THE EFFECTS OF THE LUMBOPELVIC MANIPULATION ON THE FATIGABILITY OF THE BACK AND HIP MUSCLES IN ADULTS WITH CHRONIC LOW BACK PAIN

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DEDICATION

To my lovely parents, Abdulgani and Wedad, who provided me with the motivation and encouragement to start this project.

To my brother and my sisters for all their support and for being by my side through this journey.

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ABSTRACT

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THE EFFECTS OF LUMBOPELVIC MANIPULATION ON THE FATIGABILITY OF THE BACK AND HIP MUSCLES IN ADULTS WITH CHRONIC BACK PAIN

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Patients with chronic low back pain (CLBP) have been shown to have increased fatigability levels of hip and low back muscles as measured by the surface electromyographic (EMG) median frequency (MF). In addition, literature suggests that lumbopelvic manipulation could be an effective intervention for reducing CLBP. However, the effects of lumbopelvic manipulation on lumbar or hip muscle fatigability have not been studied previously. The purposes of the study were to examine the immediate and short-term effects of a single lumbopelvic manipulation on the muscle fatigability level of the lumbar multifidus (MULT), gluteus maximus (GMAX), and gluteus medius (GMED) muscles in addition to the pain level as compared to a placebo intervention in patients with CLBP. Thirty-one participants with CLBP, 30.2 ±10.1 years of age, completed the immediate effect part of the study, and 27 participants, 29.9 ±8.1years of age, completed the short-term effect part of the study. Three EMG electrodes were placed on the painful side of the MULT, GMAX, and GMED muscles. For the immediate effect part of the study, EMG was collected during the modified Biering-Sorensen test five times: before the intervention, and immediately, 15 min, 30 min, and 45 min after the intervention. After the baseline EMG recording, each participant was randomized into one of two intervention groups: manipulation and placebo. Participants in the manipulation group received a high-velocity low amplitude

lumbopelvic manipulation. Participants in the placebo group were set up in a position for the lumbopelvic manipulation, but did not receive a thrust. For the short-term effects part of the study, EMG of the three muscles were recorded during the modified Biering-Sorensen test 3 days and 1 week after the intervention. In addition, pain level was collected at all seven time points. There was no significant difference in the fatigability level of the three muscles between groups before and at four time points after the intervention. However, the manipulation group had a significant reduction in pain as compared to the placebo group between 15 and 30 min after the intervention ($p = 0.032$). In addition, there was no significant difference between groups on fatigability level of the three muscles three days and one week after intervention. Both groups had significant pain reduction three days ($p = 0.019$) and one week ($p < 0.001$) after the intervention.

Although manual intervention had a positive effect on pain reduction, it did not alter the fatigability level of the back and hip muscles. Manual intervention can be a useful treatment approach to decrease pain in patients with CLBP. However, clinicians may consider other treatment options when the goal is to improve fatigability of the back and hip muscles for this patient population.

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CHAPTER I

INTRODUCTION

Low back pain (LBP) is considered to be the second most prevalent cause of disability among adults in the United States after arthritis and rheumatism (Centers for Disease Control and Prevention [CDC], 2001). It has been reported that approximately 80% of the general population suffers from LBP at least once in their lives (Andersson, 1998). About 90% of all patients with LBP have non-specific LBP, which may take up to a few months to subside in most cases, and up to 85% of working adults who had a previous episode of LBP reportedly had a subsequent episode of LBP (Anderson, 1999; van Tulder, Koes, & Bombardier, 2002). Although most patients stop consulting their health care practitioner about their LBP within three months of the onset of pain, the majority of patients will develop chronic low back pain (CLBP) and will experience disability up to 12 months after the initial episode (Croft, Macfarlane, Papageorgiou, Thomas, & Silman, 1998).

CLBP has been associated with decreased endurance and increased fatigability of back muscles (Hultman, Nordin, Saraste, & Ohlsèn, 1993; Pääsuke, Johanson, Proosa, Ereline, & Gapeyeva, 2002). Adults with CLBP reportedly have shorter endurance time than adults with intermittent LBP and adults without LBP (Hultman et al., 1993). In addition, patients with CLBP were found to have increased fatigability levels of both spinal and hip muscles as measured by the electromyographic (EMG) median frequency

(Pääsuke et al., 2002; Roy, De Luca, & Casavant, 1989; Sung, Lammers, & Danial, 2009). Roy et al. (1989) found increased fatigability of three lumbar spinal muscles in participants with CLBP during sustained isometric back extensions. In this study, the fatigability of the longissimus thoracis muscle at L1, the iliocostalis lumborum muscle at L2 and the lumbar multifidus (MULT) at L5 was examined using EMG median frequency. The results of the study showed that the MULT muscle at L5 and the iliocostalis lumborum muscle at L2 had significantly higher fatigue rate in participants with CLBP than in healthy participants (Roy et al., 1989). Using EMG frequency, Pääsuke et al. (2002) also found that participants with CLBP had higher fatigability of lumbar paraspinal muscles at L3 during the Sørensen test than healthy age- and gender-matched controls ($p < 0.05$). In addition, the endurance time was significantly shorter in patients with CLBP than in healthy controls ($p < 0.05$; Pääsuke et al., 2002).

Increased fatigability also was found in the thoracic extensor muscles in patients with CLBP (Sung et al., 2009). Sung, Lammers, and Danial (2009) compared the fatigability levels of bilateral longissimus thoracic muscles between healthy participants and participants with recurrent LBP. The authors found significantly higher fatigability of thoracic paraspinal muscles in patients with CLBP than in the healthy controls ($p = 0.01$; Sung et al., 2009). Besides paraspinal muscles, the fatigability of hip muscles in the CLBP population has been studied due to the anatomical proximity of the hip to the spine (Kankaanpää, Taimela, Laaksonen, Hänninen, & Airaksinen, 1998). Kankaanpaa, Taimela, et al. (1998) compared the fatigability of the gluteus maximus (GMAX) muscle between patients with CLBP and healthy controls using the EMG median frequency. The

results showed a significantly higher fatigue rate in the GMAX muscle of patients with CLBP than those of the healthy controls ($p < 0.05$; Kankaanpää, Taimela et al., 1998). The above-mentioned studies strongly suggest increased fatigability of both the paraspinal and hip muscles in CLBP.

To date, there are no published studies that have examined the best treatment options to improve the fatigability and endurance of hip muscles in adults with CLBP. However, a few studies have demonstrated the effects of rehabilitation programs and exercise regimens on the fatigability level and endurance of back muscles in patients with CLBP (Henchoz, de Goumoëns, Norberg, Paillex, & So, 2010; Kankaanpää, Taimela, Airaksinen, & Hänninen, 1999; Kofotolis, Vlachopoulos, & Kellis, 2008; Kofotolis & Kellis, 2006). Henchoz et al. (2010) examined the effectiveness of a supervised exercise program on the endurance of trunk flexors and extensors in patients with sub-acute LBP and CLBP. The authors found a significant improvement in the trunk extension endurance time measured by the Sørensen test in those patients who participated in supervised exercises ($p < 0.05$) at 1-year follow up when compared to baseline, whereas no significant improvement was found in the unsupervised group (Henchoz et al., 2010). Kankaanpää et al. (1999) also found the benefits of a 12-week exercise program, which included general stretching exercises, trunk functional exercises, and coordination exercises for improving fatigability in patients with CLBP. Similar to the results found in Henchoz et al.'s study (2010), Kankaanpää et al. (1999) found that the participants in the exercise program had significantly decreased fatigability of the lumbar paraspinal muscles at one-year follow-up ($p < 0.01$), whereas participants in a control group who

received medication, thermal agents, and massage did not show significant improvement in fatigability of these muscles (Kankaanpää et al., 1999). In addition to exercises, proprioceptive neuromuscular facilitation (PNF) techniques have been shown to be effective to improve fatigability for CLBP (Kofotolis & Kellis, 2006). Kofotolis and Kellis (2006) examined the effects of two PNF techniques, rhythmic stabilization training, and combination of isotonic exercises, on the static and dynamic endurance of back extensor muscles for CLBP. The static endurance was determined by asking each participant to hold a modified Sørensen test position as long as they could, while the number of repetitions of trunk extension that each participant could perform determined the dynamic endurance. The results of the study showed that participants with CLBP who received PNF treatment had significantly higher static and dynamic endurance of trunk extensors after receiving PNF training five sessions per week for 4 weeks ($p < 0.05$) than those participants who received instructions to avoid any type of physical exercises or activities other than those for daily living.

Furthermore, manual therapy has been recommended as a treatment strategy for patients with CLBP (Chou et al., 2007). The mechanism of how manual therapy decreases pain and improves physical function is not well known. One theory is that manual therapy produces mechanical stimuli that could alter the neurophysiologic functions of the central and peripheral nervous systems (Bialosky, Bishop, Price, Robinson, & George, 2009). Further, manual therapy may reset the function of the muscle spindles and increase the functionality of the proprioceptors, which could restore normal neuromuscular functions (Bialosky et al., 2009; Goss et al., 2012).

Various manual therapy techniques have been described for the treatment of LBP. One of the techniques used frequently by clinicians is the lumbopelvic manipulation described in Flynn et al.'s study (2002). This lumbopelvic manipulation has been shown to produce favorable results when it is used for patients with acute LBP. Childs et al. (2003) developed a clinical prediction rule for using this lumbopelvic manipulation in patients with acute LBP. Having symptoms for less than 16 days was one of the criteria that may predict positive results when using this lumbopelvic manipulation for patients with CLBP (Childs et al., 2004; Flynn et al., 2002). However, more recently, this manipulation technique has been shown to produce positive outcomes when it is used for patients with non-specific CLBP. Patients with CLBP treated with multiple lumbopelvic manipulations have demonstrated improvement in disability level and pain level when compared to a control group (Senna & Machaly, 2011). Further, in a case study of a patient with CLBP for 21 years, the percent change of MULT muscle thickness from rest to contraction significantly increased immediately after the application of lumbopelvic manipulation as well as one day after the application of the manipulation. These results indicate that lumbopelvic manipulation might alter the activation of the MULT muscle in this patient population (Brenner, Gill, Buscema, & Kiesel, 2007).

