants as either PD or NPD could allow researchers to examine common muscular activation strategies and kinematic similarities/differences within groups. Therefore, grouping PD and NPD in a transient pain developer model, researchers may be able to identify the musculoskeletal responses to a repetitive dynamic twisting exposure which is associated with a higher risk of future injury.

4.4 Participant Selection

Perhaps the most effective way to examine axial twisting of the spine is to use individuals who are experienced in performing repetitive dynamic axial twisting tasks. Those who regularly participate in twisting activities, such as some MMH workers (Marras *et al.*, 1993; Kumar *et al.* 2001), and athletes who participate in sports that involve twisting such as softball, baseball, golf, and tennis (Seay *et al.*,2016; Harris-Hayes *et al.*, 2009) could be at an increased risk of injury and LBP. The relationship between participants who routinely participate in repetitive dynamic axial twisting tasks and the risk of LBP and/or back injury is unclear. People who repetitively participate in repetitive dynamic axial twisting of the trunk should be able to perform the movement with familiarity, as they perform the dynamic task on a daily basis. Examination of an experienced population will allow researchers to examine movement strategies made by these individuals and

better understand the muscular response and kinematics behind performing a repetitive dynamic axial twisting of the trunk.

Questionnaires have been used to quantify populations of participant's similarities/differences to explain how participants relate to one another. The International Physical Activity Questionnaire (IPAQ) was developed due to the rising global concern of physical inactivity (Craig *et al.* 2003). The IPAQ is used to monitor physical activity and inactivity among adults aged 18-65 years old (Craig *et al.,* 2003). Comparing participants' physical activity levels is important during a protocol with self-selected fatigue, as physical fitness could play an important role in how quickly someone may fatigue. The Physical Activity Readiness Questionnaire (PAR-Q+) was also collected to examine if a participant was physically able to participate in the axial twisting protocol. The PAR-Q+ offers safe preliminary screening before physical activity takes place to ensure the participant is healthy enough to participate in the exposure (Thomas *et al.*, 1992). To ensure participants do not differ based on psychosocial differences, questionnaires assessing self-esteem, social physique anxiety and body image have been collected (Wanninayake *et al.,* 2017). These questionnaires are included, as psychosocial differences could alter a participant's motivation to continue with the protocol or their posture during the protocol (Wanninayake *et al.,* 2017). The Rosenberg Self-Esteem Scale (RSES) was designed to evaluate self-esteem in addition to assessing body image, to provide an individual's overall self-worth (Rosenberg, 1979). The Social Physique Anxiety Scale (SPAS) provides a further understanding of the behaviours associated with body image (Hart *et al.*, 1989). Finally, the Body Shape Questionnaire (BSQ) is a questionnaire that relies on self-reflection of body shape, and the behaviour attributes associated with body image (Cooper *et al.*, 1987). Although it is not known if body image could alter a participant's posture, Duclos *et al.* (1989) concluded that posture can

affect emotion. Duclos *et al.* (1989) saw slumped postures when participants were reflecting on sad or emotional memories. It is important to consider the psychosocial factors when assessing a population where it is possible that body image, self-esteem, and body shape could affect the participant's musculoskeletal responses.

4.5 Axial Twisting Protocol

Within the past twenty years, research has primarily focused on investigating axial twisting of the trunk using static or quasi-static motion. It has been concluded through *in vivo* research that axial twisting alone can damage vertebrae and associated structures (Drake & Callaghan, 2008; Pearcy & Tibrewal, 1984). The *in vivo* research by Marras (1998) examining trunk musculature under static and dynamic protocols, used a custom experimental apparatus and EMG to identify the muscles used during twisting of the trunk in different postures. Although it was outlined that occupational twisting tasks are performed in awkward, asymmetric postures, the application of the results from Marras (1998) might underestimate the risk of these activities since a custom apparatus was used during the Marras study. The use of an experimental apparatus restricts the movement of the pelvis, limbs, etc., and allows researchers to examine the movement of the specific segment that they are testing (i.e. the spine). Using an experimental apparatus allows researchers to attempt to eliminate confounding factors in assessing human dynamic movement. For example, Drake and Callaghan (2008) used a rigid harness to minimize the contributions from the thorax, pelvis, and lower limb, to isolate the movement of the lumbar spine. The lumbar spine was isolated specifically for research performed by Drake and Callaghan (2008) to allow for better understanding of the lumbar spine during an axial twist. Examining unrestricted repetitive dynamic axial twisting of the trunk to observe the spine's muscular activation and kinematics has not yet been conducted. Performing unrestricted repetitive dynamic axial twisting research will help

researchers better understand the muscle activation and kinematics associated with the movement and better represent the movement being done in industry and sport. Repetitive dynamic axial twisting is an important research method that should be examined, as participants do not actively twist their trunk in everyday movements attached to a restricted apparatus. The movements made by a participant axially twisting are free movements, therefore research should focus on examining the free and unrestricted movement that is indictive of everyday axial twists.

4.6 Rating of Perceived Fatigue

The BORG scale has been used as a self-reported measure of fatigue in previous exertion studies to quantify self-reported real-time fatigue (Dedering *et al.*, 1999; Strimpakos *et al.*, 2005). The BORG scale is comprised of numbered categories (6 to 20) as well as descriptive cues that range from “very, very light” to “very, very hard” (Pfeiffer *et al.*, 2002) as seen in the appendix. The term ‘self-reported fatigue' was used to refer to a decline in alertness, mental concentration, motivation, and other psychosocial factors, which is consistent with the work done by Dedering and colleagues (1998). It was also expressed that a correlation between muscular fatigue, endurance time, and rating on the BORG scale was used when performing a Biering-Sørensen test; participants who had a higher endurance time also had higher muscular fatigue and a higher BORG scale value (Dedering *et al.*, 1999). A higher BORG scale value results in a higher perceived fatigue during the task. The protocol implemented in this study will use the BORG scale to assess someone's perceived exertion throughout the repetitive dynamic axial twisting exposure and for the participant’s subjective estimate of fatigue.

5. Methods

5.1 Overview of Protocol

The study protocol was developed to quantify changes in trunk kinematics and muscle activation, which may occur during a repetitive dynamic axial twisting exposure performed to *self-determined fatigue*. The phrase 'self-determined fatigue' refers to the participant terminating the repetitive dynamic axial twisting exposure once they feel they have become too fatigued to continue with the exposure. The protocol included tracking time-varying 3D motion, muscle activation, and self-reported measures of pain and fatigue. Participants completed a repetitive dynamic axial twisting protocol and a set of pre/post measures that included an upright stand, three ROM tests (lateral bend, twist, and forward flexion and extension), and the AHAbd test. The repetitive dynamic axial twisting exposure consisted of participants repeatedly hitting a softball off a fixed tee into a screen at a rate of 15 swings per minute, until the participants deemed themselves too fatigued to continue. Once the participant had terminated the protocol, they were deemed fatigued, and a fatigued BORG rating and VAS were then collected. Before the instrumentation can be removed, the quiet stand, the ROM tests, and the AHAbd test were performed while the participant was still fatigued. The collection took place over one 2hr session in the Drake Biomechanics Lab at York University. York University's Office of Research Ethics approved the protocol: Certificate *#e2017 - 413 The impact of fatigue on the lumbopelvic control and musculoskeletal responses in dynamic rotational tasks*.

5.2 Pilot Field Collection

A pilot field collection was performed with 18 collegiate level female softball players (14 of which were then recruited to the in-lab component of the study) to quantify the duration and frequency of the typical axial twisting exposure (swings of the bat) in one practice session. York

University's Office of Research Ethics approved the protocol: Certificate *#e2017 - 367 Volume and frequency of bat swings in competitive female baseball players during practice.* A one-hour practice was recorded through a video camera to count the number of swings each player performed. On average players were actively swinging in their station for 2 minutes±25seconds and hit an average 30 ±3 softballs. Multiple rest periods were given in between swing sessions to accommodate the number of players at the practice (common at all softball practices), but the average swing total at the 1hr practice was 350 ±18 swings. Participants hit softballs from both the tee and a front underhand toss from a pitcher. The softballs hit off the tee were stationary and at a position desired from the participant (between shoulders to knee height; the strike zone). The softballs that were hit from the front underhand toss were tossed from about 3 meters in front of the participant from the coach. The softballs were pitched in the strike zone (shoulder to knee height) and could have been anywhere on the plate. From the information collected at the 1hr practice session, researchers decided that a frequency of 15 swings per minute on a continuous protocol would allow participants to reach a fatigued state, with the maximum duration set to 20 minutes (or 300 swings).

5.3 Informed Consent and Participants

Fourteen female elite level softball players were recruited from local collegiate-level softball teams within the Greater Toronto Area for the lab component of the study. Exclusion criteria included any participants who had undergone surgery to the spine in their lifetime, had any current injury that would limit or restrict their ability to perform the study tasks, and anyone who was not deemed fit to participate from the PAR-Q+. In addition, participants must have played softball at a collegiate level or higher within the last year. Participants would also be excluded from the data processing if the participant did not last in the repetitive axial twisting exposure for at least 2

minutes. According to the CSEP-PATH (2003) activity that lasts under 2 minutes is an anaerobic based physical activity, therefore including participants using two separate energy storage systems during the exposure would not be appropriate. This exclusion criteria were added and eliminated one participant (14 participants recruited, 13 participants processed). Participant characteristics including age, height, and weight, are detailed in the results section 6.1. All participants provided written consent prior to participating in the study.

5.4 Equipment and Measures

5.4.1 Muscle Activation

Muscle activation was recorded from eight muscles bilaterally using two AMT-8 EMG amplifier systems (Bortec Biomedical Ltd., Calgary, Canada). Each EMG channel was collected using pairs of disposable AG/AG-Cl surface electrodes (Ambu Blue Sensor N, Ambu A/S, Denmark) placed over the muscle belly. The skin was shaved and swabbed with alcohol to maximize adherence of the electrodes and minimize electrical impedance. All EMG signals were differentially amplified (frequency response 10 Hz – 1000Hz, common mode rejection 115 dB at 60 Hz, input impedance 10 GΩ), and the analog to digital conversion was at rate 2048 Hz (Optotrak Data Acquisition Unit, Northern Digital Inc., Waterloo).

The electrodes were placed bilaterally on the following muscles: rectus abdominis, internal/external obliques, thoracic erector spinae at the T4 and T9 levels, lumbar erector spinae at the L3 level, gluteus medius, and latissimus dorsi (Table 5.4.1.1). The reference electrodes were placed on the right and left clavicles (Table 5.4.1.1). Maximum voluntary contraction (MVC) tests were collected to normalize the muscle activations collected. The MVC tests included a modified sit up (abdominal muscles), back extension (back muscles), lying leg abduction (gluteus medius), and lateral pull down task (latissimus dorsi), which are all listed in detail in Table 5.4.1.2.

Please note: This thesis uses “L” and “R” ahead of muscle abbreviations to refer to left and right muscles (i.e. left RA would be referred to as LRA and right RA as RRA).

Table 5.4.1.1: Summary of electrode placements used to collect muscle activation from eight bilateral muscles in the anterior and posterior of the trunk and pelvis. Note: All electrodes were placed over the largest portion of the muscle belly, and as such the placements listed below are approximate locations.

Muscle	**Electrode Placement**
Rectus abdominis	~3cm lateral to umbilicus (Callaghan, *et al.*, 1998)
External obliques	~15cm lateral to umbilicus (Callaghan, *et al.*, 1998)
Internal obliques	Below external obliques and superior to the inguinal ligament (Callaghan, *et al.*, 1998)
Latissimus dorsi	Lateral to T9 (Callaghan, *et al.*, 1998)
Upper thoracic erector spinae	~5cm lateral from the T4 spinous process (Burnett, *et al.*, 2009)
Lower Thoracic erector spinae	~5cm lateral to T9 spinous process (Callaghan, *et al.*, 1998)
Lumbar erector spinae	~3cm lateral to L3 spinous process (Callaghan, *et al.*, 1998)
Gluteus medius	~15cm inferior and 5 cm posterior iliac crest (Nelson-Wong, *et al.*, 2008)

Table 5.4.1.2: Summary of manually resisted tasks that were used to isolate muscles of interest to collect MVCs necessary for the normalization of the muscle activation. All trials were performed against researcher applied resistance.

Muscle	**Resisted MVC Task**
Rectus abdominis	Bent knee sit-up posture, crunch (McGill, 1992)
External obliques	Bent knee sit up posture, twist (McGill, 1992)
Internal obliques	Bent knee sit up posture, lateral bend (McGill, 1992)
Latissimus dorsi	Modified pull down (Arlotta, *et al.*, 2011)
Upper and lower thoracic erector spinae & Lumbar erector spinae	Back extension (McGill, 1992)
Gluteus medius	Side lying hip abduction (Nelson-Wong, *et al.*, 2008)

5.4.2 Kinematics

Kinematic data were collected at 32 Hz using an active marker optoelectronic 3D motion capture system (Northern Digital Inc., Waterloo, Canada) that consisted of: five 3DInvestigator™ position sensors, NDI First Principles™ motion capture software (V1.2.4), and Smart Markers that emit infrared light. Spine motion and posture was quantified using 11 marker clusters. There were five clusters on the spine, one cluster on each arm, and two sensors on each leg. The system tracked spine motion via infrared emitting diodes (IREDs) that were fixed on a rigid surface in either a five-marker cluster orientation (adhered to the skin over the spine) or a three-marker cluster (adhered to the extremities; Figure 5.4.2.1). Spine segments were defined as upper thoracic (UT; C7 to T4), mid-thoracic (MT; T4 to T9), lower thoracic (LT; T9 to T12), and lumbar (L; T12 to L5). The digitized bony landmarks were the following; head (left and right temple and angle of the mandible; total of 4), trunk (left and right acromion processes, xiphoid process, left and right of C7 vertebrae, T4 vertebrae, T9 vertebrae and T12 vertebrae; total of 11), pelvis (left and right

anterior superior iliac spines, left and right posterior superior iliac spines, left and right iliac crests; total of 6), arms (left and right lateral joint centres of the shoulder, left and right medial and lateral epicondyles; total of 6) and legs (greater trochanters, medial and lateral epicondyles, medial and lateral malleoli; total of 10). Movement in the frontal plane was measured on the y-axis (flexion & extension), movement in the sagittal plane was measured on the x-axis (lateral bend), and movement on the transverse plane was measured in the z-axis (twist).

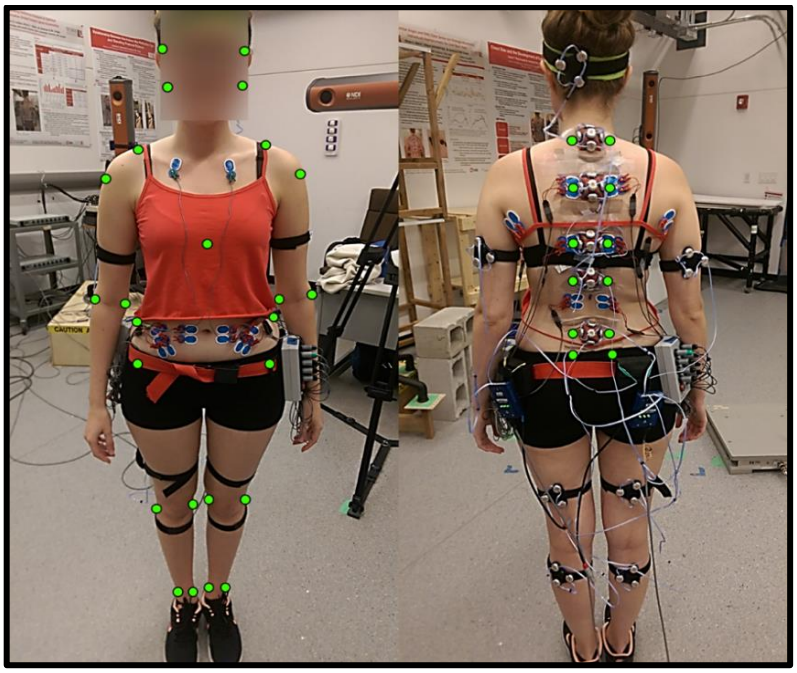

Figure 5.4.2.1: Complete instrumentation of a participant (including EMG and kinematic marker cluster placements) and the digitized landmarks used (green dots).

5.4.3 Anthropometrics and Self-Reported Items

In addition to age (in years), weight (in kg), and height (in cm), the participants' body fat percentage was quantified using bioelectrical impedance analysis (BIA). The BIA test was repeated 3 times and the average of the three scores was used. The participant held the BIA machine at shoulder height with arms facing straight out in front of themselves with their feet

shoulder width apart while the BIA reading took place. The hip circumference (measured in inches) was measured at the maximal gluteal region of the participant. The measurements were repeated three times, while the mean of the three tests was used. Finally, the waist circumference (measured in inches) was measured at the point of minimum circumference around the waist of the participant. Similar to the hip circumference, the test was repeated three times and the mean of the three testes was used. These measures were used to assess if the group being sampled was homogeneous.

IPAQ, PAR-Q+, RSES, SPAS, BSQ, and a custom softball questionnaire was collected before any instrumentation was placed on the participant. The IPAQ was used to assess the participants' physical activity and inactivity levels on a weekly basis. The PAR-Q+ was used to make sure participants were physically able to participate in the repetitive dynamic axial twisting task without an increased risk of injury. The RSES includes 10 questions that are used to assess a participant's self-esteem. While the SPAS is 11 questions and assesses a participant's social physique anxiety. The BSQ involves 24 questions, and it describes how a participant feels about their body. Finally, the custom softball questionnaire was used for qualitative purposes to ensure that participants had the same softball training and experience. These questionnaires allowed for a better understanding of the participants' physical activity levels, self-esteem, body image, and experience level in softball. Using questionnaires as a measure to quantify participants' characteristics, will allow researchers to identify similarities and differences across the population being studied.

The VAS was used to capture the participants' transient pain throughout the collection. VAS testing is considered the preferred method of pain scales when compared to discontinuous methods, such as numerical or verbal rating scales (Carlsson, 1983). It has been found that the

minimum difference to be considered clinically different in VAS can range from 9mm (Kelly, 1998) to 13mm (Bijur *et al.*, 2003). A threshold of 10-mm was used for this study, as it is a widely acknowledged threshold from biomechanics research using university aged preclinical participants (Nelson-Wong & Callaghan, 2010). Since using hash marks on the 10-mm line would allow participants to identify and count previous scores, a blank VAS was used for each self-report. The only labels on the VAS paper were 'no pain' listed on one end, and 'worst pain imaginable' on the other (Summers, 2001; Maxwell, 1978). Previous VAS ratings were not presented to individuals, which was done to reduce any bias that could be present as viewing previous VAS papers could have skewed the data, which was not desired. Self-reported transient pain was collected to group participants into NPD and PD. A participant being an NPD or PD was based on the magnitude of change in their self-reported transient pain ratings during the axial twisting exposure. The self-reported transient pain ratings were collected using a 100-mm VAS. In line with previous research, a change of <10-mm was associated with a low risk of developing a future injury (NPD) and a change of >10-mm with a high risk (PD).

The BORG scale was used to capture a real time self-reported rating of fatigue. After a baseline BORG scale rating, participants were asked to rate their perceived fatigue on a continuous scale of 6 to 20 every two minutes of the repetitive dynamic axial twisting exposure. The use of the BORG scale was to give real time feedback to the researchers on how the participant was feeling during the protocol. Although the BORG scale is a self-reported measure and can be subjective, previous studies have used BORG to quantify self-reported fatigue (Dedering *et al.*, 1999).

5.4.4 Other Measures

Lumbopelvic control was scored using the AHAbd test, which has been used as a tool to provide a general understanding of an individual's ability to maintain trunk and pelvis alignment while in an unstable position (Nelson-Wong *et al.*, 2009). The participant was instructed to lie on their side with their shoulders and legs stacked on top of one another. The participant was also instructed to cradle their head on the padded table with their bottom arm and place their top hand on top of their belly button. Being in a side lying position allowed for the participant to be in the most unstable position and prevented the use of their hands for balance. The AHAbd test is performed using an ordinal scale from zero (no loss of frontal plane position) to three (severe loss of frontal plane position; Nelson-Wong *et al.*, 2009). Any participant who scores over a two on the ordinal scale of zero to three is associated with a greater risk of developing LBP (Nelson-Wong *et al.*, 2009). As per Nelson-Wong *et al.* (2009), the AHAbd tests were blinded to the raters performing the scoring of the tests. Each rater scored each video twice with three weeks in between scoring sessions in a randomized order both times. If a discrepancy of score was raised, the raters would agree on a score after reviewing the video together as a group.

HR was collected in the protocol offline to assess a participant's effort and fatigue. Evaluating HR offline was done to identify if the participants were working at a certain percentage of their HRmax which would suggest participants were working at the same exercise intensity, and therefore were at the same state of fatigue. The HR data was analysed offline and not in real time, as the primary attempt to capture the HR data in real time was not successful. A HR monitor was attached to the participants chest during the axial twisting exposure, however the chest monitor lost contact with the participants chest and therefore did not collect consistent data throughout the exposure. The HR was collected as an indicator of cardiovascular fatigue in the absence of

muscular fatigue data, as muscular fatigue can only be measured using offline muscle activation frequency assessments. The procedure for measuring HR data is further explained in the data processing section below.

5.5.5 Axial Twisting Task

The swinging task required the participants to hit a softball with a 12-inch circumference off a fixed tee into a net repeatedly. Before the task began, the participant selected the location of their feet when hitting the softball off the tee. Once their foot placement was selected, the position was marked with black floor tape as a reference point to keep their starting position the same for each swing. The tee height was set to mid-thigh height of the participant. Mid-thigh was measured on every participant in an upright standing position from the mid-point of their anterior superior iliac spine to the patella. Each participant used the same bat and softballs to ensure they all had the same load throughout the exposure. The bat was a 33inch, 24oz Easton stealth flex. A 12inch Rawlings red dot softball was hit into a Rawlings pro-style 7' practice net in the lab. Throughout the exposure, no participant missed the softball off the tee and no participant hit the softball outside of the net. Before the exposure could begin the participants took practice swings to get used to the instrumentation attached to them. They practiced swinging to the metronome to ensure they could maintain the pace for the study and get used to the cadence. Having practice swings and performing MVC before the exposure allowed for the participant to 'warm up' and activate the appropriate muscles before the exposure started.

5.5.6 Pre-Swing Tasks

After informed consent, the IPAQ, PAR-Q+, RSES, SPAS, and BSQ were completed. Anthropometrics of the individual were then taken (i.e. height, weight, BIA, and waist and hip circumference). Next, the electrodes were placed on muscle bellies as described in Table 5.4.1.1

and shown in Figure 5.3.2.1. A five-minute rest trial was recorded with the participant positioned prone on a padded table to establish baseline muscle activations. After completion of the rest trial, initial BORG and VAS ratings were recorded. For normalization purposes, two MVC tasks per muscle were performed to obtain maximal activation in each of the target muscles (as described in Section 5.3.1). The AHAbd test was then conducted to assess lumbopelvic control of the participant. Three trials were performed on each leg and a video recording of the trials were taken from above the participants head (on a tripod elevated on a table about 1 foot away from the participant for an optimal view of the full movement) to allow three different raters to assess the trials in accordance with a specified schedule offline. Following the three trials, the kinematic markers were attached to the participant and the landmarks were digitized using First Principles as shown in Figure 6.3.2.1. Three quiet standing trials and ROM trials were then completed. The ROM trials included a lateral bend at the waist, flexion and extension of the back, and axial twist of the trunk at the desired speed of the participant (roughly 5-10 seconds) and to the point that each participant felt it was "as far as [they could] go". Blocks of three repeats of each ROM trial were performed, with the order of the blocks presented in random order for each participant. The third repeat of each ROM trial was used for analysis, the first two trials were used to allow the participant to formalize themselves with the instrumentation.

5.5.7 Swing Tasks

The repetitive dynamic axial twisting exposure consisted of participants performing a swinging task until they felt they could no longer continue. Using a script, the participants were instructed "to swing the bat until you are feeling fatigued" and that "the completion of the task will be when you can no longer swing anymore, and you feel as though you must stop". When the participant terminated the protocol, they were deemed too fatigued to continue, regardless of the

amount of time the participant lasted in the exposure. The amount of time to fatigue was a result of the participant's individual capabilities and fitness level. The participant swung the bat at a pace of 15 swings per minute, in time with a metronome, to the 20min maximum time limit (as described in Section 5.2). Each swing required the participant to hit the softball into the net and the research volunteer to replace the softball on the tee as the participant reset to the starting position. When performing multiple swings, it was important to breakdown the swing by 'waiting time', 'active time', and 'return time'. Waiting time was defined as the time that the participant was in their ready position, but not moving in attempt to hit the softball. Active time was defined as the time when the participant was actively twisting and hitting the softball. While the return time was defined as the end of the axial twist to the time they returned back into their starting position, which is when the waiting time would have begun. VAS and BORG rating sheets were given to the participants prior to the start of the swing task, after every 30 swings (2min), and when the participant stopped the swing task (could not continue). Separate sheets were used for each rating so that the previous ratings made by the participant could not be used to influence the current rating. Minimal time was spent collecting the VAS and BORG measures, as it was not used as a rest period.

Figure 5.5.7.1: Participant during the repetitive dynamic axial twisting exposure (swing task)

5.5.8 Post-Swing Tasks

After the participants stated that they could no longer continue the swinging task (the repetitive dynamic axial twisting exposure), they repeated the standing, 3 ROM trials, and AHAbd test trials. The purpose of repeating the standing, ROM, and AHAbd tests was to have these tests performed after the axial twisting protocol and while the participant was still fatigued. The standing and ROM trials were performed at a pace selected by the participant, with the participant being fully instrumented with kinematic sensors and EMG. The ROM trials took under two minutes to complete. The kinematic markers on the arms and legs were then removed so that the participant could perform the AHAbd test (for both the right and left legs repeated three times) without damaging the markers. The complete AHAbd test took less than 3 minutes to complete. The collection of all of the post-swing tasks, including the time for equipment removal, took less

than 5 min to ensure that the participants were still fatigued and preforming the postaxial twisting tasks.

5.6 Data Processing

Transient pain was used to group participants to compare muscle activation and kinematics during the repetitive dynamic axial twisting task and the pre/post-ROM trials. As per Nelson-Wong and Callaghan (2010) a change in VAS rating was used as the cut-point to differentiate participants as either a PD (>10mm) or NPD (<10mm).

Questionnaire scores were calculated according to each questionnaire guideline and the questionnaires that could not be scored were used for qualitative assessment of participants. Each question of the *RSES* was scored between 0 and 3 (Rosenberg, 1979). According to Rosenberg (1979), questions 1, 3, 4, 7 and 10 were scored as followed, an answer of 'Strongly Agree" was scored 3, 'Agree' was scored 2, 'Disagree' was scored 1 and 'Strongly Disagree' was scored 0. For questions 2, 5, 6, 8, and 9 the scoring guide was inverted (Rosenberg, 1979). The scores were summed, and a larger score reflected higher self-esteem (Rosenberg, 1979). The *SPAS* used a 5-point scale with 'not at all characteristic of me' scored as a, 1 through to 'extremely characteristic of me' which scored a 5 (Hart, *et al.*, 1989). For questions 1, 2, 5, and 11, the scores were inverted before summing (Hart, *et al.*, 1989). After summing, a greater score reflected greater social physique anxiety (Hart, *et al.*, 1989). The *BSQ* used a 6-point scale which ranged from 'Never' worth a score of 1, and 'Always' worth a score of 6 (Cooper, *et al.*, 1987). The score was summed, and a greater score reflected a greater dissatisfaction with one's body shape, and a more negative body image (Cooper, *et al*., 1987). The custom softball questionnaire to access for qualitative reasoning and was used to ensure the experience level of the participants.

The participants continued in the protocol until they deemed themselves too fatigued to continue and a final BORG scale rating was collected. The baseline and final/fatigued BORG scale ratings were used to quantify a real time self-reported fatigue from the dynamic axial twisting exposure. Heart rate (HR) data was obtained the left lower thoracic erector spinae's (LTES_12) raw EMG signal, at the beginning and end of the repetitive dynamic axial twisting exposure. The measure was taken when the participant was not actively swinging to ensure that the HR contamination was still present in the channel and the %MVC of the muscle was not too high which would remove the HR contamination from the muscle (Drake and Callaghan, 2005). Every participants' HR data was collected at the start of their swing exposure, when they were in their first period of "waiting" and at the end of their swing exposure, at the last period of "waiting" (the term "waiting" is calculated and explained in later in this section). The total length of each waiting time where HR was calculated was 4 seconds. The LTES_12 channel was selected as the HR contamination was clearly visible for all participants (Figure 5.4.4). Each peak in the lower area of the graph represents a single heart muscle depolarization (heartbeat) that took place in that time frame. The total amount of heartbeats counted during the waiting time was then multiplied out to 60 seconds so that HR would be in beats per minute (bpm). For example, Figure 5.6.1 shows the raw LTES_12 EMG signal where 12 heartbeats occurred in 4 seconds, resulting in a HR of 180bpm. HR was then expressed as a percentage of the participant's estimated HR max (%HR max) using the Karvonen equation of %HR max = (220 – age) x 100% (She *et al.*, 2015). The Karvonen equation was used over other variants, as those equations have not yet been tested for reliability and validity across large or variable populations, nor have been widely used, making the Karvonen equation the optimal choice (She *et al.*, 2015). Continuing from the example above

where the participant had a HR of 180bpm, if the participant was 30 years old their HR max would be 190, and would have a 94.7%HR max.

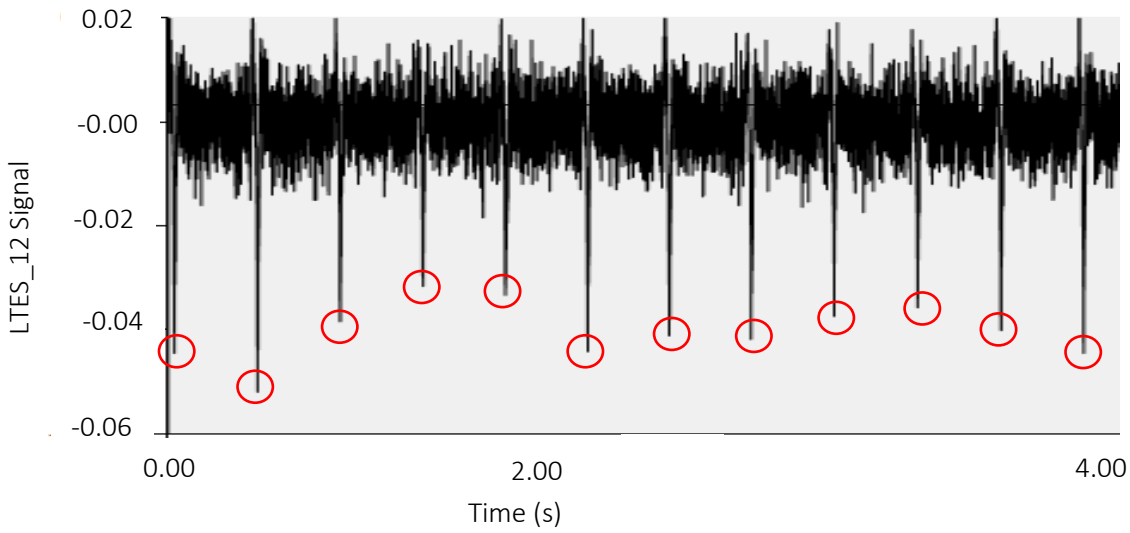

Figure 5.6.1: A visual representation of how the HR data was counted. Every red circle indicated where a heartbeat occurred in the EMG signal from the LTES_12. In this example there were total of 12 heartbeats in 4 seconds.

To make sure that the participants were similar between pain groups the mean and standard deviations for age, height, weight, BIA, hip circumference, and waist circumference were calculated. Mean active time, waiting time, and return time (defined in 5.5.7) were calculated to make sure the exposure was equal for all participants.

Participants had the option to swing from the left or the right side depending on their personal preference. If the participant chose to swing from the left side, the left and right muscles were reversed post collection so that virtually they became a right sided batter. The normalization of swing direction enabled a comparison of all participant data as “right side” data. For example, a person who swung from the left side would have their RRA %MVC results expressed as their LRA %MVC which was done so that all participants had the same swing direction, enabling the

inclusion and comparison of all participants' data. Similar to the EMG data, the kinematic data from participants that chose to swing from the left side were reversed in post collection to enable comparisons amongst all participants.