Statement of the Problem

Evidence has shown that back and hip muscle activity is altered in patients with CLBP, particularly the fatigability of lumbar paraspinal muscles and the GMAX muscle (Kankaanpää, Taimela et al., 1998; Pääsuke et al., 2002; Roy et al., 1989). Moderate

evidence also supports the use of manual therapy, such as lumbopelvic manipulation, for treatment of symptoms in patients with CLBP (Senna & Machaly, 2011). The mechanism of how manual therapy decreases pain and improves the functional level in this population is not clear. As discussed earlier, manual therapy could induce a mechanical stimulus that may alter the neurophysiological functions of the nervous system and improve the neuromuscular functions via restoring normal muscle spindles function (Bialosky et al., 2009; Goss et al., 2012). As manual therapy can have a positive impact on neuromuscular functions, we speculate that manual therapy may have an effect on the fatigability of back and hip muscles in patients with CLBP. However, no studies yet have examined the effect of lumbopelvic manipulation on back and hip muscle fatigability in patients with CLBP. Further, we are not certain if these changes can be maintained over time.

Purpose of the Study

This study had two phases, Phase I and II. The primary purpose of Phase I of this study was to examine the immediate carry-over effects of lumbopelvic manipulation on muscle fatigability level of the MULT, GMAX, and gluteus medius (GMED) muscles as compared to a placebo intervention in patients with CLBP. The secondary purpose of Phase I of this study was to examine the immediate effects of lumbopelvic manipulation on pain level as measured by the Visual Analogue Scale (VAS) as compared to a placebo intervention in patients with CLBP.

The primary purpose of Phase II of this study was to examine the short-term carry-over effects of lumbopelvic manipulation on muscle fatigability level of the bilateral

MULT, GMAX, and GMED muscles compared to a placebo intervention in patients with CLBP. The secondary purpose of Phase II of this study was to examine the short-term carry-over effects of lumbopelvic manipulation on pain level as measured by the VAS as compared to a placebo intervention in patients with CLBP.

Research Questions

The research questions for Phase I of this study were:

1. Would participants with CLBP who receive lumbopelvic manipulation have a decrease in the fatigability level of the MULT, GMAX, and GMED muscles more than those who receive a placebo intervention immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention?
2. Would all participants with CLBP have a significant decrease in the fatigability level of the MULT, GMAX and GMED muscles immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention?
3. Would participants with CLBP who receive lumbopelvic manipulation have a greater reduction in pain level than those who receive a placebo intervention immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention?
4. Would all participants with CLBP have a significant decrease in pain level immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention?

The research questions for Phase II of this study were:

1. Would participants with CLBP who received lumbopelvic manipulation have a decrease in the fatigability level of the MULT, GMAX, and GMED muscles

more than those who receive a placebo intervention three days and one week after the intervention?

2. Would all participants with CLBP have a significant decrease in the fatigability level of the MULT, GMAX and GMED muscles three days and one week after the intervention?
3. Would participants with CLBP who receive lumbopelvic manipulation have a greater reduction in pain level than those who receive a placebo intervention three days and one week after the intervention?
4. Would all participants with CLBP have a significant decrease in pain level three days and one week after the intervention?

Hypotheses

Research Hypotheses

The research hypotheses for Phase I of this study were:

1. Participants with CLBP who receive lumbopelvic manipulation would demonstrate a decrease in the fatigability level of the MULT, GMAX, and GMED muscles more than those who receive a placebo intervention immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.
2. All participants with CLBP would demonstrate a significant decrease in the fatigability level of the MULT, GMAX and GMED muscles immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.
3. Participants with CLBP who receive lumbopelvic manipulation would demonstrate a greater reduction in pain level than those who receive a

placebo intervention immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.

4. All participants with CLBP would demonstrate a significant decrease in pain level immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.

The research hypotheses for Phase II of this study were:

1. Participants with CLBP who receive lumbopelvic manipulation would demonstrate a decrease in the fatigability level of the MULT, GMAX, and GMED muscles more than those who receive a placebo intervention three days and one week after the intervention.
2. All participants with CLBP would demonstrate a significant decrease in the fatigability level of the MULT, GMAX, and GMED muscles three days and one week after the intervention.
3. Participants with CLBP who receive lumbopelvic manipulation would demonstrate a greater reduction in pain level than those who receive a placebo intervention three days and one week after the intervention.
4. All participants with CLBP would demonstrate a significant decrease in pain level three days and one week after the intervention.

Null Hypotheses

The null hypotheses for Phase I of this study were:

1. There would be no significant differences in the fatigability level of the MULT, GMAX, and GMED between participants with CLBP who receive

lumbopelvic manipulation and those who receive a placebo intervention immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.

2. There would be no significant difference in the fatigability level of the MULT, GMAX, and GMED muscles for all participants with CLBP immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.
3. There would be no significant change in pain level between participants with CLBP who receive lumbopelvic manipulation and participants with CLBP who receive a placebo intervention immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.
4. There would be no significant difference in pain level for all participants with CLBP immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.

The null hypotheses for Phase II of this study were:

1. There would be no significant differences in the fatigability level of the MULT, GMAX, and GMED between participants with CLBP who receive lumbopelvic manipulation and those who receive a placebo intervention three days and one week after the intervention.
2. There would be no significant difference in the fatigability level of the MULT, GMAX, and GMED muscles for all participants with CLBP three days and one week after the intervention.
3. There would be no significant change in pain level between participants with CLBP who receive lumbopelvic manipulation and participants with CLBP

who receive a placebo intervention three days and one week after the intervention.

4. There would be no significant difference in pain level for all participants with CLBP three days and one week after the intervention.

Operational Definitions

1. *CLBP*: Participants were considered to have CLBP if they had non-specific LBP of musculoskeletal origin for at least three months at the time of the study due to a single episode or multiple episodes of LBP (Mannion, Taimela, Müntener, & Dvorak, 2001). Clinical tests were performed to ensure that the pain is not due to nerve root compression and confirm non-specific CLBP diagnosis. LBP of non-musculoskeletal origins include tumor, infection, fracture, visceral pathology, or any other serious conditions that are not appropriate for physical therapy.
2. *Fatigability*: Fatigability refers to the fatigue rate for the muscles as measured by the EMG data during a sustained muscle contraction. For this study, the fatigability was calculated for each muscle using the EMG median frequency. The EMG median frequency data was collected during a modified Sørensen test and was normalized to the initial EMG median. The fatigability value was expressed in %/second.
3. *Endurance time*: Endurance is the maximum time a participant could hold a sustained muscle contraction. In this study, the endurance time of a modified Sørensen test was measured by monitoring the maximum time that each participant could maintain the modified Sørensen test position.

4. *EMG median frequency*: The typical EMG signal showed EMG amplitude changes over time (i.e., in the time domain). The EMG signal then was processed using a fast Fourier transformation to plot the EMG amplitude over frequency, thus converting the EMG amplitude to a frequency domain signal (Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008). EMG frequency is the rate of the action potentials picked up by the EMG electrodes per second and measured in hertz (Hz). The EMG median frequency is the frequency value that divides the EMG frequency spectrum into two equal halves Coorevits et al., 2008).

5. *Lumbopelvic manipulation*: The lumbopelvic manipulation performed in this study was a thrust manipulation that was directed to the lumbar spine and the pelvis area as described in Flynn et al.'s study (2002). The primary investigator had two attempts to perform the lumbopelvic manipulation. If a cavitation was heard during the first attempt, the manipulation was considered successful. If a cavitation was not heard during the first attempt, the primary investigator proceeded with the second attempt.

6. *Pain intensity*: Each participant's pain level was recorded using the Visual Analogue Scale (VAS). The VAS consists of a 10-cm line with the left end marked no pain, and the right end marked worst pain ever.

7. *Disability level*: The disability level of each participant was measured by the Modified Oswestry Disability questionnaire (OSW) and the Patient Specific Functional Scale (PSFS). The OSW and PSFS measure the disability level associated with LBP.

8. *Fear-avoidance beliefs*: The level of each participant's fear avoidance beliefs or the fear of performing physical activity that may exacerbate their pain was measured via the Fear-Avoidance Belief Questionnaire (FABQ). The FABQ assesses the fear of pain behavior and how the pain is be affected by physical activity and work.

Assumptions and Limitations

Assumptions

1. The EMG electrodes were placed at their ideal sites to pick up the signal from the target muscles.
2. When the participants returned to the laboratory for the 3-day and the 1-week follow-up sessions, the EMG electrodes were placed at approximately the same locations as the first sessions.
3. The participants made their maximum effort to maintain the testing position as long as they could during the fatigability testing (i.e. the modified Sørensen test).
4. Participants truthfully filled out the VAS, OSW, and FABQ.
5. Participants performed the fatigability testing as instructed.
6. Participants had similar motivation levels and similar psychological statues due to their pain level.

Limitations

1. The duration of symptoms may have been different for each participant. This could have affected the fatigability of the muscles, thus affecting the results of

this study. However, participants were randomly assigned to either a manipulation group or a placebo group.