All kinematic and EMG data were analyzed using Visual3D^{TM} (v6, C-Motion Logistics Inc., Ontario, Canada). To process EMG, heart rate contamination was removed using a high-passed filter with a dual pass, 4th order, Butterworth filter, with a cut-off frequency of 30Hz; (Drake & Callaghan, 2006) and signals were then full wave rectified and low-pass filtered with a dual pass 4th order Butterworth filter with a cut-off of 2.5Hz (Brereton & McGill, 2006). Resting EMG was subtracted from every channel collected, to remove the baseline muscle activation from resting muscles as well as the common noise that might be affecting the signal obtained. Two MVC tasks were performed for each muscle and the maximum values for each trial was then calculated. The two maximum values were then averaged, and the resulting value was then used to normalize the EMG channels collected. Since participants stopped the repetitive dynamic axial twisting exposure when they were too fatigued to continue, the use of phases enabled the data to be normalized to the duration each participant completed. The phases were determined by the first 5 swings (first 20 seconds of exposure), middle 5 swings (middle 20 seconds of exposure), and last 5 swings that the participant completed (last 20 seconds of exposure). Both the mean and *mean maximum* EMG values (expressed as %MVC) were calculated for each channel over the repetitive dynamic axial twisting exposure (each phase has a mean and a *mean maximum* value per channel). The term '*mean maximum*' is referring to the five maximum values for each phase, which was averaged for one maximum mean value. Five maximums were used since five swings were performed in the 20 second window that was analyzed, therefore, one maximum per swing. An example of a participant's LTES_12 during the start of their swing is shown in Figure 5.6.2. This figure shows

where the 5 maximum values would be. The 5 maximum values in Figure 5.6.2 would then be averaged for one maximum value. Kinematics were also processed in phases for the repetitive dynamic axial twisting exposure and the mean and the *mean maximum* spine angles for each spine segment was calculated.

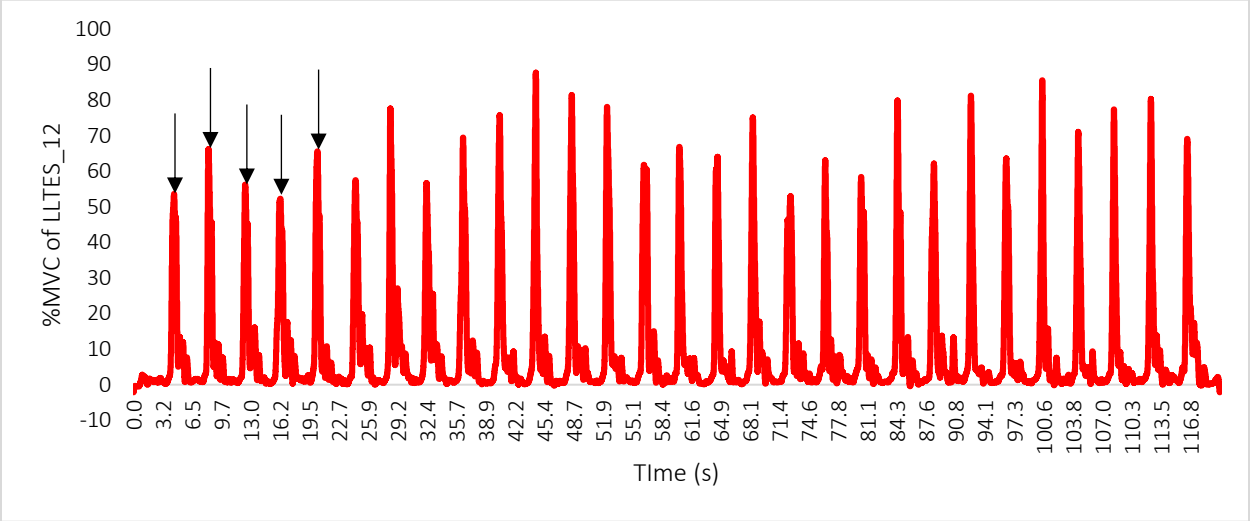

Figure 5.6.2: Each arrow points to an individual maximum %MVC of the LTES_12 of a participant at the start of their repetitive dynamic axial twisting exposure. The first 5 swings were used (first 20 seconds of exposure) to analyze the start of the participants exposure. Each maximum value in the first 5 swings was then averaged to create a *mean maximum* value, this value was used for data processing.

To examine the ROM trials, both EMG data and kinematic data was collected. The ROM trials were used to determine the maximum EMG and maximum spine segment angle during flexion/extension, lateral bending, and an axial twisting task. These measurements were completed in order calculate/determine if there were muscular or kinematic differences in these standardized ROM after someone had been fatigued from a repetitive dynamic axial twisting exposure.

The video recordings of the AHAbd tests were scored offline by three raters after all collections were completed. The raters included J. E. Vieira and two other trained spine biomechanics graduate students (N. Kareer and D. Desroches). Each rater scored each video twice

(three weeks apart). Participants' videos were randomized between participants and pre/post-tests. The scores from each rater was then combined. If there is a discrepancy between scores, the three raters discussed the scores together and decided on the final score. The largest score between the left and right legs was then used as the participants score.

5.7 Statistical Analysis

All statistical analyses used an alpha level of 0.05 to indicate statistical significance and was performed using SPSS (IBM SPSS Statistics version 24). Participants were grouped as a PD or a NPD from the difference in their baseline and final self-reported transient pain levels captured with the VAS scores (last-first score). The change in VAS scores represented the overall change in transient pain for each participant during the repetitive dynamic axial twisting exposure. The range, mean, and standard deviation of the pain groups scores were calculated. To compare the data between the PD and NPD groups, separate independent samples T-Test were used to analyze the anthropometric data (age, weight, height, BIA, hip circumference, waist circumference), total number of swings performed, timing of the axial twists (the waiting, active, and return times), BORG, %HR maximum, and the questionnaire scores.

To analyze the repetitive dynamic axial twisting exposure, the mean and *mean maximum* EMG and kinematic variables were analyzed with separate 2-way ANOVAs (2 x 3) with repeated measures. The two levels included were the pain groups (NPD and PD) and the phases of the repetitive dynamic axial twisting exposure (start, middle, and end). The term '*mean maximum*' is referring to the average of the five maximum %MVCs and spine segment angles for each phase (start, middle, and end) of the repetitive dynamic axial twisting exposure (further explained the section 5.6). Likewise, there were separate 2-way ANOVAs (2 x 3) with repeated measures run on each of the 16 EMG channels (e.g. LGM, LIO, LEO, LTES_4, etc.) and 4 spine segment angles

(UT, MT, LT, L): mean of EMG, *mean maximum* EMG, mean spine angles, and *mean maximum* spine angles. When significant differences were detected ($p > 0.05$), a Bonferroni post hoc test was used to identify individual differences between phases. For the ROM tasks the *mean maximum* EMG and kinematic data were analyzed with separate 2-way ANOVAs (2 x 2) with repeated measures. The two levels included were the pain groups (NPD and PD) and the time at which the ROM task was performed (pre and post axial twisting exposure). Therefore, there were two separate 2-way ANOVAs (2 x 2) with repeated measures performed separately on: maximum EMG from each of the 16 channels (e.g. LGM, LIO, LEO, LTES_4, etc.) and maximum spine segment angles from each of the 4 spine segments (UT, MT, LT, L).

6 Results

6.1.1 Self-Reported Transient Pain Outcomes

The thirteen female participants were separated into two groups based on the magnitude of their self-reported transient pain (relative to baseline) after the repetitive dynamic twisting exposure: seven PD (54% of participants) and 6 NPD (Section 5.3.3). Briefly, participants were considered a PD when their self-reported transient pain (VAS rating) increased by 10-mm or more from the initial baseline, while those who remained under the 10-mm threshold were deemed a NPD. The mean NPD and PD VAS differences were 2.0mm ±2.0 and 27.0mm ±24.0 respectively (Figure 6.1.1). In a preclinical population, an exposure can induce transient pain in 40-70% of individuals who were previously asymptomatic (Nelson-Wong and Callaghan, 2014; Marshall *et al*., 2011; Nelson-Wong and Callaghan, 2010; Nelson-Wong *et al.*, 2008; Babiolakis *et al.*, 2005; Schinkel-Ivy *et al.*, 2013). Therefore, our research is consistent with this finding, as 54% of participants developed clinically relevant transient pain. The NPD and PD groupings were used to analyse all other data that were collected.

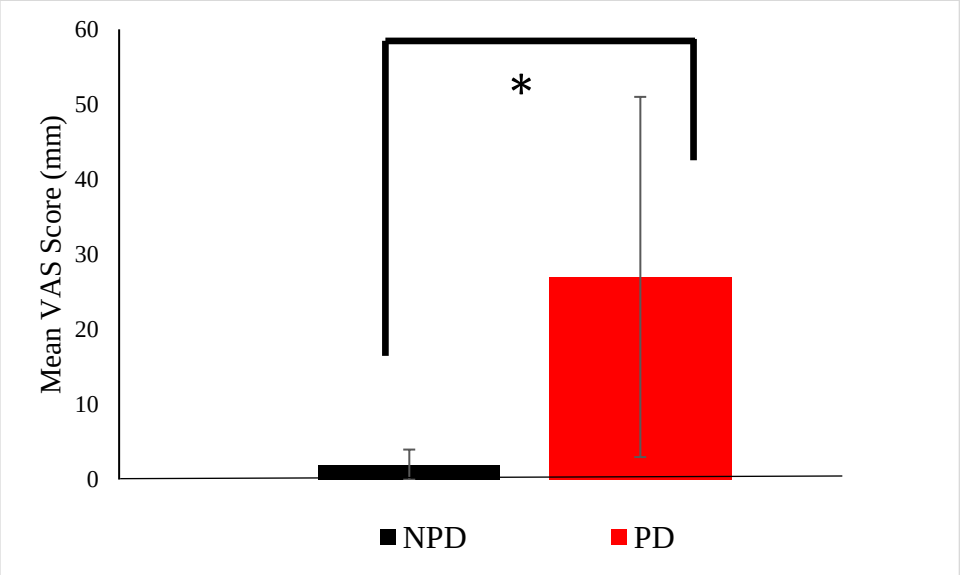

Figure 6.1.1: The transient pain that developed during the repetitive dynamic axial twisting exposure relative to baseline was 14 times larger in the PD (red) than NPD (black; p=0.028).

6.2 Participant Characteristics

The two transient pain groups had statistically similar physical characteristics (Table 6.2.1). There were no significant differences between PD and NPD for age [t(11)=1.188; p=0.260], height [t(11)=-1.817; p=0.95], weight [t(11)=-1.664; p=0.118), BIA [t(11)=-1.123; p=0.285], hip circumference [t(11)= -2.229 p=0.075), or waist circumference (t(11)=-0.765 p=0.460). Since the participant characteristics were statistically similar between the two groups, it was concluded that the groups were from the same population and researchers were recruiting from the same population.

Table 6.2.1: No differences were found in the anthropometric measures between PD and NPD. Data are reported as mean ±SD.

	NPD	PD
Age	21yrs ±3	19yrs ±2
Height	166cm ±4	170cm ±5
Weight	68Kg ±4	82Kg ±20
BIA	26% ±4	29% ±7
Hip Circumference	84cm ±3	96cm ±15
Waist Circumference	84cm ±4	89cm ±17

6.3 ROM

ROM tests were performed before and after the repetitive dynamic axial twisting exposure to examine if there were differences in muscle activation (maximum %MVC) and spine segment angles (maximum spine segment angles) after being exposed to a repetitive dynamic axial twisting exposure. Again, the ROM tasks included a ten second upright stand, R/L lateral bend, R/L twist, and flexion-extension performed to the participants' self-determined maximal point. The findings from each of these tasks are described in the subsections below. From these ROM tests, 3 outcomes could have been identified as being statistically significant. There could be an effect of time (or fatigue), an effect of pain group (NPD or PD), or an interaction effect (that time and pain group were interacting with each other).

6.3.1 Upright Stand

The upright stand was used to assess if any changes occurred to a static posture after the repetitive dynamic axial twisting exposure. There were no significant differences seen in the muscle activation data. The closest muscle to significance was RLES with an effect of pain which had a p-value of 0.069 [f(1,18)=3.735] between NPD (1.92%MVC ±1.73) and PD (0.75%MVC

±1.03). The furthest muscle from significance was RTES_12 with an effect of pain which had a p-value of 0.956 [f(1,18)=0.003] between NPD (0.54%MVC ±0.44) and PD (0.52%MVC ±1.13). Not having a significant difference in EMG during the upright stand, suggests that the postural muscles which maintain the stability of the spine were activated the same way before and after the repetitive dynamic axial twisting exposure. There was however a significant change within the maximum kinematic data during the upright stand. While performing an upright stand the UT spine segment in PD (7.20º ±5.60) had more lateral bend in the UT spine segment in comparison to the NPD (-0.39º ±4.83) as shown in Figure 6.3.1.1 [f(1,18)=9.604 and p=0.008]. The LT spine segment in the PD was not in a neutral position (higher segment angle) in comparison to the NPD who remained around -2 degrees to 2 degrees (more neutral) during the pre and post upright stand. The next closest spine segment to significance was the MT spine segment (p=0.094), which had increased lateral bend between NPD (17.68º ±1.73) and PD [25.1º ±8.77; f(1,14)=3.222]. The furthest spine segment from significance (p=0.989) was the L spine segment which had increased flexion as an effect of phase [f(1,14)=0.000] between pre-exposure (27.66º ±56.49) and post-exposure (26.65º ±4.86).

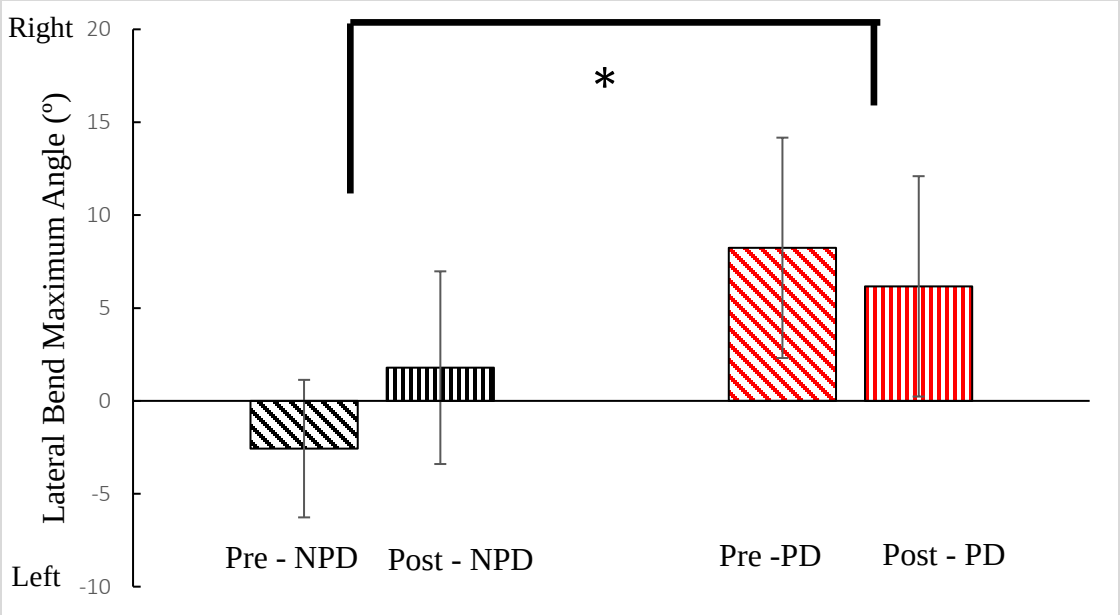

Figure 6.3.1.1: The PD (red) had higher maximum lateral bend angles in their lower thoracic spine (LTX) than NPD (black) for the pre/post 10s upright stand task (p=0.008).

6.3.2 Twist

Performing an axial twisting task to the participants' self-determined maximum ROM before and after the repetitive dynamic axial twisting exposure had significant differences in the maximum muscular activation and maximum kinematic data. There was significantly more LGM muscle activation in the NPD (25.10%MVC ±33.39) in comparison to the PD (3.32%MVC ±6.40) during the axial twist ROM task as shown in Figure 6.3.2.1 [f(1,18)=4.519 p=0.048]. The change in LGM was the sole muscular activation difference in the twisting ROM task. Likewise, only one kinematic difference was seen in the twist ROM task. NPD (16.19º ±13.55) were more right laterally bent (coupled with the twist) than the PD (1.70º ±8.24) in the lumbar spine when performing the axial twist ROM task (Figure 6.3.2.2; [f(1,14)=6.197; p=0.026].

The closest muscle to significance was LIO with an effect of pain [p=0.071; f(1,18)=3.687] between NPD (30.94%MVC ±27.89) and PD (12.57%MVC ±15.69). The furthest muscle from

significance was LTES_12 with an effect of pain [p=0.929; f(1,18)=0.008] between NPD (14.86%MVC ±27.65) and PD (15.78%MVC ±18.95). The closest spine segment to significance was MT as an effect of pain [p=0.179; f(1,14)=1.997] between NPD (131.21º ±62.30) and PD who had an increased amount of lateral bend (165.00º ±9.21). The furthest spine segment from significance was UT (testing the amount of lateral bend), as an effect of phase [p=0.999; f(1,14)=0.001] between pre-exposure (1.13º ±3.36) and post-exposure (1.09º ±3.64).

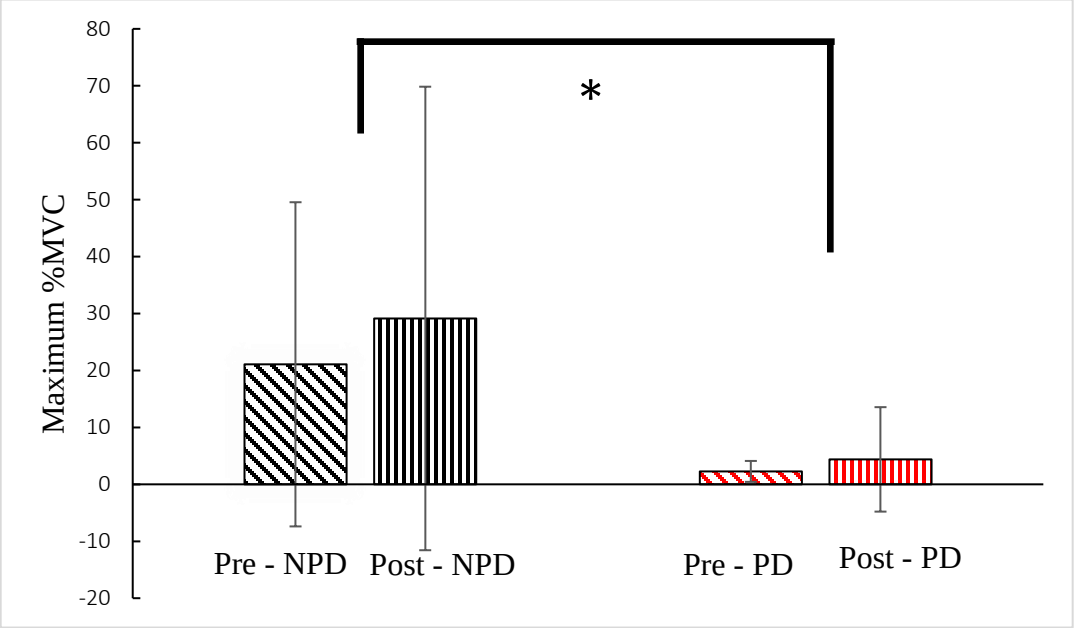

Figure 6.3.2.1: The NPD (black) had a 7.6x greater %MVC of the LGM than the PD (red) during an axial twisting ROM task (p=0.048).

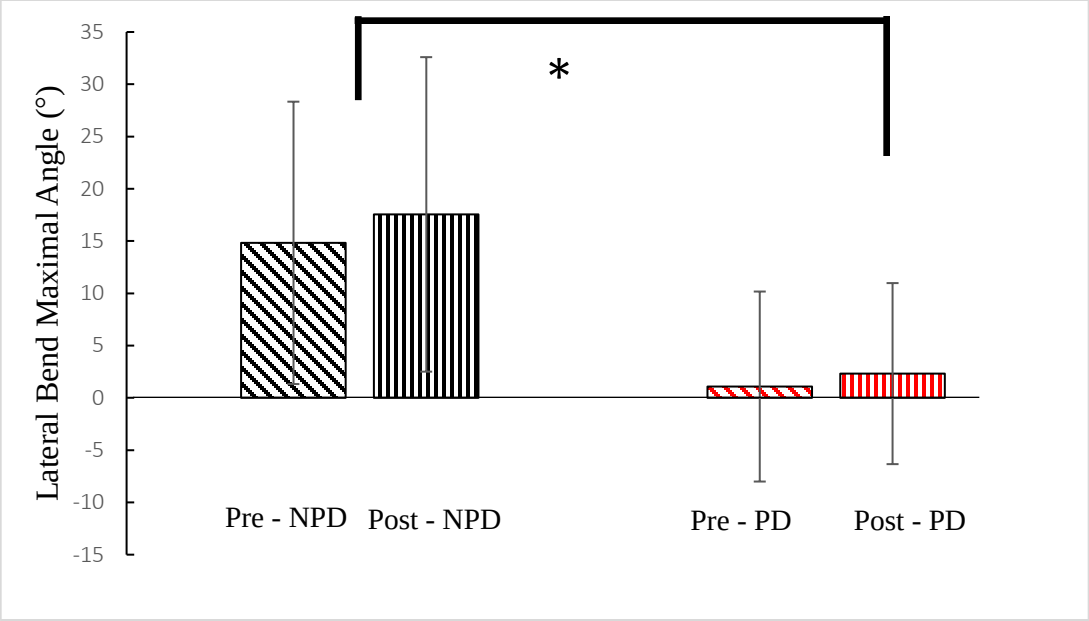

Figure 6.3.2.2: NPD (black) had a 9.5x greater maximum lateral bend angle in the lumbar spine in comparison to the PD (red) during an axial twisting ROM task (p=0.026).

6.3.3 Bend

Similar to the upright standing task there was no significant differences seen between pain groups or pre/post repetitive dynamic axial twisting exposure in muscular activation. There were three kinematic differences between pain groups in the lower thoracic spine segment on the z-axis (LTZ; twist), the lumbar spine segment on the x-axis (LX; lateral bend), and the upper thoracic spine segment on the y-axis (UTY; flexion/extension). The NPD (45.11º ±7.62) had a significantly larger twisting angle in the lower thoracic spine in comparison to the PD (33.82º ±2.10) during the lateral bend ROM task as displayed in Figure 6.3.3.1 [f(1,16)=15.571; p=0.002]. The NPD (20.87º ±9.07) during the lateral bend ROM task started with a larger lumbar segment angle on the x-axis in comparison to the PD (3.16º ±8.29) as displayed in Figure 6.3.3.2. [f(1,16)=15.297; p=0.002]. The NPD also increased their lateral bend angle in the lumbar spine after the repetitive dynamic axial twisting exposure, and in comparison, the PD had a smaller lumbar segment angle. Finally, the NPD (25.60º ±1.40) lower thoracic segment was more flexed before and after the repetitive

dynamic axial twisting exposure during the lateral bending ROM task in comparison to the PD (22.56º ±1.40) as displayed in Figure 6.3.3.3 [f(1,14)=7.356; p=0.022].

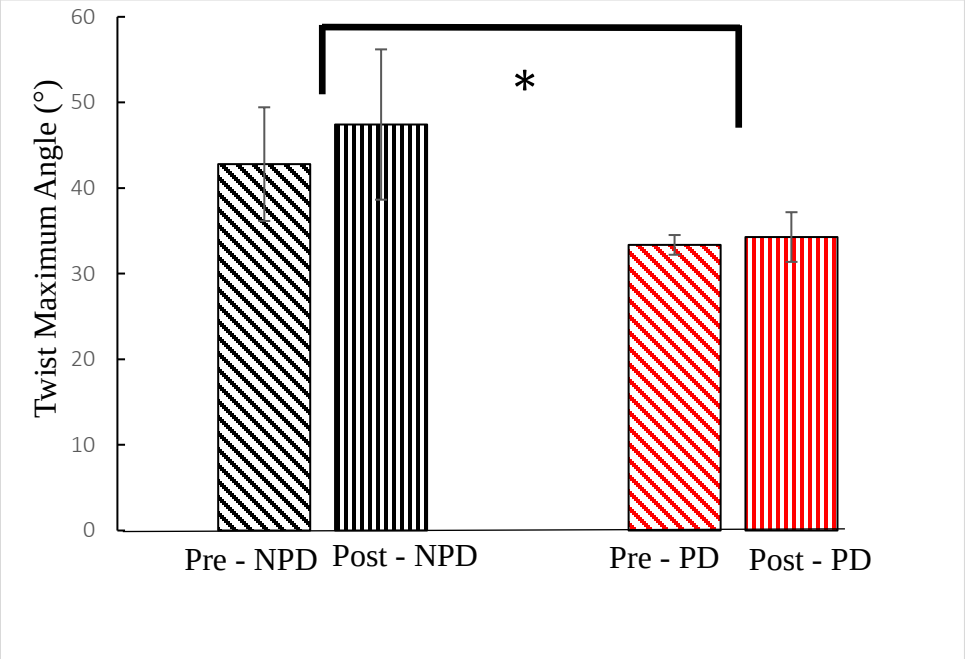

Figure 6.3.3.1: The NPD (black) had a higher lower thoracic right-side twist angle during the repetitive dynamic axial twisting exposure, while the PD (red) had a smaller right-side twist angle (p=0.002).

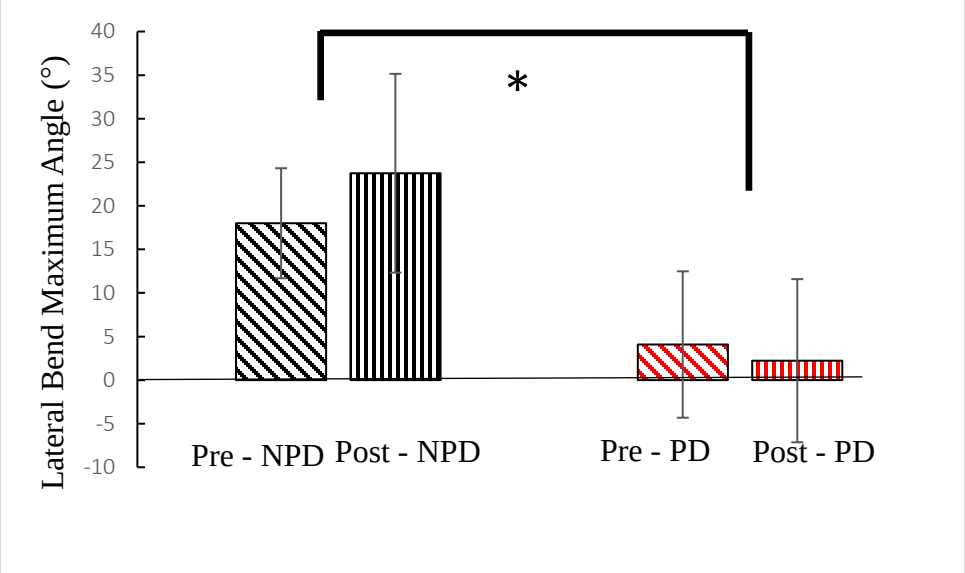

Figure 6.3.3.2: The NPD (black) had a higher lateral bend angle in the lumbar spine during the lateral bend ROM task in comparison to PD (red; p=0.002).

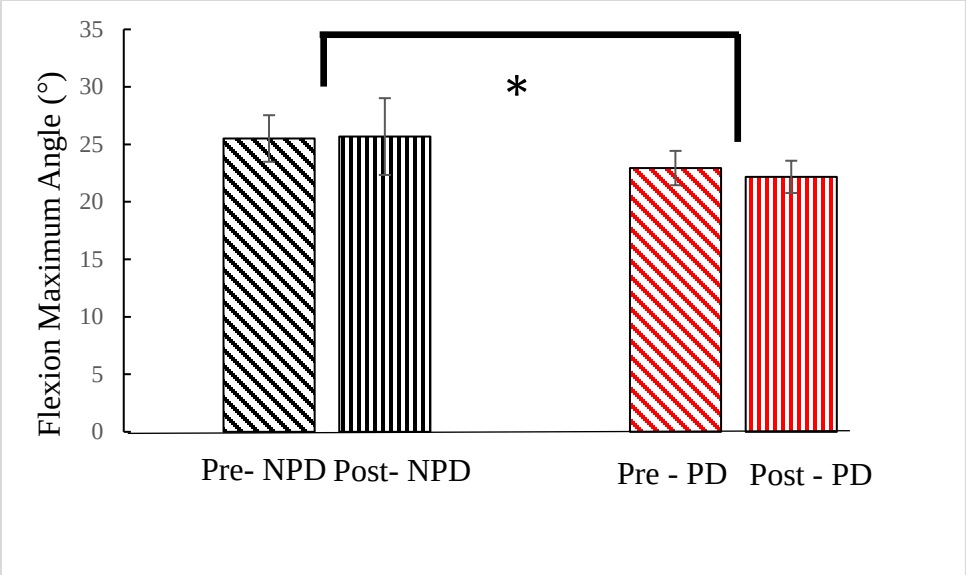

Figure 6.3.3.3: The NPD (black) had a larger flexion angle in the upper thoracic spine segment during the lateral bend ROM task in comparison to the PD (red; p=0.022).

The closest muscle to significance was RGM as an effect of pain [p=0.062; f(1,18)=3.954] between NPD (3.02%MVC ±3.33) and PD (24.70%MVC ±35.43). The furthest muscle from significance was LLAT as an effect of phase [p =0.960; f(1,18)=0.003] between pre-exposure (14.86%MVC ±27.65) and post-exposure (15.78%MVC ±18.95). The closest spine segment to significance was LY as an effect of pain [p=0.164; f(1,14)=2.192] between NPD (38.73º ±67.73 and PD (0.29 º ±5.67). The furthest spine segment from significance was LY as an effect of phase [p=0.981; f(1,14)=0.001] between pre-exposure (19.82º ±51.47) and post-exposure (19.20º ±53.63).

6.3.4 Flexion and Extension

There was no significant difference seen in muscular activation or kinematics during the pre/post flexion/extension ROM task. The closest significant difference in muscular activation was in RLES with a p-value of 0.140 [f(1,18)=2.378]. The closest kinematic significant difference was

in the UT spine segment on the y-axis (UTY) which had a p-value of 0.163 [f(1,17)=2.189]. Since there were no significant differences in EMG or kinematic data after the repetitive dynamic axial twisting exposure, the exposure did not affect the participants ability to perform the flexion/extension ROM task.

6.4 Lumbopelvic Control

The AHAbd test was used to assess the participant's lumbopelvic control, as it was taken pre/post-exposure on each leg. As stated previously, a score of 0-1 represents a participant who is not at an increased risk of developing LBP, where a score of 2-3 indicates that the participant is at an increased risk of developing LBP. For the NPD group, they had a pre-AHAbd test mean score of 1.3 ±0.52 and a post-AHAbd test mean score of 1.7 ±0.52. The PD had a pre-AHAbd mean score of 1.4 ±0.52 and a post-AHAbd test mean score of 1.75 ±0.46. While lumbopelvic control may still be a factor, it was not likely a major player in the development of transient pain from repetitive dynamic repetitive twisting.

6.5 Repetitive Dynamic Twisting Exposure

The rate of the swings was controlled at 15 swings per minute, however the duration of a swing, return to start, or waiting time between swings could have varied amongst the participants and may have contributed to the potential changes shown in the swing data. As such, the duration of these events was calculated. There were no significant differences between the PD and NPD in total mean waiting time between repeats (swings) of the repetitive dynamic axial twisting exposure in the start position [t(11)=-0.116; p=0.910], the dynamic axial twisting time [t(11)=0.656; p=0.525], or the time it took for the participants to return to their starting position [t(11)=1.487; p=0.165] as shown in Table 6.5.1. The total amount of swings by the participant was also examined, to identify if PD lasted longer in the protocol than the NPD. There was no statistically

significant difference in the mean amount of total axial twists between groups (NPD 120 ±62.93 and PD 101.25 ±53.03; p=0.556). The amount of time spent in the exposure by pain group is shown in Figure 6.5.1. Likewise, the repetitive dynamic axial twisting exposure was the same for all participants, regardless of pain group.

Table 6.5.1: There is no difference between pain groups while examining the timing of the repetitive dynamic axial twisting exposure during the two-minute epochs. Data displayed as mean ±SD.