2. The sample of this study included both men and women. The fatigability may have been different for men than for women. However, participants were randomly assigned either to a manipulation group or to a placebo group.
3. The sample for this study was a sample of convenience. This may limit the generalizability of the results of this study.
4. As the placebo group received a sham manipulation, the sham manipulation could have had a treatment effect on the muscles being studied. This may have altered participants' performance after the intervention. To minimize this effect, participants were blinded to the intervention that the other group received, and participants in both groups spent the same amount of time in the laboratory.
5. The clinical tests that were used in this study to confirm the diagnosis of non-specific CLBP could have had some false positive or false negative results.
6. Participants might not have made a maximum effort to hold the testing position as long as they could when performing the fatigue test (i.e., the modified Sørensen test).
7. Participants might not have had the same level of motivation during the performance of the fatigue test.
8. Participants in both groups could have had different activity levels and disability levels. To determine the activity level, participants were asked to report the

number of hours they spent per week performing structured physical activity. The number of hours was summed and the median was calculated to classify participants to a high-activity group or a low-activity group (Moffroid, 1997). The disability level was determined using the modified OSW.

Significance of the Study

LBP is the second most prevalent cause of disability among adults in the United States after arthritis and rheumatism (CDC, 2001). More than 75% of the patients with LBP will experience CLBP (Croft et al., 1998). An association has been found between CLBP and the increased fatigability of back and hip extensor muscles (De Luca, 1984; Kankaanpää, Taimela et al., 1998).

Although the effectiveness of exercise programs and PNF techniques has been shown to improve back muscles' fatigability in patients with CLBP, no studies have examined the effects of lumbopelvic manipulation on the fatigability of these muscles in this population.

The results of this study might help to understand the underlying mechanism of how lumbopelvic manipulation can improve the health status for patients with CLBP. The results of this study also may shed light on the use of lumbopelvic manipulation for reducing the fatigability level of the back and hip muscles in patients with CLBP and whether these effects can last over a week-period of time after the intervention. The results may help therapists to understand the treatment strategies to optimize lumbopelvic manipulation outcomes for this population.

CHAPTER II

REVIEW OF LITERATURE

The purposes of this chapter are to review the following topics: (1) prevalence and costs of LBP, (2) fatigability of back and hip muscles in CLBP, (3) hypotheses for altered fatigability in LBP, (4) fatigability assessment of back and hip muscles, (5) outcome measures for LBP, (6) interventions to improve muscle fatigability for CLBP, and (7) manual therapy interventions for CLBP.

Prevalence and Costs of LBP

LBP has been recognized as a common health care condition that has a tremendous impact not only on individuals and families, but also on communities, governments and businesses worldwide (Hoy, Brooks, Blyth, & Buchbinder, 2010; Volinn, 1997). In 2001, LBP reportedly was the second most cause of disability among adults in the United States (US) after arthritis and rheumatism (CDC, 2001). According to the results of a National Health interview survey, LBP is the most frequent pain experienced among adults in the US and about one fourth of the adults in the US report LBP within any given 3 months (Deyo, 2006). Approximately 80% of the general population suffers from LBP at least once in their lives (Andersson, 1998). van Tulder, Koes, and Bombardier (2002) reported that approximately 90% of all LBP patients have non-specific LBP, which may take up to a few months to subside in most cases and up to 85% of working adults who had a previous LBP episode reportedly had a subsequent episode of LBP (Anderson, 1999; van Tulder et al., 2002). Although most of the

patients with LBP stop consulting their health care practitioner about their LBP within 3 months of the onset of pain, the majority of patients will still experience LBP recurrences and disability up to 12 months after the initial episode of LBP (Croft et al., 1998). In the working population, up to 44% of patients with LBP will experience recurrent episodes within the first year after the first episode and up to 85% of them will experience recurrences in their lifetime (Anderson, 1999; van Tulder et al., 2002).

The costs for LBP have been estimated at between $100 and $200 billion per year with two thirds of these costs due to decreased wages and productivity (Katz, 2006). Patients with recurrent episodes of LBP accounted for 75% of these costs (Katz, 2006). Back pain is considered to be the most frequent cause of absences from work (Frank et al., 1996; Rubin, 2007). Patients with LBP reportedly tended to request sick leave from their jobs (Frank et al., 1996; van Tulder et al., 2002). About 67% of these patients on sick leave due to LBP returned to work within 2 weeks from the onset of the pain, and 91% of them returned to work within 3 months. Only less than half of the patients who were on sick leave for 6 months return to work. However, when the patients were on sick leave for over two years, they never returned to work (Waddell, 2004). Furthermore, the annual total healthcare costs for patients with LBP were estimated to be 60% higher than the costs for patients without LBP. The annual average health care expenditure for individuals with LBP was estimated to be $3,498 as compared to $2,178 for individuals without LBP (Luo, Pietrobon, Sun, Liu, & Hey, 2004).

Fatigability of Back and Hip Muscles in CLBP

CLBP has been associated with decreased endurance and increased fatigability

of back muscles (Hultman et al., 1993; Pääsuke et al., 2002). Hultman, Nordin, Saraste, and Ohlsèn (1993) examined the endurance time of back muscles in healthy men, men with intermittent LBP, and men with CLBP using the Sørensen isometric test. The authors found that participants without LBP had significantly longer endurance times than participants with intermittent LBP and participants with CLBP (Hultman et al., 1993).

One year later, Paquet et al. (1994) compared the electromyographic (EMG) activity patterns of the lumbar paraspinal muscles in healthy participants to that of participants with acute/sub-acute LBP during a back extension contraction in standing. The authors found different EMG patterns between patients with and without LBP. The EMG activity showed a monophasic pattern (one peak) in participants with LBP but showed a biphasic pattern (two peaks) in participants without LBP. The authors also found that the longer a participant had LBP, the more likely the participant would be to develop abnormalities in the EMG activation patterns. Thus, changes in back muscle endurance and EMG activation patterns appear more evident in patients with chronic symptoms than those with acute symptoms do.

Patients with CLBP have been shown to have decreased back extensor endurance, as demonstrated by increased fatigability level of these muscles using EMG median frequency (Pääsuke et al., 2002; Roy et al., 1989; Sung et al., 2009). Surface and needle EMG studies showed that back extensor muscles have reduced EMG frequency and steep EMG frequency slopes during isometric contractions, indicating a high fatigability rate of back muscles in patients with CLBP (Pääsuke et al., 2002; Roy et al., 1989; Sung et al., 2009). The fatigability of back extensor muscles in patients with

CLBP can vary across the different levels of the spine. Sung, Lammers, and Danial (2009) investigated the fatigability of the iliocostalis lumborum and longissimus thoracic muscles in 40 patients with CLBP who had no neurological signs and symptoms, and those muscles in 40 asymptomatic individuals. The fatigability was also determined using surface EMG median frequency during the performance of the Sørensen test. The EMG results revealed that the thoracic paraspinal muscles in participants with CLBP had significantly lower EMG median frequency when compared to asymptomatic individuals ($p = 0.01$). In addition, the patients with CLBP had significantly greater fatigability in their thoracic erector spinae muscles than in their lumbar erector spinae muscles. Sung et al. (2009) attributed the increased fatigability of the thoracic erector spinae muscles to a shorter moment arm during contraction. Therefore, during the Sørensen test, the thoracic erector spinae muscles are required to generate a stronger force (i.e., increase muscle activation) to maintain the testing position, thus fatiguing quickly (Sung et al., 2009).

Unlike Sung et al.'s findings, Roy et al. (1989) had different results in the fatigability in patients with CLBP. They also used surface EMG median frequency to assess the fatigability of back extensors in 12 patients with CLBP, but found that the fatigability of the paraspinal muscles at L5 was higher than that at L1 and L2 when performing isometric back extension in a standing position. Roy et al. speculated that the difference in the fatigability at different spinal levels was due to the difference in the location of the pain. They also speculated that the lower lumbar muscles than the upper lumbar muscles due to the greater forces generated this difference in fatigability because the back extension was performed in the standing position (Roy et al., 1989). Therefore, different back muscles at different spinal levels may contract differently to perform back

extensions, which may result in different fatigue rates of these muscles. There is no consensus about which spinal level may demonstrate the highest fatigability in CLBP. To better identify the fatigability of the back extensor muscles, it has been recommended to record EMG median frequency data using surface or intra-muscular electrodes from different spinal muscles at different levels in order to objectively measure the fatigability of those muscles (Beneck, Baker, & Kulig, 2013; Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008; Sparto, Parnianpour, Reinsel, & Simon, 1997).

Patients with CLBP have been shown to have decreased fatigability not only of spinal muscles, but also of the hip muscles. Kankaanpää, Taimela, et al. (1998) compared the fatigability of the lumbar paraspinal muscles and the gluteus maximus (GMAX) muscle between 20 patients with CLBP and 15 healthy controls using surface EMG median frequency. In addition to significantly lower back extension endurance time in patients with CLBP as compared to healthy controls ($p < 0.05$), Kankaanpää, Taimela, et al. (1998) found that a significantly higher fatigue rate in the GMAX muscle in patients with CLBP (Kankaanpää, Taimela et al., 1998). Therefore, the increased muscle fatigability in patients with CLBP is not limited only to the back muscles. Furthermore, the GMAX muscles appear to fatigue faster in this population than in healthy individuals.