	NPD	PD	p-value
Waiting Time	47s ±7	48s ±11	0.910
Active Time	31s ±5	29s ±5	0.525
Return Time	37s ±6	32s ±7	0.165

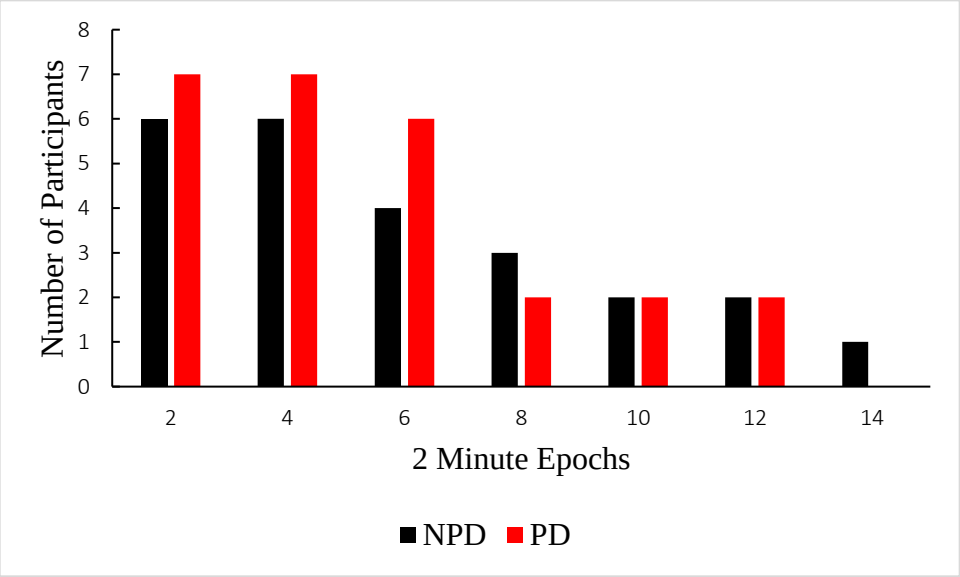

Figure 6.5.1: There were no differences between NPD and PD in the number of participants at each epoch who continued in the repetitive dynamic axial twisting exposure [e.g. all participants completed the 2min and 4 min epochs, whereas only 1 NPD completed the 14 min epoch; (p=0.556)].

To verify that the exposure was completed to the point the participant was fatigued and not in pain, HR data and the participants BORG scale ratings were evaluated for all participants. HR data and BORG was collected to justify that the NPD were in fact working at the same %HR maximum and BORG scale rating as the PD. In terms of the level of self-reported fatigue both PD and NPD experienced similar levels of physical exertion as identified by the reported BORG rating and their %HR maximum data throughout the exposure. The starting and final BORG measurements were evaluated between pain groups and no significant difference was found (start p=1.00 and end p=0.089) shown in Figure 6.5.2. The %HR maximum data was also collected at the start and finish of the repetitive dynamic axial twisting exposure, and like the BORG data, there were no significant differences between pain groups (start p=0.230 and end p=0.297) as shown in Table 6.5.2. Not having a significant difference in pain groups at the end of the exposure in BORG and %HR maximum identified again that the exposure was similar. The high %HR maximum suggests that participants were physically fatigued even if their BORG rating did not suggest that they were fatigued (a rating of 11 is deemed fairly light, a rating of 13 is somewhat hard, a rating of 15 is hard, continuing to 20 which is very, very hard).

Table 6.5.2: A comparison of NPD and PD HR and BORG data at the start and end of the axial twisting exposure. Data displayed as mean± standard deviation.

	NPD	PD	p-value
HR Start (%HR Max)	44%HR Max ±4	50%HR Max ±11	1.000
HR End (%HR Max)	87%HR Max ±4	90%HR Max ±4	0.089
BORG Start	6 ±0	6 ±0	0.230
BORG End	13 ±2	16 ±3	0.297

6.6 EMG

6.6.1 Mean EMG

Mean EMG data was collected from the 8 bilateral muscles, however only the LGM and the RLES showed statistically significant differences in muscular activation. The LGM in both groups decreased muscular activation from start (7.66%MVC ±8.13) to end (1.93%MVC ±2.04) of the repetitive dynamic axial twisting exposure as shown in Figure 6.6.1.1 [f(2,33)=4.030; p=0.027]. In regard to the RLES, the NPD (4.15%MVC ±1.79) had a statically higher mean %MVC in comparison to the PD (2.35%MVC±2.19) in every phase as shown in Figure 6.6.1.2 [f(1,33)=7.153; p=0.012]. The next closest muscle to significance was RGM as an effect of pain which had a p-value of 0.051 [f(1,33)=4.113] between NPD (5.55%MVC ±3.26) and PD (3.52%MVC ±2.89).

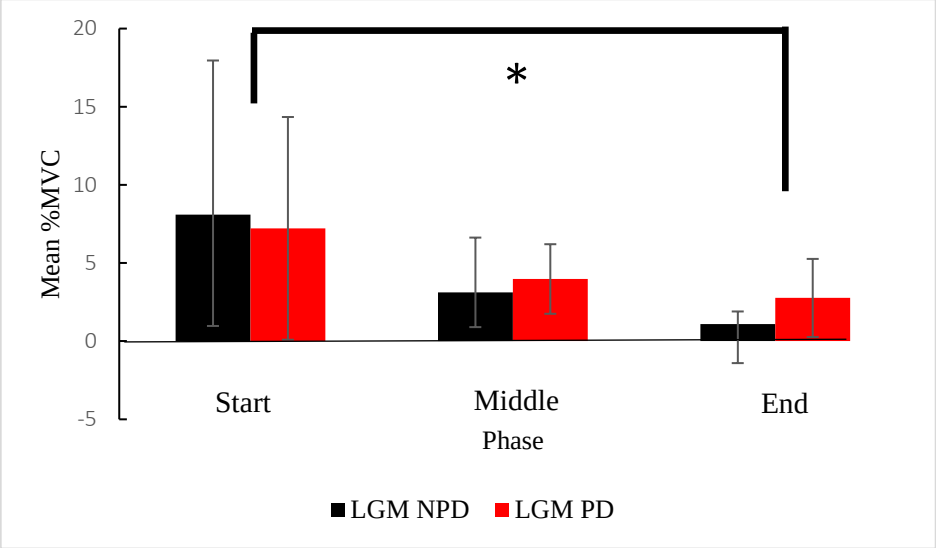

Figure 6.6.1.1: There is about a 4x higher %MVC of the LGM in the start of the repetitive dynamic axial twisting exposure in comparison to the end of the exposure in both groups pain groups (p=0.027).

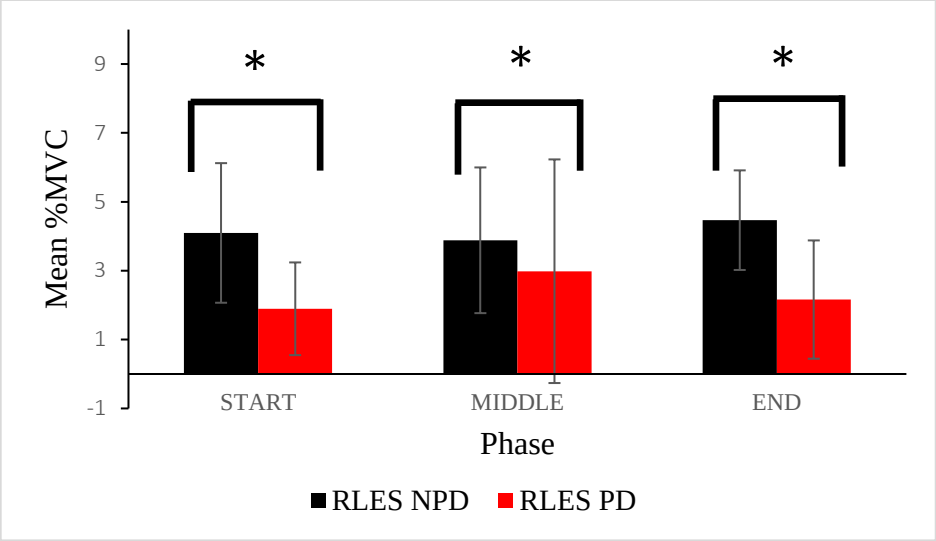

Figure 6.6.1.2: The NPD (red) had a 1.8x larger mean %MVC of the RLES during the repetitive dynamic axial twisting exposure across all phases in comparison to the PD (black; p=0.012).

6.6.2 Maximum EMG Data

Only one muscle was significant during the swing in both the maximum and mean %MVC, which was the RLES. While examining the maximum EMG data for RLES, the NPD (51.30%MVC ±21.49) are at a higher %MVC than the PD (32.90%MVC ±29.45) throughout each phase of the exposure as shown in Figure 6.6.2.1 [f(1,33)=5.02; p=0.032].

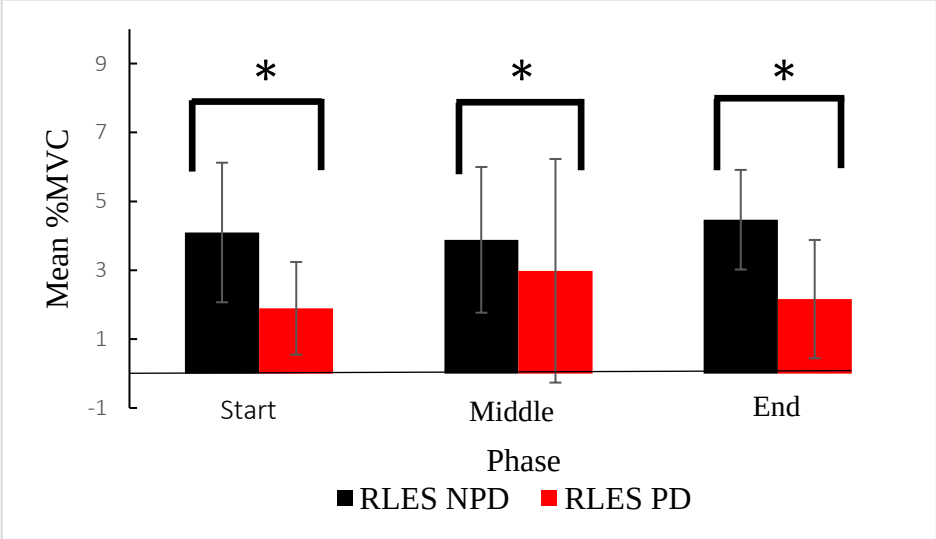

Figure 6.6.2.1: The NPD (red) have a 1.6x higher maximum %MVC of the RLES during the repetitive dynamic axial twisting exposure in comparison to the PD (black; p=0.032).

Another statistically significant change in maximum muscular activation was displayed in the RRA with an interaction effect of phase and pain. In the RRA the PD (16.41%MVC ±8.91) in the start of the exposure have a significantly smaller maximum %MVC than the PD in other phases and all NPD phases as shown in Figure 6.6.2.2 [f(2,33)=4.290; p=0.22]. The next closest muscle to significance was LIO on phase which had a p-value of 0.071 [f(2,33)=2.871].

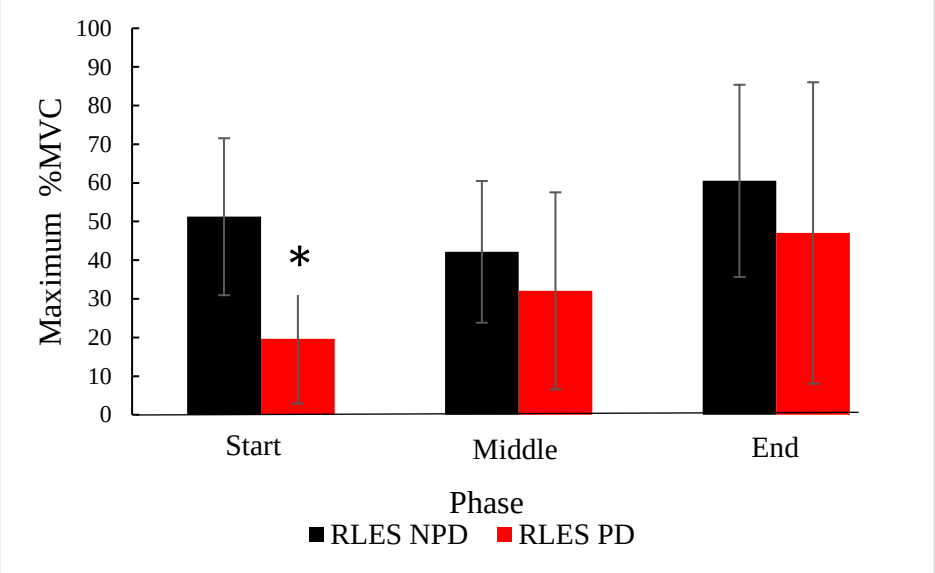

Figure 6.6.2.2: NPD (black) and PD (red) maximum %MVC of the RRA during the repetitive dynamic axial twisting exposure compared over the three phases (start, middle and end). There is a significant interaction between PD and the start of the repetitive dynamic axial twisting exposure (p=0.022).

6.7 Kinematics

6.7.1 Mean Kinematics

During the repetitive dynamic axial twisting protocol, three kinematic differences were seen in the mean segment angle changes throughout the exposure. The first was seen in the lower thoracic spine segment. The NPD (34.72º ±5.64) have a significantly higher flexion angle than the PD (31.62º ±2.50) in all phases as shown in Figure 6.7.1.1 [f(1,30)=4.229; p=0.049]. The second was seen in the lumbar spine segment. Like the differences in the lower thoracic spine, the NPD (9.20º ±9.26) had a higher lateral bend angle in the lumbar spine in comparison to the PD (2.32º

±10.58) as shown in Figure 6.7.1.2 [f(1,28)=4.310; p=0.47]. Finally, the last difference in mean kinematics was in the upper thoracic spine segment. The NPD (1.66º ±8.26) had a significantly higher mean flexion angle in all phases in comparison to the PD (-2.70 ±1.30) as shown in Figure 6.7.1.3 [f(1,30)=4.508; p=0.042] . The next closest spine segment to significance was midthoracic spine segment measuring the deviation of flexion/extension, there was almost an effect of pain which had a p-value of 0.83 [f(1,30)=3.222] between NPD (123.80º ±45.88) and PD (144.48º ±3.42).

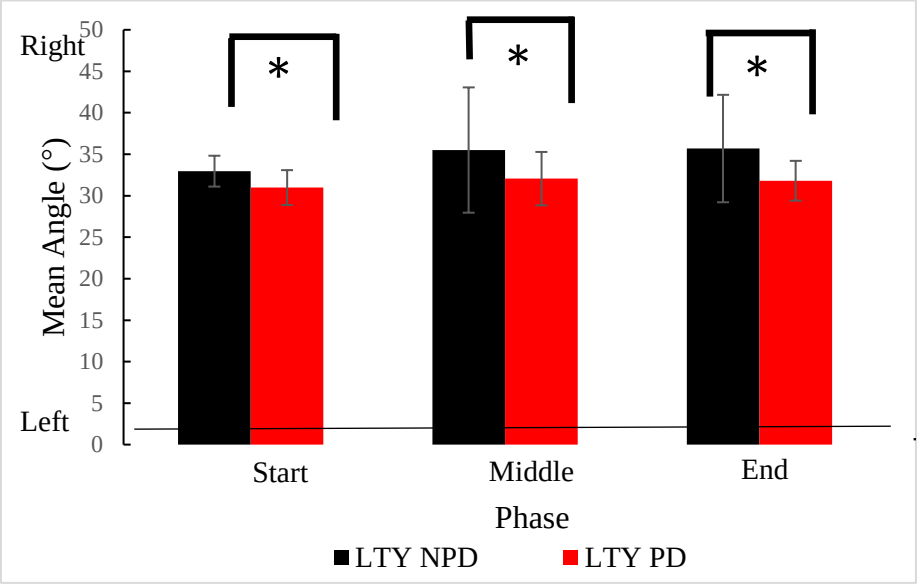

Figure 6.7.1.1: The NPD (red) had about a 1x larger flexion angle in the mean lower thoracic spine segment angle on the y-axis (flexion/extension) than the PD (black) across all phases (p=0.049).