There are limited prospective studies that have examined how increased fatigability and/or decreased endurance of back and hip muscles lead to the development of CLBP. However, two other studies have examined how increased fatigability and/or decreased endurance of back and hip muscles can predict the occurrence of acute LBP (Biering-Sørensen, 1984; Marshall, Patel, & Callaghan, 2011). Notably, about half of

the individuals who experienced acute LBP develop recurrent and CLBP (Moffroid, 1997). The role of back muscle strength and endurance in predicting the occurrence of LBP over a one-year period also has been examined (Biering-Sørensen, 1984). Biering-Sørensen (1984) examined 449 healthy men and 479 healthy women in their 30s, 40s, 50s, and 60s. One year later, the participants were asked to fill out a follow-up questionnaire. Biering- Sørensen (1984) found that men who had shorter isometric back extension endurance times were more likely to experience LBP for the first time during the follow-up year more than men who had longer isometric back extension endurance times (Biering- Sørensen, 1984). This finding is in agreement with the results of other studies that found the shorter endurance time as well as higher fatigability level as measured by the EMG median frequency of the lumbar and thoracic erector spinae muscles can predict future LBP (Alaranta, Luoto, Heliövaara, & Hurri, 1995; Mannion & Connolly, 1997).

In a more recent study, Marshall, Patel, and Callaghan (2011) examined the effects of muscle endurance and fatigability of the gluteus medius (GMED) muscle on developing acute LBP in eight healthy men and 16 healthy women. EMG median frequency data was collected via surface electrodes to quantify muscle fatigue during the side-plank activity. The participants were asked to stand up for a 2-hour period of time while performing activities that simulate the tasks done by bank tellers, cashiers, assembly line workers, or casino dealers. The authors found that the endurance time was significantly higher ($p < 0.001$) in the participants who did not develop LBP than in participants who developed LBP at the end of the 2-hour standing period. Those who developed LBP also demonstrated a significantly higher fatigue rate of the contra-lateral

GMED muscles during the side-plank test ($p = 0.03$) compared to those who did not develop LBP (Marshall et al., 2011). As hip muscles are important in transferring loads between the spine and the extremities, decreased endurance of those muscles could lead to future development of LBP.

Hypotheses for Altered Fatigability and Endurance

There is a controversy about the nature of the association between the altered back muscle endurance and fatigability and CLBP. Several hypotheses have tried to explain this association. The first hypothesis is that patients with CLBP tend to avoid back movements due to fear of pain (Waddell, Newton, Henderson, Somerville, & Main, 1993). Therefore, these patients might avoid the excessive exertion of back muscles during endurance testing. Another hypothesis is that these patients become inactive and have sedentary life styles as they avoid physical activity that could aggravate their pain. Over time, lumbar spine mobility, muscle strength, and muscle endurance decrease due to muscle atrophy (Cooper, St, & Jayson, 1992; Mayer, Smith, Keeley, & Mooney, 1985).

To support this hypothesis, Hultman et al. (1993) examined the muscle strength of trunk flexors and extensors in healthy adults, adults with intermittent LBP and adults with CLBP. Hultman et al. used a trunk dynamometer to assess isometric and isokinetic trunk strength. Although Hultman et al. did not find any significant difference in the trunk flexor strength between the three groups, the healthy participants had a significantly higher isometric and isokinetic trunk extension strength than participants with CLBP ($p = 0.001–0.04$). Participants with intermittent LBP also had higher isometric and isokinetic strength of trunk extensors than participants with CLBP ($p = 0.001, 0.008$) (Hultman, Nordin, Saraste, & Ohlsèn, 1993). However, there is a lack of prospective studies that

have examined the effects of trunk muscle weakness on the development of CLBP. Another possible reason is that these patients might have had increased fatigability of trunk muscles before they developed CLBP. This increase in fatigability could alter spinal movements. As the trunk muscles fatigue quicker, this alteration in spinal movements could place an abnormal load on the passive structures such as intervertebral discs and ligaments, thus causing CLBP (Wilder et al., 1996).

Unlike the changes in the endurance and fatigability of trunk muscles, the changes in the endurance and fatigability levels of hip muscles have not been extensively studied. It was hypothesized that the activity of hip muscles, especially the GMAX muscle, is coupled with the paraspinal muscle activity through the throacolumbar fascia (Vleeming, Pool-Goudzwaard, Stoeckart, van Wingerden, & Snijders, 1995). Therefore, deconditioned paraspinal muscles could lead to deconditioning of the GMAX muscles (Kankaanpää, Taimela et al., 1998).

Fatigability Assessment of Back and Hip Muscles

The Sørensen test has been used in the literature as a tool to assess the isometric endurance of the back and hip extensors. The test was first described by Beiring-Sørensen in 1984, and measures how many seconds a person can presume a prone horizontal position with the upper body is unsupported from the level of the iliac crests while the buttocks and legs are stabilized to the exam table by three straps. The test is terminated whenever the individual being tested can no longer keep his or her trunk horizontal or until a self-reported fatigue is reached (Biering-Sørensen, 1984). Biering-Sørensen (1984) used this test to measure the endurance time of back extensors of healthy adults.

As discussed in an earlier section, at one year follow-up, the author found that men who had shorter isometric back extension endurance times were more likely to experience LBP for the first time more than men who had longer isometric back extension endurance times (Biering-Sørensen, 1984). Latimer, Maher, Refshauge, and Colaco (1999) evaluated the reliability and the discriminative validity of the Sørensen test in three groups: healthy participants (n = 20), participants with previous non-specific LBP (n =20), and participants with current non-specific LBP (n = 23). A rater recorded the time needed for each subject to perform the Sørensen test. After a rest time of 15 minutes was given to all participants, a second rater repeated the Sørensen test. Both the raters terminated the test if the participants deviated 10 degrees in the sagittal plane, or if the participant complained of the excessive fatigue or pain. The results showed that the test was reliable for all three groups ($ICC_{1.1}$ = 0.77 – 0.88). Furthermore, the test was found to be reliable regardless of physical activity level of the participants. In this study, the Biering-Sørensen test was reported to have good discriminative validity as healthy participants could hold the testing position for a longer time (132.6 s) than participants with previous LBP (107.7 s) and participants with current LBP (94.6 s), and these differences were statistically significant ($p < 0.05$; Latimer et al., 1999). Therefore, the Sørensen test is considered a reliable and valid tool to assess the back muscles endurance in patients with current or previous history of LBP as well as in healthy individuals.

Fifteen years after the Sørensen endurance test was developed, Gruther et al. (2009) examined the accuracy of this test in patients with CLBP and evaluated its long-term reliability. Twenty-three patients with CLBP, 19 healthy controls, and 15 individuals with chronic headaches completed the study. The patients with CLBP had

symptoms for at least 3 months, rated their pain as three or more on the VAS, had not sought medical care for headaches, and had no headaches for 6 weeks prior to the study. The back muscles endurance tests were carried out on two days 2-3 weeks apart only for patients with CLBP. The healthy controls and the individuals with chronic headaches were not tested on the second day. The results revealed that the Sørensen test has excellent concurrent construct validity when used for patients with CLBP as a significant difference in endurance time ($p < 0.001$) was found between individuals with CLBP and healthy controls, and between individuals with CLBP and those with chronic headaches ($p < 0.001$). Gruther et al. (2009) also demonstrated the Sørensen test to have acceptable between-day test-retest reliability (ICC = 0.59) when the test was performed on two occasions 2-3 weeks apart. With excellent validity and reliability shown in Gruther et al.'s study (2009), the Sørensen test has been recommended for testing the back muscles function in patients with CLBP (Gruther et al., 2009). The results of this study are similar to the results of the studies mentioned previously indicating that the Sørensen test can be used to distinguish between patients with CLBP and healthy controls and to examine the treatment outcomes for patients with CLBP (Latimer et al., 1999).

Electromyographic (EMG) median frequency has been used in the literature to determine muscle fatigability rate. The use of EMG median frequency to assess the fatigability of skeletal muscles was advocated by De Luca (De Luca, 1984) because changes of EMG median frequency have been observed during a prolonged contraction. At the beginning of an isometric contraction, the EMG median frequency is highest. As an isometric contraction continues, the EMG median frequency shifts toward lower values. This is due to the changes on the firing rate of the motor units and due to the

accumulation of hydrogen ions and lactic acid as the muscle fatigues (Kankaanpää, Taimela et al., 1998). This technique has been used in the literature to determine the fatigability of both the lower extremity and the upper extremity muscles, such as the quadriceps, biceps brachii, and paraspinal muscles (Coorevits et al., 2008; Falla, Rainoldi, Merletti, & Jull, 2003; Grabiner, Koh, & Miller, 1991; Mathur, Eng, & MacIntyre, 2005). Roy, De Luca, Emley, and Buijs (1995) used EMG median frequency collected by surface electrodes to determine whether this technique can discriminate between asymptomatic participants, and participants with CLBP. These researchers collected EMG median frequency data from 42 asymptomatic participants, and 28 participants with CLBP who underwent a 4-week rehabilitation program. The EMG median frequency data was collected from the longissimus thoracic muscle at L1, the iliocostalis lumborum muscle at L2-3, and the lumbar multifidus (MULT) muscle at L5 during isometric back extensions of 50% and 80% of the maximum voluntary contraction (MVC) at baseline for both the participants with CLBP and the asymptomatic participants, and at the end of the 4-week rehabilitation program for the participants with CLBP. A significant reduction of the EMG median frequency slope was found after the completion of the 4-week rehabilitation program ($p = 0.002$), indicating that their rehabilitation program significantly improved lumbar paraspinal muscle fatigability. Furthermore, the researchers used the EMG frequency slope of to classify all of the participants into two groups: CLBP and healthy groups.

Using a stepwise discriminant statistical analysis, 85% of participants with CLBP were classified correctly into the CLBP group and 86% of healthy participants were classified correctly into the healthy group. The results indicated that EMG median

frequency was able to distinguish between asymptomatic participants and participants with CLBP. In addition, for participants with CLBP, the EMG median frequency slope was not related to physical characteristics such as height and body mass index of the participants. However, for healthy participants, the EMG median frequency data was significantly associated with body mass index and the MVC ($p = 0.001$) (Roy et al., 1995). In conclusion, the EMG median frequency collected using surface electrodes can be a valid tool to assess back muscle fatigability in patients with CLBP and can be used to distinguish between patients with CLBP and individuals without CLBP.

Biedermann, Shanks, and Inglis (1990) examined the between-day test-retest reliability of the EMG median frequency recorded from the lumbar MULT and iliocostalis muscles during sustained resisted back extension in 31 healthy individuals. The researchers collected the EMG median frequency data twice five days apart to determine the between-day test-retest reliability. The recording was performed while the participants were prone lying on a curved board placed below the anterior superior iliac spine (ASIS). To make sure a consistent trunk extension contraction, the participants were asked to hold a free weight instead of using a percentage of the MVC. The results showed that the EMG median frequency has an excellent test re-test reliability for the lumbar MULT muscle (right $r = 0.95$, left $r = 0.90$) and a good reliability for the iliocostalis muscle (right $r = 0.76$, left $r = 0.79$). Therefore, Biedermann et al. (1990) concluded that EMG median frequency was an appropriate measure of muscle functions and it was appropriate to be used in clinical research (Biedermann, et al., 1990).

More recently, the Sørensen test has been used in combination with EMG median frequency testing to assess the endurance and fatigability of back and hip muscles.

Coorevits et al. (2008) established a protocol measuring the endurance of six back muscles and two hip muscles. In this study, 10 healthy men and 10 healthy women were recruited. EMG data were collected using surface electrodes from eight locations: the latissimus dorsi, the thoracic and lumbar parts of the longissimus thoracis, the thoracic and lumbar parts of the iliocostalis lumborum, the MULT, the GMAX, and the biceps femoris muscles. The EMG data were filtered between 10 and 500 Hz and collected at a sampling rate of 1,000 Hz and a common mode rejection ratio < 100 dB. Data were transformed into median frequency and instantaneous median frequency wavelet-Fourier transformation function. Two vertical stands connected by a rope were placed on the sides of the examination table. Participants were instructed to perform the modified Sørensen test while holding their hands against their forehead instead of crossing their arms against their chests as described in the original Sørensen test. Participants then were instructed to extend their backs until they touched the rope, which provided them with a tactile feedback. To determine when to terminate the modified Sørensen test, the authors used an ultrasound movement analysis system that performs as a three-dimensional motion analysis device. Markers were attached to the skin over the spinous processes from L1 to L5. The modified Sørensen test was terminated when the lumbar spine angle deviated 30% from the horizontal position. They reported that the reliability of EMG median frequency testing of the lumbar MULT and the GMAX muscles was good (ICC = 0.72 and 0.73, relatively; Coorevits et al., 2008). The results indicated that EMG median frequency is a reliable measure for assessing muscle fatigue of back and hip muscles during the modified Sørensen test.

Ng and Jull (1997) also studied the EMG amplitude and the frequency of back muscles during the modified Sørensen test. In this study, surface EMG was used to record the amplitude and the frequency of the iliocostalis lumborum and the MULT muscles in healthy individuals. They found that the lumbar MULT muscle had a higher fatigue rate than the iliocostalis lumborum muscle, which was demonstrated by a steeper median frequency slope of the lumbar MULT muscle as compared to that of the iliocostalis lumborum muscle ($p = 0.0005$; Ng & Jull, 1997). This finding is consistent with the results reported by Coorevits, Danneels, Cambier, Ramon, and Vanderstraeten (2008). Coorevits, Danneels, Cambier, Ramon, and Vanderstraeten (2008) also found that the MULT muscle had higher EMG fatigability than the iliocostalis lumborum muscle in healthy adults ($p < 0.001$) and the MULT muscle was more closely correlated to the endurance time ($r = 0.62$) than the iliocostalis lumborum muscle ($r = 0.55$).

The gender factor has been considered to have an impact on back extensor muscle fatigability. Clark, Manini, Thé, Doldo, and Ploutz-Snyder et al. (2003) conducted a study to assess how gender and absolute load affect back extensor muscle endurance time, and to compare the EMG fatigability patterns between men and women. The participants consisted of 10 healthy men and 10 healthy women who did not have any history of current or previous LBP and were recreationally active. The participants were asked to attend three testing sessions on three different days. On the first visit, demographic data were collected and the participants were familiarized with the study. On the second visit, the lumbar muscles strength was determined using a Roman chair. Each participant was asked to wear a trunk harness which had a ring attached to the mid-sternal area. Then, a tensiometer was attached to the ring in the mid-sternal area to the

floor. Participants were asked to lie prone on a Roman chair with their back at 15 degrees of flexion (i.e., 15 degrees down toward the floor). Next, an isotonic strength test for back extension was performed. During the isotonic strength test, the participants were asked to extend their back to a horizontal position with their maximum effort and hold that position for 2-3 seconds. Three trials were performed and participants were given 2-3 minutes to rest between each trial. During the third visit, participants were asked to perform a modified Sørensen test. During the Sørensen test, the EMG activity was recorded from the right and left lumbar paraspinal, the right GMAX and the right biceps femoris muscles. Participants were asked to maintain a horizontal position with 50% MVC. The time and the EMG median frequency data were recorded. The authors found no significant difference between men and women with regard to the isotonic strength of the back extensors. However, women had longer endurance times compared to men (p = 0.008) and this difference was not influenced by the length of their trunk. In addition, the EMG results showed that men's paraspinal muscles fatigued faster than women's ($p <$ 0.000; Clark et al., 2003). Therefore, gender may impact the fatigue rate of back and hip muscles while performing the modified Sørensen test.

Furthermore, the association between back extensor muscle fatigability and muscle endurance of the lower extremities has been examined. Suter and Lindsay (2001) examined the association between muscle endurance time and fatigability of back extensors in 25 male golfers with CLBP and 16 age-matched controls. The researchers assessed back extensor muscle endurance time via the Sørensen test and fatigability of these muscles using the EMG median frequency at the level of T12 and L4-5. Quadriceps muscle inhibition was assessed by asking the participants to perform a maximum knee

extension against a dynamometer with the knee placed in 90 degrees of flexion. Then, an electrical impulse was applied to the femoral nerve and repeated until a maximal muscle contraction was achieved. If there was a difference between voluntary maximal contraction and electrical impulse induced maximal muscle contraction, the difference was calculated. Suter and Lindsay found no significant difference in back extensor muscle endurance time between golfers with CLBP and healthy controls. However, in golfers with CLBP, inhibition of quadriceps muscle was positively associated with fatigability of back extensors during the Sørensen test at the level of L4-5 (r = -0.39, p = 0.005 for the right side and r = 0.54, p = 0.005 for the left side). Suter and Lindsay (2001) speculated that CLBP might have led to abnormal muscle activity, contributing not only to the increased fatigability levels of back extensor muscles, but also to the inhibition of the quadriceps muscles (Suter & Lindsay, 2001).

Two studies have found that the increased fatigability of back muscles in patients with CLBP was associated with BMI as patients with high BMI had increased fatigability of back extensor muscle during the Sørensen test than those with low BMI (Kankaanpää, Laaksonen et al., 1998; Pääsuke et al., 2002). Kankaanpää and Laaksonen et al. (1998) examined the fatigability of the lumbar paraspinal muscles in 133 asymptomatic women and 100 asymptomatic men. The results showed that high BMI was associated strongly with high fatigability of lumbar paraspinal muscles at the level of L1-L2 (r = -0.51) and at the level of L4-L5 (r = -0.49). In a similar study, Pääsuke et al. (2002) examined the fatigability of lumbar paraspinal muscles at the level of L3 in 12 participants with CLBP and in 12 healthy age-matched, gender-matched controls during the performance of the Sørensen test. Pääsuke et al. (2002) also found that participants with CLBP who had high

BMI had shorter endurance time than those with low BMI (r = -0.71, p < 0.01). The BMI was found to be correlated with the EMG median frequency fatigue rate (r = 0.62, p < 0.05) in the asymptomatic participants, indicating that healthy individuals with high BMI tend to have higher lumbar paraspinal muscle fatigability. However, this association was not found in participants with CLBP (Pääsuke et al., 2002). Interpreting the fatigability data of the lumbar paraspinal muscle should be done with caution as these data may be influenced by the participants' BMI as well as participants' gender.

Lariviére, Gravel, Arsenault, Gagnon, and Loisel (2003) have examined the recovery time following an isometric fatigue test for the back extensors. Lariviére et al. (2003) were interested to know whether 10 minutes or 15 minutes was sufficient rest time to recover after a fatigue test of back extensors. Twelve healthy men without any known pathology completed the study. The fatigue test of back extension was performed using a triaxial dynamometer that measured the back extension force while the participant was standing inside of the dynamometer frame and his/her feet, knees, pelvis were stabilized to the dynamometer frame. After recording the MVC of the back extension, three trials of the fatigue test of back extensor were performed. For each trial, participants were asked to perform an isometric back extension at 75% of the MVC force until they no longer maintained muscle contraction at the 75% level. EMG median frequency data was collected during each trial. Participants were given a 15-minute rest between the first and the second trial and a 10-minute rest between the second and the third trials. The results of the study found no significant difference between the three trials, suggesting that a rest time of 10 or 15 minutes was enough recovery time between each back isometric test (Larivière et al., 2003). Therefore, a rest time as short as 10 minutes was concluded to be

sufficient to ensure full recovery of back extensors following sustained back extension fatigability testing.