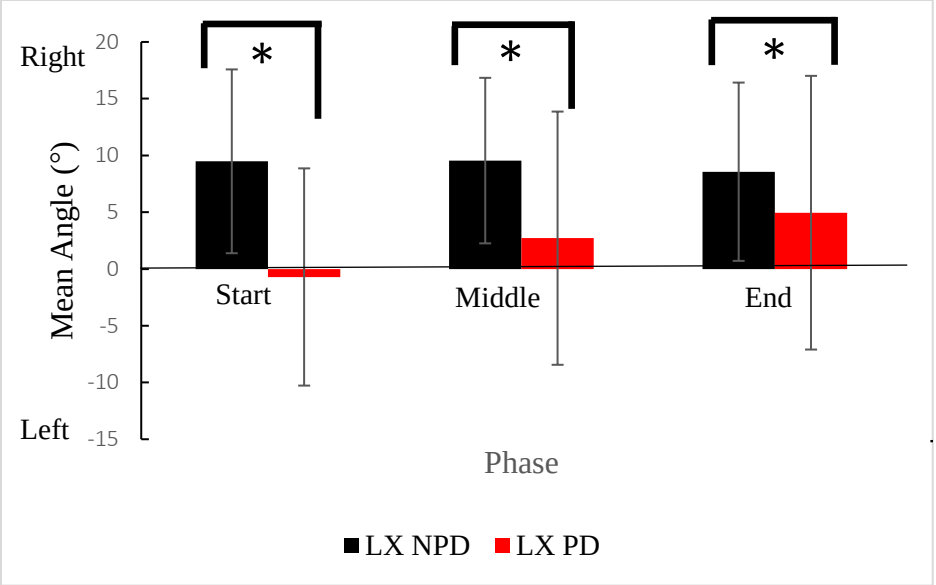

Figure 6.7.1.2: The NPD (red) was at a 4x larger lateral bend angle in the lumbar spine segment angle during the repetitive dynamic axial twisting exposure in comparison to the PD (p=0.047).

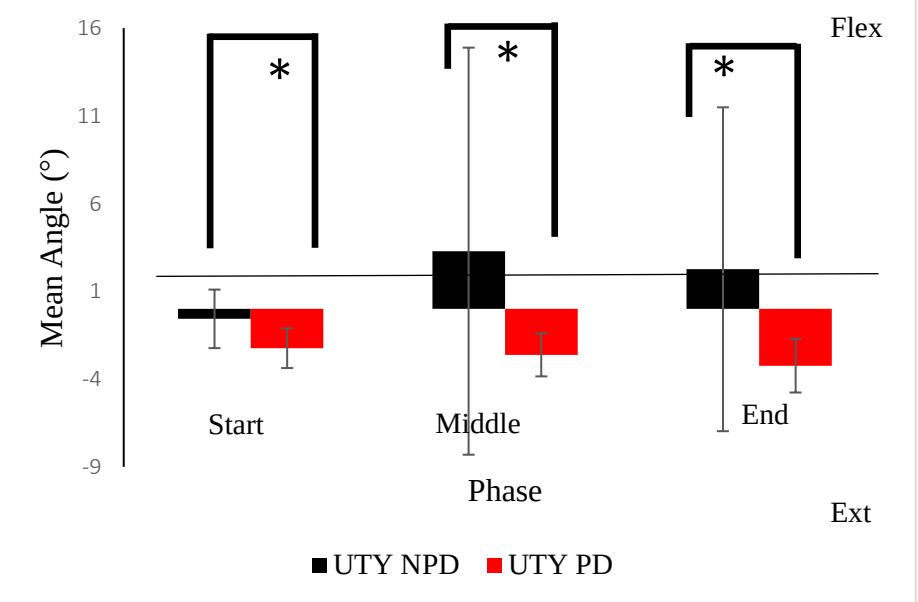

Figure 6.7.1.3: The NPD (red) had a 1x higher mean flexion angle in the upper thoracic spine segment angle during the repetitive dynamic axial twisting exposure than the PD (black; p=0.042).

6.7.2 Maximum Kinematics

There were no significant differences in maximum spine segment angles (UT, MT, LT, L) in any of the three axes (lateral bending, flexion/extension, or twist) during the repetitive dynamic axial twisting exposure when assessing the difference in pain groups ($p < 0.063$). Having no difference in maximum spine angles means both pain groups (NPD and PD) were performing the axial twisting exposure at the same maximum angles. However, it was seen previously that PD are doing so with a decreased muscular activation, which could be why they are developing pain and the NPD are not.

6.8 Questionnaires

Mean scores of the questionnaires were calculated and a comparison was made between NPD and PD groups as shown in Figure 6.8.1 and Figure 6.8.2. Mean RSES scores were 14.40 ±6.95 and 16.71 ±4.03 out of a possible score of 30 [t(10)=-0.733; p=0.480], mean SPAS scores were 32.2 ±4.76 and 40.57 ±8.72 out of a possible 60 [t(10)=-1.934; p=0.082], and mean BSQ scores were 81.6 ±16.95 and 96.57 ±32.77 out of 204 [t(10)=-0.928; p=0.375], for NPD and PDs respectively (data above shown in Figure 6.8.1). From the IPAQ questionnaire, both total activity minutes and sitting minutes per week were calculated. Mean activity minutes were 11701.2minutes per week ±7122.72 and 6444.14minutes per week ±4578.42 [t(10)=1.566; p=0.143], while sitting minutes were 26640.00 minutes per week ±903.60 and 2404.28 minutes per week ±704.72 [t(10)=0.561; p=0.587] as shown in Figure 6.8.2. No significant difference was found between NPD and PD groups from the questionnaire information.

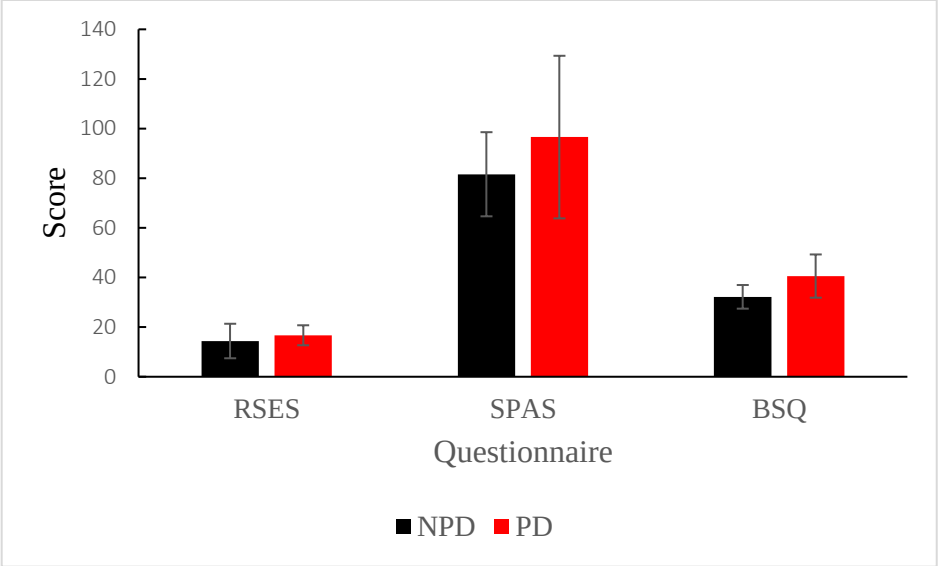

Figure 6.8.1: Questionnaire data comparing NPD (black) and PD (red), there is no significant difference NPD and PD (RSES p=0.480, BSQ p=0.375, and SPAS p=0.082) therefore, no difference in self-esteem, social physique anxiety, and how they feel about their body.

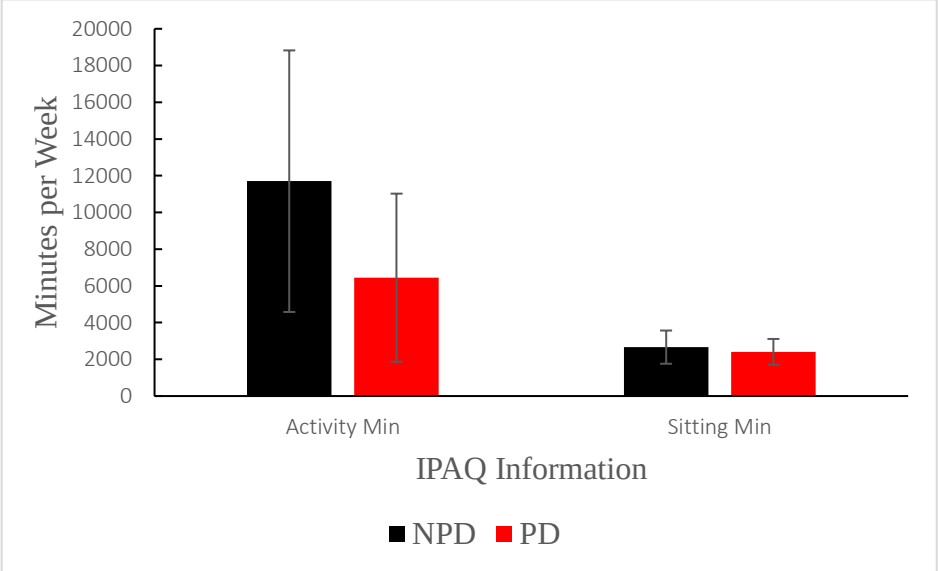

Figure 6.8.2: There is no difference between NPD (black) and PD (red) in the information drawn from the IPAQ (activity minutes p=0.148 and sitting minutes p=0.587).

7 Discussion

LBP is one of the most prevalent types of musculoskeletal pain in adults, and axial twisting of the trunk is associated with over 60% of all back injuries (Sadeghisani *et al.*, 2015; Kumar *et al.*, 2001). This thesis contributed to the limited understanding of repetitive dynamic axial twisting research by providing a better understanding on how the repetitive dynamic axial twisting exposure effects an elite population of participants who regularly participate in repetitive dynamic axial twisting of the trunk. It was concluded that the repetitive dynamic axial twisting exposure and the physical and psychosocial profile was identical for PD and NPD participants. Both pain groups performed the same amount of axial twists, had the same %HR max at the end of the exposure, had the same BORG ratings at the end of the exposure, had the same anthropometric data, and the same questionnaire results, the only differences seen were in the muscular responses that the repetitive dynamic axial twisting exposure elicited. The PD had decreased muscle activation and mean spine segment angles during the repetitive dynamic axial twisting exposure and ROM tasks, showing that PD were adapting differently to the exposure in comparison to the NPD. However, an interesting point to consider is that the PD and NPD had the same maximum spine segment angles during the repetitive dynamic axial twisting exposure, meaning they reached the same maximum spine angle during the swing. Yet, PD used less muscle activation during the repetitive dynamic axial twisting exposure which could lead to less stability of the spine, and a heavy reliance of other muscles and/or on passive structures to resist the effects of the axial twist, which could lead to the transient pain development. Therefore, although fatigue was not observed as an effect in this data, the PD adapted different muscular and kinematic strategies to perform the repetitive dynamic axial twisting exposure. It is suspected that the alteration in muscle response imposed higher loading on spine joints (e.g. compression) and altered load distribution between the active

and passive tissues (e.g. increased loading on ligaments and IVD), which may have contributed to the increased pain reported by PD.

In a preclinical population, an exposure can induce transient pain in 40-70% of individuals who were previously asymptomatic (Nelson-Wong and Callaghan, 2014; Marshall *et al*., 2011; Nelson-Wong and Callaghan, 2010; Nelson-Wong *et al.,* 2008; Babiolakis *et al.,* 2005; Schinkel-Ivy *et al.*, 2013). These participants are not seeking any care for LBP, they are individuals who have said they are not in any form of pain and are healthy. It is important to remember that they were asymptomatic individuals who developed clinically relevant transient pain from the exposure. It was work by Nelson-Wong and Callaghan (2014) that demonstrated that PD have a greater risk of developing future clinically relevant levels of pain within their lifetime. Nelson-Wong and Callaghan (2014) conducted a 2-hr prolonged standing protocol, and grouped their participants as NPD and PD from their VAS scores (using a threshold of 10-mm; as conducted in this thesis). These researchers followed their participants for a total of three years, and the PD had significantly higher rates of clinical LPB and were 3 times more likely to experience an episode of clinical LBP in the first 24 months of the follow-up in comparison to the NPD in their study (Nelson-Wong and Callaghan, 2014). Therefore, it was interpreted that the participants identified as PD are more likely to develop clinical LBP in the near future as compared to the NPD participants, and the differences in the musculoskeletal responses are important to better understanding of the development of transient pain. Nelson-Wong *et al.* (2008) also suggested that PD recruited muscles differently (through the co-contraction analysis of the musculature involved, it was shown that PD activate their muscles together instead of individually like the NPD) which could contribute to the transient pain development seen. In this thesis, 54% of the asymptomatic and preclinical population developed transient LBP, which is consistent with previous research on

transient pain (Nelson-Wong and Callaghan, 2014; Marshall et al., 2011; Nelson-Wong and Callaghan, 2010; Nelson-Wong *et al.,* 2008; Babiolakis *et al.,* 2005; Schinkel-Ivy *et al.*, 2013). It is also important to note that the recruitment of muscles is different in the PD in comparison to the NPD in this study, which is consistent with the results of Nelson-Wong *et al.* (2008). Therefore, it can be concluded that although these participants did not differ in the repetitive dynamic axial twisting exposure or physical/psychosocial characteristics, there were participants who developed clinically relevant transient pain from the repetitive dynamic axial twisting exposure. With the PD displaying significantly different movement and muscle activation strategies during the repetitive dynamic axial twisting exposure and the ROM tasks, it allows for a better understanding of the clinically relevant transient pain and to the further understanding of the effect axial twisting of the trunk can have on a participant.

The mean %MVC during the repetitive dynamic axial twisting exposure was from 2.24-8.75%MVC for NPD and 1.93-7.63%MVC for PD which were within the magnitudes reported in previous axial twisting research. Ng *et al.* (2001) investigated the %MVC in the rectus abdominis, external oblique, and internal oblique muscles during axial twist at 100%, 70%, 50%, and 30% exertion level in standing position. The abdominal muscles in the study performed by Ng *et al.* (2001) when at a 30% exertion level are within a mean of 1-15%MVC, which is consistent in the results of this thesis. This provides confidence that the values obtained by the novel approach used in this thesis are reasonable, and comparable to previous research done using an axial twisting exposure.

The decrease in the PD muscle activation observed during the repetitive dynamic axial twisting exposure and the pre/post ROM tasks could be due to the participants activating non-primary twisting muscles required to generate the twisting of the trunk, which could reduce the

stability of the spine. It was concluded from the work of Bonato *et al.* (2003) that because of the multi-segmental structure of the spine, it has a large reliance on muscles to stabilize the spine. The instability of the spine was also expressed by the work done by Ng *et al.* (2001), as this research outlined the importance of the abdominal muscles for anterior stability and the erector spinae for posterior stability. In addition, the work done by Gregory *et al.* (2008) outlines that there was a decrease in muscular activity in the abdominal muscles after a fatiguing task during a firefighter work simulation task. Therefore, it is possible that the primary muscles that are required for twisting the truck are not being recruited properly and other muscles are contributing to the dynamic twisting of the spine (a phenomenon discussed by Nelson-Wong *et al*., 2008). The muscles being recruited in PD could be muscles that act on the pelvis (creating a twist in the pelvis would result in twisting of the trunk), could be muscles that are deep to other muscles and their contributions were not detected by EMG, or it could be muscle that are not primary twisters of the spine that are generating the movement and these muscles were not monitored in this study. It is unclear why the primary muscles responsible for axial twisting of the trunk are showing a decrease in %MVC in comparison to the NPD, yet what is clear is that the movement strategy by the PD has been associated with the development of clinically relevant transient pain. Therefore, more research needs to be conducted to identify specifically what muscle activation strategies PD are using to perform the repetitive dynamic axial twisting.

Not only did the PD have a decrease in muscle activation during the ROM tasks, but they also had significantly decreased spine segment angles during the ROM tasks. Having a decrease in spine segment angles meant that the NPD had larger ROM in the lateral bend, flexion/extension, and twisting tasks. Yet, the NPD and PD reached the same maximum spine segment angles in the repetitive dynamic axial twisting exposure. Therefore, the PD actually went past their ROM to

perform the repetitive dynamic axial twisting exposure, which could be the source of the clinically relevant transient pain they developed. On average the PD had a 5.3° increase in ROM across all spine segments in the swing exposure in comparison to the twist ROM task, while the NPD had a 2.15° difference. It is possible that in order for the PD to reach the same maximum spine segment angles during the repetitive dynamic axial twisting exposure, with a decreased ROM, they used a different movement strategy to perform the repetitive dynamic axial twisting exposure. As the PD develop clinically relevant transient pain, it can be concluded that the altered movement strategy is not optimal, and further investigation into the altered movement strategy should be conducted. In addition, the PD also had decreased mean segment angles during the repetitive dynamic axial twisting task in comparison to the NPD. The decreased mean segment angles coincide with the decreased muscular activation seen by PD during the repetitive dynamic axial twisting exposure. If there is a decrease in spine segment angles, it would justify the lower muscle activation, as the participant is not deviating from neutral, therefore the participant does not need to activate more muscles to keep the spine stable. It is clear there are differences in movement strategies between the NPD and the PD, what is not clear, is why. More research needs to be conducted to identify why NPD and PD have different kinematic strategies throughout a repetitive dynamic axial twisting exposure.