Measurement of hip abductors endurance has been carried out through the side-plank test, which is also called the side-bridge test. To perform the side-plank test, participants lie on their tested side and put their top foot in front of their bottom foot. Next, participants place their weight on the tested side foot and shoulder, and then lift their hips off the table. Then, participants place the arm of their untested side across their chest, and hold that position as long as they can. The test is terminated once the participants' hips touch the table. McGill, Childs, and Liebenson (1999) studied the GMED endurance time during the side-plank test (McGill et al., 1999). McGill et al. found that this test had excellent between-day test-retest reliability for the right and left GMED muscles (r = 0.96 and 0.99, respectively). Although the side-plank test has been used to assess the endurance of the GMED muscles, there are no studies that used the EMG median frequency to objectively assess the fatigability of the GMED muscles during the performance of this test (McGill et al., 1999).

However, the EMG median frequency was used to assess the fatigability of the GMED muscles in other positions other than the side-plank position. Jacobs, Uhl, Seeley, Sterling, and Goodrich (2005) used the EMG median frequency to assess the hip abductor fatigability and peak torque during an isometric hip abduction on a side-lying position. Forty-two healthy participants were recruited. A dynamometer was used to determine the MVC of the right and left hip abductors and to monitor the force applied during the isometric fatigue testing. After asking the participants to lie on their side, three trials of MVC of the contralateral hip abduction were recorded for each side. Next, participants

were given a rest time of two minutes before proceeding to the fatigue trial. For the fatigue trial, participants were asked to lie on their contralateral side to the side being tested, and were instructed to abduct their ipsilateral hip against 50% of the MVC for 30 seconds. The EMG data was then divided into 0.512 second intervals. The EMG median frequency was calculated for each interval. The same procedure was repeated for the other side. The results revealed that there was a significant difference in the peak torque between the dominant side and the non-dominant side ($p = 0.02$). However, there was no significant difference in the fatigability (i.e., EMG median frequency) between the dominant and the non-dominant sides (Jacobs et al., 2005). Although the hip abductors on the dominant side were stronger than those on the non-dominant side, the hip abductors on both sides appeared to have a similar fatigue rate.

Outcome Measures for LBP

Pain Level

The Visual Analogue Scale (VAS) has been used to assess the intensity of LBP. The VAS consists of a 10-cm line with the left end marked "no pain" and the right end marked with "worst pain ever" (Paungmali, Sitilertpisan, Taneyhill, Pirunsan, & Uthaikhup, 2012). The VAS is described in the literature as one of the most valid measurements to document pain (Scott & Huskisson, 1976). The reliability of the VAS has been assessed for patients with LBP. Paungmail et al. (2012) examined the intrarater reliability of different quantitative tests in patients with non-specific LBP for at least 3 months and no referred pain or neurological involvement. The VAS was used to assess the level of LBP and a thermal sensory analyzer unit was used to induce cold or heat stimuli to the skin over the L5-S1, deltoid insertion, and tibialis anterior muscles. Next,

the investigators adjusted the temperature in a fixed rate. When the participants started feeling pain, the temperature was recorded to determine the cold and heat pain threshold. In addition, a pressure algometer was used to determine the pressure pain threshold. The data was collected on two separate days 48 hours apart. These scales were found to be reliable to assess the pain in patients with non-specific LBP, with ICC = 0.90 for subjective VAS pain rating, ICC = 0.89 for the cold pain threshold test, ICC = 0.87 for the heat pain threshold test, and ICC = 0.99 for the pressure pain threshold (Paungmali et al., 2012). The reliability of the VAS was also found to be good to assess pain level for CLBP (Leboeuf, Love, & Crisp, 1989). Leboeuf, Love, and Crisp, (1989) studied several self-report measures in addition to the VAS: the McGill pain questionnaire, and pain drawing. Sixty-five patients with CLBP for at least 6 months were included in the study. The VAS and the self-reported measures were completed on the first day and again a few days later. The VAS was found to be reliable when it was used to describe the current pain (r = 0.77) and the remembered previous pain experience such as reporting the worst pain the participant had (r = 0.49). The McGill Pain Questionnaire also was reported to be a reliable tool to evaluate the qualitative aspects of pain. On the contrary, the pain drawing was shown to be unreliable in this population (Leboeuf et al., 1989). The minimal clinically important difference (MCID) for the VAS in patients with CLBP is about 1.8 cm (Hägg, Fritzell, & Nordwall, 2003).

The Numeric Pain Rating Scale (NPRS) has been used in studies to assess the effects of treatment interventions on the pain level in adults with acute LBP and CLBP (Chapman et al., 2011; Childs, Piva, & Fritz, 2005). The NPRS is an 11-point numerical scale ranging from 0 representing no pain and 10 representing worst imaginable pain. The

NPRS was found to have fair-to-excellent test-retest reliability over one week and four weeks when measuring the pain level for adults with LBP (ICC = 0.72 and 0.92, respectively). The minimal detectable change (MDC) of the NPRS was found to be 2.2 points over a 1-week test-retest period and 1.5 points over a 4-week test-retest period (Childs et al., 2005). However, the reliability of this pain scale has not been determined for adults with CLBP.

Disability and Functional Levels

The Oswestry Disability Questionnaire (OSW) has been used to measure the disability related to LBP. The original OSW questionnaire, first described by Fairbank et al. in 1980, consists of 10 items, which are pain intensity, lifting, walking, sitting, standing, sleeping, social life, traveling, and sex life. Each item can be scored from 0 to 5 and the total score is multiplied by 2 to get the final score (in percentage) of the OSW, with a possible score of 0 - 100% and higher scores indicating greater disability levels (Fairbank, Couper, Davies, & O'Brien, 1980). Because the "sex life" item was left blank most of the time, a modified version of OSW was developed and replaced the "sex life" item with "employment and homemaking" (see Appendix A; Fritz & Irrgang, 2001). The modified OSW has been found to be a reliable measure for back pain-related disability (ICC = 0.84) and can indicate disability improvement and worsening in individuals with LBP with MDC of 10.5% (Davidson & Keating, 2002). The MCID for OSW is 10% for patients with CLBP (Hägg et al., 2003).

The patient-specific functional scale (PSFS) has been used in the literature to assess the functional limitations for patients with LBP. The PSFS requires patients to identify up to three activities that patients are not able to perform or they are having

difficulty in performing. The patients are then asked to rate each activity from 0 to 10, where 0 means inability to perform the activity and 10 means that the patient is able to perform the activity at the pre-injury quality. The scores are summed and then averaged by the number of the activities to reach a final score of the PSFS with a possible score of 0-10. Research has shown that the PSFS is a valid scale for measuring disability in patients with LBP. Hall et al. (2011) reviewed four studies in which the validity of the PSFS was examined by comparing (or correlating) the PSFS to the Ronald Morris Disability Questionnaire (RMDQ). The PSFS and the RMDQ were compared concurrently at baseline, immediately after the intervention, three months after the intervention and six months after the intervention. Hall et al (2011) concluded that PSFS has good internal responsiveness with effect size > 0.80 in patients with LBP for follow up time points up to six months. They also concluded that PSPS has good external responsiveness when its scores were correlated to the global perceived effect scale in patients with LBP for follow up time points up to six months (p = 0.60–0.70; Hall, Maher, Latimer, Ferreira, & Costa, 2011). In addition, the MCID for the PSFS was reported to be 2 points of the average score in adults with CLBP (Maughan & Lewis, 2010). However, its responsiveness depends on the level of functional limitations, as this scale is more responsive in patients with lower levels of functional limitations (Hall et al., 2011). In addition, this scale is limited to only three activities identified by the patients.

The Quebec Back Pain Disability Scale (QUE) has been used to assess disability level in patients with LBP (Demoulin, Ostelo, Knottnerus, & Smeets, 2010; Fritz & Irrgang, 2001). The QUE is a 6-point questionnaire that assesses the patient's performance of 20 different activities such as walking, getting out of bed, carrying

groceries bags, and prolonged sitting on a chair. Each item is scored between 0 and 5, with 0 indicating no trouble performing the activity, and 5 indicating inability to perform the activity. The scores are summed to get a final QUE score between 0 and 100 (Kopec et al., 1995). The QUE scale was found to be reliable in patients with LBP (ICC = 0.89) with MDC of 15 points (Davidson & Keating, 2002). Although this scale assesses the performance of 20 different activities, it takes a longer time to administer the questionnaire than it takes to administer the OSW.

Fear Avoidance Beliefs Level

The Fear Avoidance Beliefs Questionnaire (FABQ), which was first described by Waddell et al. in 1993, consists of 16 items (see Appendix B). These items can be scored from 0 to 6, with 0 indicating absence of fear avoidance beliefs and 6 indicating the highest level of fear avoidance beliefs. This questionnaire has two sections: work-related fear avoidance beliefs and fear avoidance beliefs related to physical activity. The FABQ-work consists of seven items that can be scored between 0 and 42. The FABQ-physical activity consists of four items and can be scored between 0 and 24. Higher scores indicate higher levels of fear of pain and higher levels of activity changes to avoid LBP (Waddell et al., 1993). The literature has shown that there is an association between the FABQ score and work loss and disability in patients with CLBP (Crombez, Vlaeyen, Heuts, & Lysens, 1999; Fritz, George, & Delitto, 2001; Hadjistavropoulos & Craig, 1994). Both the FABQ-work and FABQ-physical activity were found to be reliable for patients with CLBP (ICC = 0.96, 0.90; MDC = 6.8, 5.4, respectively; George, Valencia, & Beneciuk, 2010). Although the MCID for FABQ-physical activity has been identified to be four

points, no studies yet have determined the MCID for FABQ-work (George, Bialosky, & Fritz, 2004).