Although a clear effect of clinically relevant transient pain was seen, there was not an effect of fatigue seen consistently throughout the repetitive dynamic axial twisting exposure. There was one muscle (LGM) that through the repetitive dynamic axial twisting exposure saw a significant difference of time, which would suggest fatigue took place over time and changed the muscular responses. However, the change in LGM was the only case that fatigue could have been concluded to affect the participants regardless of pain group. The lack of evidence in real time fatigue does

not insinuate that the participants were not fatigued, it suggests a cardiovascular fatigue as opposed to a muscular fatigue was detected through these measures. It is possible that the effect of fatigue could not have been identified without a secondary analysis of the frequency in the muscle activation data. It is also possible that the exposure needs to be repeated in order to see muscular fatigue in addition to cardiovascular fatigue. Perhaps performing the exposure to a self-selected fatigue, then waiting for HR to return to resting, then continuing the exposure to a self-selected fatigue, could elicit muscular fatigue without a secondary frequency analysis. Although muscular fatigue was not observed in this study, it remains an important issue to be included and considered for future research.

7.1 Future Directions

Future directions include continuing to further analyze the EMG data for co-contraction of muscles and assess muscle activation timing. Examining co-contraction would allow for a better understanding of when muscles are firing (at contact during the swing, etc.), the duration the participant fires their muscles for (having high muscle activation has been proven to be harmful; Moreside *et al.*, 2007), and finally the sequencing of the participants muscle activation (as one muscle turns off another turns on). Looking further into the timing of muscle activation will allow for a better understanding of the mechanistic properties going on in the body during certain parts of the swing. For example, defining what muscles are active at impact with the ball, and what the spine segment angles are, could give further information to predicting future injury. It is also known that when the spine is moving at a high velocity in a non-neutral position it can lead to injury (Marras and Granata, 1995). But perhaps the most meaningful future direction would be following up with these participants to see if they have ever experienced LBP, and if the PD have a higher incidence of injury in comparison to the NPD. Following these participants and

performing the same study as a follow-up could allow for a better understanding of transient PD over time. It will also allow for identification of the participants (PD or NPD) who do develop injuries. In addition to quantifying injury incidence, having performance and fitness levels of these participants would also allow for a better understanding of the differences between NPD and PD and guide future research directions.

7.2 Limitations

A notable observation is that although the participants are an elite group of experts who perform these axial twists more frequently than the average population, it is possible that some participants are exposed to more axial twists in their everyday life than others are. The difference in amount of axial twists could mean they have mastered and adapted a movement pattern that protects them from injury, or it could result in overuse injuries that could have resulted in a higher VAS rating.

Performing MVC tasks to normalize EMG is a standard practice; however, the test is subjected to its own limitations and drawbacks. A concern when performing MVC tasks it is always a concern whether the participant is performing a true maximal contraction. The motivation of the subject could be low to perform MVC tasks, the fear of pain or being uncomfortable, and the small risk of injury are all reasons why someone would not complete the task to his or her maximum which would give a false MVC tasks and the results would be skewed higher.

Even though the BORG scale ratings, the questionnaire data and the VAS scores were validated and deemed reliable for measuring the desired outcome, they are still self-reported measures. Self-reported measures although very useful and in most cases great for real time feedback, they are subjective. Self-reported measures in this study have relied on honesty of the

participant, introspective ability, understanding of the question being asked of them, and finally having a response bias.

During the original protocol, collection of real time HR data was included. The Polar M400 HR watch and blue tooth monitor was used during all collections, however, the strap on the participant had multiple issues. The suspected problems were due to the strap buckling or losing contact with the participants skin. Although the strap was tightened and fixed underneath the sports bra of the participant, HR data was still lost because the strap lost contact with the skin from buckling. Another problem arose as the participant began to sweat profusely. Which made the strap lose contact with the skin and did not allow for a constant reading of HR data. The disfunction in the HR monitor resulted in full HR data for only 30% of the participants. Having some HR data did allow for a quality check of the method used in data processing to obtain HR data after the fact (explained further in Section 5.6). For example, using the visual counting method of HR a participants HR data was calculated at 183bpm, while the HR monitor calculated a HR of 185bpm.

Further to the visual counting HR method, HR was only obtainable in periods of quite muscle activation as explained in a study performed by Drake and Callaghan (2005). Since there were only brief moments of limited muscle activation during the repetitive dynamic axial twisting exposure, there was a very small window in which HR data could be assessed. Which could lead to a misrepresentation of HR. To avoid this, multiple muscles were assessed during the moment of lower muscle activation in order to evaluate the most consistent HR. As explained above, the HR method used in this thesis was also matched with the minimal HR data from the Polar M400 HR monitor during the protocol and similar HR were displayed in both methods.

8 Hypotheses Revisited

1. Participants who are PD will have a larger twist, flexion, and lateral bend angles in the spine while:
    a) Performing the repetitive dynamic axial twisting task. - Rejected
    b) Performing the pre/post-ROM tasks. – Rejected

Hypothesis 1: PD had a decrease in mean kinematic angles (L/R axial twist, flexion and extension, and L/R lateral bend) in comparison to the NPD during the repetitive dynamic axial twisting exposure. However, during repetitive dynamic axial twisting same exposure, both the PD and NPD reached the same maximum angles (L/R axial twist, flexion and extension, and L/R lateral bend) in all phases (start, middle, end) of the task. In all ROM tests, except upright stand, the PD had lower maximum end ROM spine angles than the NPD. During the upright stand trials, PD stood with more lateral bend in the lower thoracic spine segment than the NPD. Although these hypotheses were rejected, the findings of the thesis raise concerns about how the PD are repeatedly able to obtain the same maximal angles as their NPD counterparts during dynamic testing, but demonstrate much lower maximum spine angles during the ROM tests that were performed to their self-selected maximum (L/R axial twist, flexion and extension, and L/R lateral bend). Therefore, the hypotheses that PD would be associated with greater spine angles were rejected, but the observed disconnect in mechanics of the PD may be contributing to a potential pain pathway of twisting exposure.

2. Participants who are PD will have a higher mean and max muscle activation while:
    a) Performing the repetitive dynamic axial twisting task. – Rejected
    b) Performing the pre/post-ROM tasks. – Rejected

Hypothesis 2: The PD had lower mean and mean maximum %MVC in the trunk and pelvis muscles throughout the repetitive dynamic axial twisting exposure. While these findings may be logical given the lower mean kinematic angles also observed for PD, they are not congruent with PD and NPD having similar maximum kinematic angles reached during the dynamic exposure. The lower EMG levels in the muscles (prime movers) that were collected in this thesis suggest that the PD are using additional muscles to generate the required force to reach the same maximum angles as the NPD during the repetitive dynamic axial twisting task (i.e. deep muscles and/or muscles that move the pelvis that were not measured). It is suspected that the alteration in muscle response imposed higher loading on spine joints (e.g. compression) and altered load distribution between the active and passive tissues (e.g. increased loading on ligaments and IVD), which may have contributed to the increased pain reported by PD. The PD did not likely use additional muscle during the ROM tasks despite having lower maximum %MVC than NPD, since the PD mean kinematic angles were also lower than the NPD. Perhaps the PD and NPD were using a similar movement strategies using prime mover muscles to perform the ROM tasks, but different strategies during the repetitive dynamic axial twisting exposure. If so, it would appear that the dynamic movement strategy used by PD was associated with a pain generating pathway. Therefore, the hypotheses that PD would have higher muscle activation were rejected, but of concern was the evidence of altered muscle responses associated with the development of higher levels of transient pain (PD).

3. Fatigue will increase twist, lateral bend, and flexion angles in the spine segments in all participants regardless of pain group classification while:
    a) Performing the repetitive dynamic axial twisting task. - Rejected
    b) Performing the pre/post-ROM tasks. - Rejected
4. Fatigue will increase the mean and max muscle activation regardless of pain group classification while:
    a) Performing the repetitive dynamic axial twisting task. – Rejected
    b) Performing the pre/post-ROM tasks. – Rejected

Hypothesis 3 and 4: There was no effect of phase (start, middle, and end) on the kinematics or muscle activation during the repetitive dynamic axial twisting exposure and in the post-ROM tasks, suggesting there was no effect of fatigue as measured in this thesis. Despite the participants' continuing the protocol until they could no longer continue, and the HR data indicated they were cardiovascular fatigued, it may be that all of the participants did not reach muscular fatigue or similar levels of muscular fatigue (specifically in the musculature of the trunk and pelvis collected in this thesis). This may have occurred as the measurement of cardiovascular fatigue was used as a surrogate for muscular fatigue (like Gregory et al., 2008), which could have led to inconsistent levels of muscular fatigue between participants despite the protocol termination criteria being met. Or perhaps the participants used different muscles that were not collected to complete the repetitive dynamic axial twisting exposure, and muscular fatigue occurred in these muscles rather than in those collected. An offline frequency analysis of the EMG data may be useful in quantifying whether fatigue occurred (using mean power frequency shifts), but would not have been useful during the collection. It is important to note that the rejection of these hypotheses should not be taken to support that no fatigue occurred, nor

that fatigue is of no consequence in a repetitive dynamic twisting exposure, but that fatigue as measured in this thesis had no impact on the musculoskeletal responses.

9 Conclusion

Despite strong epidemiological and in vitro evidence associating twisting to an increased risk of injury, there remains little to no understanding of the musculoskeletal responses to twisting. Further, it is known that twisting of the spine requires a large recruitment of muscles to work in conjunction (exactly how in dynamic twisting is not well understood), and depending on the activation magnitudes may raise spine compression values to an unsafe level and/or lead to fatigue. Fatigue has been shown to have the potential to increase risk of injury, but again little is known about fatigue from a repetitive dynamic axial twisting exposure. If participants can be grouped NPD and PD, the differences/similarities between pain groups could lead researchers toward a better foundational understanding of the addressed issues. The goal of this thesis was to better understand the musculoskeletal responses to a repetitive dynamic axial twisting exposure when performed to a limit of self-reported fatigue.

After grouping the participants into their appropriate NPD and PD groups, researchers then concluded that both groups performed the same exposure: worked at the same %HR max, performed the same number of axial twists, and the timing of participants axially twisting their trunk was the same. Individuals in both groups did not have any significant differences in their anthropometrics or their questionnaire data which is indicative of participants having similar physical and psychosocial characteristics. Evidence from this exposure displayed the difference in NPD and PD in both the ROM tasks and the repetitive dynamic axial twisting exposure for EMG and kinematics. There was a decrease in muscle activation and a decrease in spine segment angles in the PD during the ROM tasks and the repetitive dynamic axial twisting exposure, yet the PD reached the same maximum spine segment angle as the NPD during the axial twisting exposure. This demonstrates that the PD were using a different muscular and kinematic strategy to perform

the repetitive dynamic axial twisting exposure, a strategy that could be the source of the transient pain development. More research needs to be conducted to better understand the different movement and muscular changes seen in PD to identify the possible mechanisms that lead to LBP/injury.

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2017 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

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

GENERAL HEALTH QUESTIONS

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

If you answered NO to all of the questions above, you are cleared for physical activity.
Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

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

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

Delay becoming more active if:

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

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FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

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

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

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

2. Do you currently have Cancer of any kind?

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

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

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

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

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

4. Do you have High Blood Pressure?

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2017 PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

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

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

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

Delay becoming more active if:

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

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

PARTICIPANT DECLARATION

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

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

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

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01-01-2017

MODIFIED OSWESTRY LOW BACK PAIN DISABILITY INDEX (ODI)

Purpose: The ODI is a disease-specific disability measure is used to establish a level of disability, stage a patient's acuity status[1], and monitor change over time.

Scoring:

1. The ODI is made up of 10 questions. Each question is scored from 0-5 (minimum to maximum).

   EXAMPLE:
   Pain Intensity
   _____The pain is mild and comes and goes. ***(A check at this level is scored as 0)***
   _____The pain is mild and does not vary much. ***(A check at this level is scored as 1)***
   _____The pain is moderate and comes and goes. ***(A check at this level is scored as 2)***
   _____The pain is moderate and does not vary much. ***(A check at this level is scored as 3)***
   _____The pain is severe and comes and goes. ***(A check at this level is scored as 4)***
   _____The pain is severe and does not vary much. ***(A check at this level is scored as 5)***

2. The point total from each section is summed and the then divided by the total number of questions answered and multiplied by 100 to create a percentage disability. The scores range from 0-100% with lower scores meaning less disability.

   ODI = (Sum of items scored/Sum of sections answered) X 100

3. Typically all items are filled out so you can just add up the score from each section and double it to get the final percentage score.

Measurement Characteristics: The measurement characteristics of the ODI are good to excellent. Test-Retest ICC (2,1) 0.83 - 0.94 (1-14 days)[2] and 0.90 over 4 weeks in a group of patients judged stable.[3] The minimal clinically important difference for the Oswestry is 8 – 12 percentage points.[2]

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MODIFIED OSWESTRY LOW BACK PAIN DISABILITY QUESTIONNAIRE[1]

Section 1: To be completed by patient

Name:_____ Age:_____ Date:_____

Occupation:_____ Number of days of back pain:_____(this episode)

Section 2: To be completed by patient

This questionnaire has been designed to give your therapist information as to how your back pain has affected your ability to manage in every day life. Please answer every question by placing a mark on the line that best describes your condition today. We realize you may feel that two of the statements may describe your condition, but **please mark only the line which most closely describes your current condition**.

Pain Intensity

_____The pain is mild and comes and goes.
_____The pain is mild and does not vary much.
_____The pain is moderate and comes and goes.
_____The pain is moderate and does not vary much.
_____The pain is severe and comes and goes.
_____The pain is severe and does not vary much.

Personal Care (Washing, Dressing, etc.)

_____I do not have to change the way I wash and dress myself to avoid pain.
_____I do not normally change the way I wash or dress myself even though it causes some pain.
_____Washing and dressing increases my pain, but I can do it without changing my way of doing it.
_____Washing and dressing increases my pain, and I find it necessary to change the way I do it.
_____Because of my pain I am partially unable to wash and dress without help.
_____Because of my pain I am completely unable to wash or dress without help.

Lifting

_____I can lift heavy weights without increased pain.
_____I can lift heavy weights but it causes increased pain
_____Pain prevents me from lifting heavy weights off of the floor, but I can manage if they are conveniently positioned (ex. on a table, etc.).
_____Pain prevents me from lifting heavy weights off of the floor, but I can manage light to medium weights if they are conveniently positioned.
_____I can lift only very light weights.
_____I can not lift or carry anything at all.

Walking

_____I have no pain when walking.
_____I have pain when walking, but I can still walk my required normal distances.
_____Pain prevents me from walking long distances.
_____Pain prevents me from walking intermediate distances.
_____Pain prevents me from walking even short distances.
_____Pain prevents me from walking at all.

Sitting

_____Sitting does not cause me any pain.
_____I can only sit as long as I like providing that I have my choice of seating surfaces.
_____Pain prevents me from sitting for more than 1 hour.
_____Pain prevents me from sitting for more than 1/2 hour.
_____Pain prevents me from sitting for more than 10 minutes.
_____Pain prevents me from sitting at all.

Section 2 (con't): To be completed by patient

Standing

_____I can stand as long as I want without increased pain.
_____I can stand as long as I want but my pain increases with time.
_____Pain prevents me from standing more than 1 hour.
_____Pain prevents me from standing more than 1/2 hour.
_____Pain prevents me from standing more than 10 minutes.
_____I avoid standing because it increases my pain right away.

Sleeping

_____I get no pain when I am in bed.
_____I get pain in bed, but it does not prevent me from sleeping well.
_____Because of my pain, my sleep is only 3/4 of my normal amount.
_____Because of my pain, my sleep is only 1/2 of my normal amount.
_____Because of my pain, my sleep is only 1/4 of my normal amount.
_____Pain prevents me from sleeping at all.