Interventions to Improve Muscle Fatigability for Patients with CLBP

CLBP has been found to be associated with abnormal changes in endurance and fatigability of back and hip muscles (Hultman et al., 1993; Kankaanpää, Taimela et al., 1998; Mannion & Connolly, 1997; Pääsuke et al., 2002; Roy et al., 1989). There is an emerging need for designing treatment and rehabilitation programs to improve the fatigability and endurance of these muscles in patients with CLBP. To date, there are no published studies that have examined the best treatment options to improve the fatigability and endurance of hip muscles in adults with CLBP. However, a few studies have examined the effects of rehabilitation programs and exercise regimens on the endurance and fatigability of back muscles (Henchoz et al., 2010; Kankaanpää et al., 1999; Kofotolis & Kellis, 2006; Mannion et al., 2001). Most of these programs employed multidisciplinary approaches, intensive therapeutic exercises, or proprioceptive neuromuscular facilitation concepts to improve the fatigability and endurance of back muscles in patients with CLBP.

Multidisciplinary Approach

Two studies examined the effects of a multidisciplinary program combined with exercises on the fatigability and endurance of back muscles in adults with CLBP (Bendix et al., 1996; Henchoz et al., 2010). Henchoz et al. (2010) examined the effectiveness of a multidisciplinary program, which was carried out in out-patient clinical settings for up to 3 weeks, with each treatment session lasting for 5 to 7 hours. Patients were assigned to either a group that received multidisciplinary treatment (multidisciplinary-only group) or

to a group that received a multidisciplinary approach combined with exercises (combined group). The multidisciplinary approach consisted of different pharmaceutical and psychological interventions and each patient had a follow-up with the treating physician regularly. In addition, patients received information about body mechanics and fear-avoidance beliefs. The exercises given to the combined group included various exercise regimens such as cardiovascular endurance exercises, strengthening exercises using rubber bands, Swiss balls, and dumbbells. The authors found that participants in the combined group had significantly higher static endurance time of the trunk flexors (p = 0.01) and trunk extensors (p = 0.001) than those who received the multidisciplinary approach alone (Henchoz et al., 2010). Bendix et al. (1996) had similar results and found that patients with CLBP who were assigned to an interdisciplinary approach group had significantly higher static endurance time of the back extensor muscles than those who did not receive any treatment (p = 0.001; Bendix et al., 1996). Although these programs have been shown to be effective for improving muscle endurance, the duration of each session was 5-6 hours, which makes these programs hard to implement in a typical physical therapy out-patient clinic in the US.

Intensive Exercise Programs

Studies have found that intensive exercise programs are effective in increasing the endurance time and decreasing the fatigability levels of back muscles in patients with CLBP (Kankaanpää et al., 1999; Mannion et al., 2001; Mellin et al., 1993). The goals of these programs are to improve physical functional capacity, pain level, and patient awareness in managing his or her CLBP. These programs can extend for a prolonged period of time and may last up to three months. During these programs, patients are

exposed to a variety of exercise training techniques such as aerobic exercises, stretching exercises, back muscles isometric exercises, and trunk strengthening exercises (Kankaanpää et al., 1999; Mannion et al., 2001; Mellin et al., 1993). Kankaanpää et al. (1999) compared the effects of an intensive exercise program and a placebo treatment program on the pain level, physical activity level, and lumbar paraspinal muscle fatigability in patients with CLBP. Each of the two programs consisted of 24 sessions (1.5 hr. each session) that were carried out over a period of 12 weeks and the exercise load was increased gradually through 12 weeks based on each patient's capabilities. After the intervention, patients who received the intensive exercise program had significantly lower pain level ($p = 0.03$) and higher physical activity level ($p = 0.04$) than patients who received a placebo treatment program, which consisted of medications, thermal therapy, and massage. This improvement was maintained for 6 months and one year. The authors also found that patients who received the intensive exercise program had lower fatigability levels of the lumbar paraspinal muscles as measured by the EMG frequency after the intervention ($p < 0.002$) and at the 6-month follow-up ($p = 0.02$) than patients who received the placebo treatment program. However, there was no significant difference between both groups in terms of lumbar muscle fatigability at the one-year follow-up (Kankaanpää et al., 1999).

Mannion et al. (2001) also found benefits of exercises for improving fatigability in CLBP. They compared the effects of three treatment programs: aerobic classes, trunk muscle strengthening exercises, and isometric exercises. After assigning participants into one of the three programs, all attended two sessions per week over a period of three months. The fatigability levels of lumbar extensor muscles were assessed while the

participants performed a Sørensen test (static testing) and repetitive trunk flexions and extensions for 90 seconds (dynamic testing). Mannion et al. (2001) found that all three programs significantly improved the lumbar erector spinae muscle fatigability during the Sørensen test ($p = 0.0001$) without any significant between-group differences. The dynamic testing result showed a significantly higher fatigability of the lumbar paraspinal muscle at the level of L5 in participants who were assigned to the trunk strengthening program than participants who were assigned to the aerobic exercises program or the isometric exercises program ($p = 0.002$; Mannion et al., 2001). This indicated that strengthening exercises might not be the key to improving the fatigability of back paraspinal muscles in patients with CLBP. However, exercise programs such as those that include both aerobic and isometric exercises may improve the fatigability of the lumbar paraspinal muscles in this population. Even though exercise programs have been shown to improve the endurance and the fatigability levels of back extensors in this population, the duration for these programs is relatively long and may add some financial burdens to patients.

Proprioceptive Neuromuscular Facilitation (PNF)

Kofotolis and Kellis (2006) examined the effects of the PNF approach on the endurance of back muscles. Two PNF techniques were used to increase the endurance of trunk muscles: rhythmic stabilization training (RST) and combination of isotonic exercises (COI). In Kofotolis and Kellis' study (2006), RST consisted of isometric truck flexion and extension that were performed alternatively against resistance. The hold time for each contraction was 10 seconds. COI exercises consisted of concentric and eccentric contractions of trunk flexion that were performed alternatively without rest. The resisted

contractions were maintained for five seconds in each direction. For both techniques, the contractions were performed in three sets of 15 repetitions, with 30 to 60 seconds of rest between each set. Kofotolis and Kellis (2006) examined the effects of these PNF techniques on the static and dynamic endurance of back extensor muscles. In this study, the authors used the Sørensen test to measure the static endurance of back extensor muscles. Repetitive extension movements were used to determine dynamic endurance of back extensor muscles. Back extension was performed at a rate of 25 per minute up to 25 repetitions in the Sørensen test position. The authors found that participants with CLBP who were assigned to the PNF groups had significantly higher static and dynamic endurance of trunk flexors and extensors after receiving PNF training five sessions per week for 4 weeks ($p < 0.05$) than participants who were assigned to a control group who were asked not to participate in any structured exercises. One other study also demonstrated the effects of the RST on increasing the dynamic endurance of trunk flexors and the static endurance time of the back extensors in women with CLBP (Kofotolis et al., 2008). In summary, trunk PNF techniques appear to be able to activate the back muscles and increase back endurance. However, these studies did not examine how these techniques can alter the fatigue rate of the back extensors as measured by the EMG median frequency.

Manual Therapy Interventions for Patients with CLBP

In general, the mechanism of how manual therapy decreases pain and improves the physical function is not well known. It was speculated that manual therapy produces mechanical stimuli that could alter the neurophysiologic functions of the central and peripheral nervous systems (Bialosky et al., 2009). Manual therapy may reset the

function of the muscle spindles and increase the functionality of the proprioceptors, which could restore the normal neuromuscular functions (Bialosky et al., 2009; Goss et al., 2012).

Many studies have shown that manual therapy, specifically thrust lumbopelvic manipulation, can decrease pain and disability in patients with acute LBP (Cleland et al., 2009; Flynn et al., 2002). Additionally, manual therapy has been recommended as a treatment strategy for patients with CLBP (Chou et al., 2007). Some manual therapy techniques have been shown to be effective in managing this population (Chiradejnant, Maher, Latimer, & Stepkovitch, 2003; Geisser, Wiggert, Haig, & Colwell, 2005; Senna & Machaly, 2011). There are no studies that have reported that one manual therapy technique is more superior to another. Therefore, clinicians are encouraged to choose an appropriate technique for each patient based on the clinical physical examination (Chiradejnant et al., 2003; Lucy, 2006).

Non-thrust Spinal Manual Therapy

Non-thrust manual therapy techniques employ passive, low-velocity oscillatory movements that are directed to the joint segments within their physiological range to passively mobilize joint segments, and these techniques usually do not produce audible sound (Cook, Learman, Showalter, Kabbaz, & O'Halloran, 2013; Goss et al., 2012). These techniques were defined by Maitland (Maitland, 2005) and can be modified based on the clinical evaluation performed by a therapist. These techniques may vary in terms of the amount of force applied and the application range of motion (Maitland, 2005). Non-thrust manual therapy has been recommended as a treatment strategy for patients with CLBP (Chiradejnant et al., 2003; Geisser et al., 2005; Niemistö et al., 2003). The

effectiveness of a variety of non-thrust manual therapy techniques to the low back has been examined in this population.

Chiradejnant et al. (2003) examined the effects of two lumbar mobilization techniques on the severity of symptoms in 140 patients with CLBP. In this study, the treating therapists were asked to apply either a mobilization technique based on patient's physical examination findings, or to apply a random mobilization technique at a random spinal level and direction regardless of the results of the physical examination. Chiradejnant et al. (2003) concluded that both techniques resulted in a significant reduction in pain levels ($p = 0.01$) and a significant increase in global perceived improvement ($p = 0.04$). However, when the mobilization was applied to the lower spinal segments, it resulted in a greater reduction of pain level than when the mobilization was applied to higher segments of the lumbar spine (Chiradejnant et al., 2003). In summary, mobilization techniques that are applied to the painful segments and that are selected based on the clinical examination findings are more effective in reducing pain level in patients with CLBP than random techniques applied to random segments.