Social Life

_____My social life is normal and does not increase my pain.
_____My social life is normal, but it increases my level of pain.
_____Pain prevents me from participating in more energetic activities (ex. sports, dancing, etc.)
_____Pain prevents me from going out very often.
_____Pain has restricted my social life to my home.
_____I have hardly any social life because of my pain.

Traveling

_____I get no increased pain when traveling.
_____I get some pain while traveling, but none of my usual forms of travel make it any worse.
_____I get increased pain while traveling, but it does not cause me to seek alternative forms of travel.
_____I get increased pain while traveling which causes me to seek alternative forms of travel.
_____My pain restricts all forms of travel except that which is done while I am lying down.
_____My pain restricts all forms of travel.

Employment/Homemaking

_____My normal job/homemaking activities do not cause pain.
_____My normal job/homemaking activities increase my pain, but I can still perform all that is required of me.
_____I can perform most of my job/homemaking duties, but pain prevents me from performing more physically stressful activities (ex. lifting, vacuuming)
_____Pain prevents me from doing anything but light duties.
_____Pain prevents me from doing even light duties.
_____Pain prevents me from performing any job or homemaking chores.

Section 3: To be completed by physical therapist/provider

SCORE: **Initial_____%** **Subsequent_____%** **Subsequent_____%** **Discharge_____%**

Number of treatment sessions:_____

Diagnosis/ICD-9 Code:_____

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

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

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective.* Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

   ☐ Yes

   ☐ No → ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

   _____ **days per week**

   ☐ No vigorous job-related physical activity → ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

   _____ **hours per day**
   _____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

   _____ **days per week**

   ☐ No moderate job-related physical activity → ***Skip to question 6***

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**
_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No bicycling from place to place → ***Skip to question 12***

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

_____ **hours per day**
_____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days **walking** from place to place?

_____ **hours per day**
_____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
_____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐ No vigorous activity in leisure time → ***Skip to question 24***

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

_____ **hours per day**
_____ **minutes per day**

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

_____ **days per week**

☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?
_____ **hours per day**
_____ **minutes per day**

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

_____ **hours per day**
_____ **minutes per day**

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

_____ **hours per day**
_____ **minutes per day**

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

Code: _____

Study Questionnaire

We are interested to know about how you feel regarding your self-esteem, body, pain attitudes and beliefs, and exercise/activity. Please answer all of the questions honestly and return this package to the researcher. The information you provide will not be shared and will remain completely anonymous.

Rosenberg Self-esteem Scale (Rosenberg, 1979) **Section I:** Please circle ONE of the answers below which best represents how you feel.	Strongly Disagree	Disagree	Agree	Strongly Agree
1. On the whole, I am satisfied with myself.	SD	D	A	SA
2. At times I think I am no good at all.	SD	D	A	SA
3. I feel that I have a number of good qualities.	SD	D	A	SA
4. I am able to do things as well as most other people.	SD	D	A	SA
5. I feel I do not have much to be proud of.	SD	D	A	SA
6. I certainly feel useless at times.	SD	D	A	SA
7. I feel that I am a person of worth, at least on an equal plane with others.	SD	D	A	SA
8. I wish I could have more respect for myself.	SD	D	A	SA
9. All in all, I am inclined to feel that I am a failure.	SD	D	A	SA
10. I take a positive attitude toward myself.	SD	D	A	SA

Social Physique Anxiety Scale (Hart, Leary & Rejeski, 1989) **Section II:** Please circle ONE of the answers below which best represents how you feel. 1 = Not at all characteristic of me 2 = Slightly characteristic of me 3 = Moderately characteristic of me 4 = Very characteristic of me 5 = Extremely characteristic of me	Not at all characteristic of me	Slightly characteristic of me	Moderately characteristic of me	Very characteristic of me	Extremely characteristic of me
11. I am comfortable with the appearance of my physique or figure.	1	2	3	4	5
12. I would never worry about wearing clothes that might make me look too thin or overweight.	1	2	3	4	5
13. I wish I wasn't so up-tight about my physique or figure.	1	2	3	4	5
14. There are times when I am bothered by thoughts that other people are evaluating my weight or muscular development negatively.	1	2	3	4	5
15. When I look in the mirror I feel good about my physique or figure.	1	2	3	4	5
16. Unattractive features of my physique or figure make me nervous in certain social settings.	1	2	3	4	5
17. In the presence of others, I feel apprehensive about my physique or figure.	1	2	3	4	5
18. I am comfortable with how fit my body appears to others.	1	2	3	4	5
19. It would make me uncomfortable to know others were evaluating my physique or figure.	1	2	3	4	5
20. When it comes to displaying my physique or figure to others, I am a shy person.	1	2	3	4	5
21. I usually feel relaxed when it's obvious that others are looking at my physique or figure.	1	2	3	4	5
22. When in a bathing suit, I often feel nervous about how well proportioned my body is.	1	2	3	4	5

Body Shape Questionnaire (Cooper et al., 1987) **Section III:** Please circle ONE of the answers below which best represents how you feel. 1. Never 2. Rarely 3. Sometimes 4. Often 5. Very Often 6. Always	Never	Rarely	Sometimes	Often	Very Often	Always
23. Has feeling bored made you brood about your shape?	1	2	3	4	5	6
24. Have you been so worried about your shape that you have been feeling you ought to diet?	1	2	3	4	5	6
25. Have you thought that your thighs, hips or bottom are too large for the rest of you?	1	2	3	4	5	6
26. Have you been afraid that you might become fat (or fatter)?	1	2	3	4	5	6
27. Have you worried about your flesh being not firm enough?	1	2	3	4	5	6
28. Has feeling full (e.g. after eating a large meal) made you feel fat?	1	2	3	4	5	6
29. Have you felt so bad about your shape that you have cried?	1	2	3	4	5	6
30. Have you avoided running because your flesh might wobble?	1	2	3	4	5	6
31. Has being with thin individuals made you feel self-conscious about your shape?	1	2	3	4	5	6
32. Have you worried about your thighs spreading out when sitting down?	1	2	3	4	5	6
33. Has eating even a small amount of food made you feel fat?	1	2	3	4	5	6
34. Have you noticed the shape of other people and felt that your own shape compared unfavourably?	1	2	3	4	5	6

Please circle ONE of the answers below which best represents how you feel. 1. Never 2. Rarely 3. Sometimes 4. Often 5. Very Often 6. Always	Never	Rarely	Sometimes	Often	Very Often	Always
35. Has thinking about your shape interfered with your ability to concentrate (e.g. while watching television, reading, listening to conversations)?	1	2	3	4	5	6
36. Has being naked, such as when taking a bath, made you feel fat?	1	2	3	4	5	6
37. Have you avoided wearing clothes which make you particularly aware of the shape of your body?	1	2	3	4	5	6
38. Have you imagined cutting off fleshy areas of your body?	1	2	3	4	5	6
39. Has eating sweets, cakes, or higher calorie food made you feel fat?	1	2	3	4	5	6
40. Have you not gone out to social occasions (e.g. parties) because you have felt bad about your shape?	1	2	3	4	5	6
41. Have you felt excessively large and round?	1	2	3	4	5	6
42. Have you felt ashamed of your body?	1	2	3	4	5	6
43. Has worry about your shape made you diet?	1	2	3	4	5	6
44. Have you felt happiest about your shape when your stomach has been empty (e.g. in the morning)?	1	2	3	4	5	6
45. Have you thought that you are in the shape you are because you lack self-control?	1	2	3	4	5	6
46. Have you worries about other people seeing rolls of fat around your waist or stomach?	1	2	3	4	5	6
47. Have you felt that it is not fair that other women are thinner than you?	1	2	3	4	5	6

Please circle ONE of the answers below which best represents how you feel. 1. Never 2. Rarely 3. Sometimes 4. Often 5. Very Often 6. Always	Never	Rarely	Sometimes	Often	Very Often	Always
48. Have you vomited in order to feel thinner?	1	2	3	4	5	6
49. When in company have you worried about taking up too much room (e.g. sitting on a sofa, or bus seat)?	1	2	3	4	5	6
50. Have you worried about you flesh being dimply?	1	2	3	4	5	6
51. Has seeing your reflection (e.g. in a mirror or shop window) made you feel bad about your shape?	1	2	3	4	5	6
52. Have you pinched areas of your body to see how much fat there is?	1	2	3	4	5	6
53. Have you avoided situations where people could see your body (e.g. communal changing rooms or swimming baths)?	1	2	3	4	5	6
54. Have you taken laxatives in order to feel thinner?	1	2	3	4	5	6
55. Have you been particularly self-conscious about your shape when in the company of people?	1	2	3	4	5	6
56. Has worry about your shape made you feel you ought to exercise?	1	2	3	4	5	6

Newly Developed Breast/Chest Specific Questions **Section IV:** Please circle ONE of the answers below which best represents how you feel. 1. Never 2. Rarely 3. Sometimes 4. Often 5. Very Often 6. Always	Never	Rarely	Sometimes	Often	Very Often	Always
57. Individuals with smaller breasts/chest than me make me feel jealous.	1	2	3	4	5	6
58. Getting breast/chest reduction surgery is something that I think about.	1	2	3	4	5	6
59. Have you hunched forward in order to feel comfortable while sitting for a long time due to your breasts/chest?	1	2	3	4	5	6
60. I feel that the size of my breasts/chest impact my ability to exercise.	1	2	3	4	5	6
61. I think my chest/breasts is/are too small.	1	2	3	4	5	6
62. I am embarrassed of my breasts/chest, so I slouch in order to hide them.	1	2	3	4	5	6
63. Has being with people who have bigger breasts/chest that yours made you feel self-conscious about your breasts/chest?	1	2	3	4	5	6
64. While standing or walking for a long time, I hunch forward in order to feel comfortable because of my breasts/chest.	1	2	3	4	5	6
65. I wear certain clothes to bring attention to my breasts/chest.	1	2	3	4	5	6
66. I think about getting breast/chest augmentation surgery.	1	2	3	4	5	6
67. I often feel jealous of individuals who have larger breasts/chest than me.	1	2	3	4	5	6
68. I think that my chest/breasts is/are too large.	1	2	3	4	5	6

Please circle ONE of the answers below which best represents how you feel. 1. Never 2. Rarely 3. Sometimes 4. Often 5. Very Often 6. Always	Never	Rarely	Sometimes	Often	Very Often	Always
69. Have you worn certain clothes in order to hide your breasts/chest?	1	2	3	4	5	6
70. Has being with people who have smaller breasts/chest than yours have made you feel self-conscious about my breasts/chest?	1	2	3	4	5	6
71. Have you hunched forward in order to feel comfortable while standing or walking for a long time due to you breasts/chest?	1	2	3	4	5	6
72. Have you felt frustrated with the size of your breasts/chest?	1	2	3	4	5	6
73. My breast/chest size impacts my confidence to exercise.	1	2	3	4	5	6

Pain Attitude and Beliefs Questionnaire
(Questions from the Cognitive Risk Profile for Pain –CRPP)

Section V: Please circle ONE of the answers below which best represents how you feel.

1. Strongly Agree
2. Moderately Agree
3. Slightly Agree
4. Slightly Disagree
5. Moderately Disagree
6. Strongly Disagree

Strongly Agree	Moderately Agree	Slightly Agree	Slightly Disagree	Moderately Disagree	Strongly Disagree	Please rate your level of agreement with the following statements.
1	2	3	4	5	6	Feeling angry can increase my pain.
1	2	3	4	5	6	Pain can put me in a bad mood.
1	2	3	4	5	6	Exercise can help to manage pain.
1	2	3	4	5	6	My life should be pain free.
1	2	3	4	5	6	Worry can increase the pain that I feel.
1	2	3	4	5	6	My attitude and the way I think are an important part of how to manage my pain.
1	2	3	4	5	6	Stress in my life can make my pain feel worse.
1	2	3	4	5	6	Pain can make me feel depressed.

Pain Attitude and Beliefs Questionnaire
(Questions from the Survey of Pain Attitudes – Brief, SOPA-b)

Section V: Please circle ONE of the answers below which best represents how you feel.

0. Very Untrue
1. Somewhat Untrue
2. Neither True nor Untrue /or Does Not Apply
3. Somewhat True
4. Very True

Please rate your level of agreement with the following statements.	Very Untrue	Somewhat Untrue	Neither True nor Untrue /or Does Not Apply	Somewhat True	Very True
There are many times when I can influence the amount of pain I feel.	0	1	2	3	4
When I hurt, I want my family to treat me better.	0	1	2	3	4
Anxiety increases the pain I feel.	0	1	2	3	4
When I am hurting, people should treat me with care and concern.	0	1	2	3	4
It is the responsibility of my loved ones to help me when I feel pain.	0	1	2	3	4
Exercise and movement are good for a pain problem.	0	1	2	3	4
Just by concentrating or relaxing, I can 'take the edge' off my pain.	0	1	2	3	4
Medicine is one of the best treatments for chronic pain.	0	1	2	3	4
Depression increases the pain I feel.	0	1	2	3	4
If I exercise, I could make my pain problem much worse.	0	1	2	3	4
I believe that I can control how much pain I feel by changing my thoughts.	0	1	2	3	4

Section V: Please circle ONE of the answers below which best represents how you feel.

0. Very Untrue
1. Somewhat Untrue
2. Neither True nor Untrue /or Does Not Apply
3. Somewhat True
4. Very True

Often I need more tender loving care than I am now getting when I am in pain.	0	1	2	3	4
There is a strong connection between my emotions and my pain level.	0	1	2	3	4

Pain Attitude and Beliefs Questionnaire
(Questions from the Fear Avoidance Beliefs Questionnaire (FABQ)

Section V: Please circle ONE of the answers below which best represents how you feel.

0. Completely Disagree
1. Moderately Disagree
2. Slightly Disagree
3. Unsure
4. Slightly Agree
5. Moderately Agree
6. Completely Agree

Please rate your level of agreement with the following statements.	Completely Disagree	Moderately Disagree	Slightly Disagree	Unsure	Slightly Agree	Moderately Agree	Completely Agree
Physical activity might harm my back.	0	1	2	3	4	5	6
I should not do physical activities that (might) make my pain worse.	0	1	2	3	4	5	6
My work is too heavy for me.	0	1	2	3	4	5	6
My work might harm my back.	0	1	2	3	4	5	6

Custom Softball Study Questionnaire Form

GENERAL INFORMATION

1. Do you perform any lifting, bending or twisting while you participating activities of daily living (work, school, hobbies, etc.)? If so, please explain: Y or N

_____

On a scale of 1-10, how physically demanding do you find participating in softball? _____
(1 = Not Demanding; 10 = Most Demanding)

2. How long have you participated in the sport of softball and at what level (list all levels and years that apply)?

_____

3. Have you ever missed time from softball for any injury? If yes, list injury and time away from practice/games. Y or N

_____

4. What element of the sport softball causes you the most pain or discomfort (swinging, fielding, practice, game, etc.)? Where is that pain or discomfort (ankle, shoulder, back, etc.)?

_____

BACK PAIN QUESTIONS

5. Have you ever experienced lower back pain due to injury? Y or N

If "Y", was this caused by playing softball? Y or N

If "Y", did you seek medical care? Y or N

If "Y", how long ago did the most recent injury occur? _____

6. Did your low back pain interfere with your ability to play softball? Y or N

If "Y", did you have to be accommodated? Y or N

If "Y", what was the accommodation? _____

If "Y", how long were you not participating fully? _____

7. If any, what element of softball causes you back pain (swinging, throwing, etc.)?

_____

8. After a practice or game, have you ever experienced back pain that impacted your activities of daily living for the following day/days?

_____

SITTING

10. During an average day, how much time do you spend
sitting at a desk or a computer? _____ total hrs (cumulative)

11. When sitting at your desk or computer how long do you sit continuously for (How long do you sit for without standing up)? _____ hours (1 bout)

12. Do you adjust the chair's seat height, seat angle, backrest angle, and/or arm rests? (Circle the best answer.)

[ ] Always [ ] Most of the Time [ ] Sometimes [ ] Rarely [ ] Never

STANDING

13. During an average day, how much time do you spend **standing still** at work?
_____ total hours (cumulative)

14. During one bout of standing, what's the longest amount of time that you stand continuously for? (How long do you stand in one position for without moving)? _____ hours

15. Do you bend over to complete desk or computer work while standing at a seated work station?

[ ] Always [ ] Most of the Time [ ] Sometimes [ ] Rarely [ ] Never

16. Do you complete desk or computer work while standing at a standing work station?

[ ] Always [ ] Most of the Time [ ] Sometimes [ ] Rarely [ ] Never

Thank you for your time.