Muscle energy techniques, a form of non-thrust manual therapy, use patient's voluntary contraction against a counter-force that is applied in a specific amount and toward a specific direction to mobilize joint segments (Niemistö et al., 2003). Muscle energy techniques commonly are used in conjunction with other forms of interventions to maximize their effectiveness when they are used for patients with CLBP. Niemistö et al. (2003) examined the effectiveness of muscle energy techniques that aimed to stretch the biceps femoris, rectus femoris, iliopsoas, and gluteus muscles combined with abdominal drawing-in stabilization exercises and physician consultation versus physician

consultation alone. The selection of the muscle energy techniques was based on the presence of muscle tension found during the physical examination. It was found that patients with CLBP who received muscle energy techniques combined with stabilization exercises and physician consultation for four weeks had a significant reduction in their pain level ($p < 0.001$) and their disability scores ($p = 0.002$) compared to those who received physician consultation alone. These results were consistent over a period of a year (Niemistö et al., 2003). In a study that was conducted by Geisser et al. (2005), patients with CLBP who received muscle energy techniques combined with disability-specific exercises reported a significant reduction of their pain levels ($p < 0.05$) when compared to patients who received placebo manual therapy techniques combined with general exercise (Geisser et al., 2005). The muscle energy techniques selected were based on each patient's musculoskeletal dysfunctions identified in the clinical examination. In conclusion, muscle energy techniques combined with selected exercises based on each patient's musculoskeletal dysfunction can have a positive impact on pain and disability levels in patients with CLBP.

Thrust Spinal Manual Therapy

Thrust manual therapy techniques use a high-velocity low-amplitude force to mobilize joint surfaces that may produce an audible sound (Goss et al., 2012). The application of thrust manual therapy techniques has been shown to produce favorable outcomes for patients with CLBP (Fernando, Liebano, Costa, Rissato, & Leonardo, 2013; Senna & Machaly, 2011). The application of thrust manual therapy techniques is not limited to the painful spinal segments. These techniques can be applied to different spinal levels to decrease pain intensity in patients with CLBP.

Fernando et al. (2013) conducted a study to compare the effects of spinal manipulation directed at the painful segments of the lumbar spine and those applied to non-painful upper thoracic spine levels between T1 and T5 in patients with CLBP. In this study, the participants were assigned either to a manipulation group that received a manipulation based on the lumbar examination, or to a random manipulation group that received a random manipulation at non-painful thoracic segments. The authors found that both manipulations, regardless of the application level, had an immediate effect on improving the LBP level in this population ($p < 0.001$; Fernando et al., 2013). In conclusion, single or multiple applications of thrust manipulation techniques directed to the painful level or to a level away from the pathology may improve pain levels in patients with CLBP. However, these findings should be interpreted with caution as other studies mentioned previously in this review recommended the use of manual therapy techniques based on the clinical evaluation for each patient with CLBP (Chiradejnant et al., 2003; Niemistö et al., 2003).

One of the techniques that have been investigated in patients with CLBP is the lumbopelvic manipulation (see Appendix C). The lumbopelvic manipulation has been shown to give favorable results when it is used for patients with non-specific CLBP. One study conducted by Senna and Machaly (2011) compared the effects of the lumbopelvic manipulation on patients who had non-specific CLBP for at least six months. The authors investigated the effects of the lumbopelvic manipulation on several areas: disability level as measured by the original OSW, pain level as measured by the VAS, general health status as measured by the General Health Survey (SF-36), patients' global assessment of outcomes, and spinal mobility in patients with CLBP. Sixty participants were randomly

assigned to one of three groups: a control group, a manipulation group, or a maintained lumbopelvic manipulation group. Participants in the control group received a placebo treatment consisting of sham spinal manipulation for one month. Participants in the manipulation group received 12 sessions of the lumbopelvic manipulation for a month with an average of three sessions a week. This manipulation technique has been previously described in the literature for patients with LBP (Cibulka, Delitto, & Koldehoff, 1988). Participants in the maintained manipulation group received 12 sessions of lumbopelvic manipulation for a month with an average of three sessions a week, and then additional lumbopelvic manipulations once every two weeks for 9 months. When compared to the control group, the maintained manipulation group demonstrated significant improvement in the OSW score ($p = 0.012$), the VAS scores ($p < 0.001$), the modified Schober test results ($p < 0.001$), right lateral bending mobility ($p = 0.026$), and left lateral bending mobility ($p = 0.022$; Senna & Machaly, 2011). In summary, this lumbopelvic manipulation technique appears to be effective in reducing pain level, increasing spinal mobility, and improving disability associated CLBP.

Studies have investigated the effects of lumbopelvic manipulation in participants with acute and sub-acute LBP (Delitto, Cibulka, Erhard, Bowling, & Tenhula, 1993; Erhard, Delitto, & Cibulka, 1994). Delito, Cibulka, Erhard, Bowling, and Tenhula (1993) assessed the effects of the lumbopelvic manipulation technique in patients who had acute LBP and demonstrated signs of sacroiliac joint dysfunction. In this study, 24 patients with LBP who had symptoms for less than 7 days were recruited in this study. In addition, the participants also demonstrated positive sacroiliac joint dysfunction, and their symptoms improved or centralized with activities that place the lumbar spine in

extension. Participants were randomly assigned either to an extension-oriented (manipulation) group or to a flexion-oriented comparison group. Participants in the extension-oriented (manipulation) group received a lumbopelvic manipulation intervention and were instructed to follow up with prone press-ups, whereas participants in the comparison group received general flexion-oriented exercises. The researchers concluded that the participants in the extension-oriented group had better treatment outcomes in terms of the OSW scores as compared to the participants in the flexion-oriented group ($p < 0.05$; Delitto et al., 1993). However, the positive outcomes cannot be attributed to the lumbopelvic manipulation alone because the treatment effect could have come from the extension exercises. Later, Erhard, Delitto, and Cibulka (1994) compared the effects of a flexion-extension exercise program combined with lumbopelvic manipulation and an extension-oriented exercise program only on disability that was measured by the OSW in patients with acute and subacute LBP. Twenty-four participants with LBP for less than 3 months and positive sacroiliac joint signs completed the study. In addition, all participants demonstrated improvement of the symptoms with sustained or repeated trunk extensions.

Erhard et al. (1994) randomly assigned the participants to either an exercise-manipulation group or extension exercises group. Participants in the exercise-manipulation group received an intervention of lumbopelvic manipulation in addition to a flexion-extension exercise program. Participants in the extension-exercise group received extension press-ups only. It was concluded that extension-flexion exercises gave more favorable outcomes when it is combined with lumbopelvic manipulation than extension-exercise program alone in regards to the OSW scores ($p < 0.05$; Erhard et al., 1994).

Again, the positive outcomes cannot be attributed entirely to the lumbopelvic manipulation alone because the treatment effect could have come from the different exercises received by the two groups.

Later, Childs et al. (2004) examined the effectiveness of this manipulation on a subset of patients with LBP. This subset of the patients were those who had LBP with or without referral to the lower extremity, had disability levels of at least 30% on the OSW, and had no contraindications to spinal manipulation. Participants were assigned either to a manipulation group or to an exercise group. During the first week of the study, participants in the manipulation group received two sessions of lumbopelvic manipulation combined with range of motion exercises whereas participants in the exercise group received two sessions of low-stress aerobic exercise and lumbar spine strengthening exercises. All participants received low-stress aerobic exercise and lumbar spine strengthening exercises on average of once a week for the following 3 weeks of the study. Childs et al. (2004) found that participants in the manipulation group had better disability levels as measured by OSW at the 1-week follow-up ($p < 0.001$), at the 4-week follow-up ($p = 0.006$), and at the 6-month follow-up ($p = 0.001$) when compared to the group, which received exercises only (Childs et al., 2004). The results imply that the lumbopelvic manipulation combined with range of motion exercises could be beneficial for this subset of patients with LBP.

Several studies have examined the predictor factors that are associated with positive outcomes when treating patients with LBP using the lumbopelvic manipulation (Childs et al., 2004; Fritz, Childs, & Flynn, 2005). Childs et al. (2004) have developed a clinical prediction rule for using a lumbopelvic manipulation in patients with LBP. One

hundred thirty-one participants with LBP were randomly assigned either to a manipulation group, in which participants received lumbopelvic manipulations and extension exercises, or to an exercise group, in which participants received extension excises only. Based on the outcomes of the treatment, the authors developed a prediction rule for patients with LBP who are more likely to experience improvement in disability level as measured by the OSW and pain level as measured by the NPRS. These criteria were (1) duration of symptoms of less than 16 days, (2) FABQ score of less than 18, (3) one or more hypomobile lumbar segments, (4) hip internal rotation range of motion of more than 35 degrees on one or both sides, and (5) no symptoms below the knee. The clinical prediction rule was considered positive when a patient had at least four out of the five of these criteria. The odds ratio of having successful treatment outcomes for patients who received the lumbopelvic manipulation and had a positive clinical prediction rule were 60.8, and 1.0 for those who did not receive the lumbopelvic manipulation. This means that patients with a positive clinical prediction rule who received the manipulation were almost 61 times more likely to have successful treatment outcome than those who did not receive the manipulation. The odds ratio of having a successful treatment outcome for patients who received the lumbopelvic manipulation but did not have a positive clinical prediction rule was 2.4, meaning that these patients were 2.4 times more likely to have a positive treatment outcome when treated with lumbopelvic manipulation.

Childs et al. (2004) concluded that patients with a positive clinical prediction rule had a 90% chance of having successful treatment outcomes when treated with lumbopelvic manipulation. One year later, Fritz, Childs, and Flynn (2005) found that the presence of only two criteria, which were duration of symptoms of less than 16 days and no

symptoms below the knee, could predict positive treatment outcomes in patients with LBP (Fritz et al., 2005). Both of these studies advocated acuity of symptoms as an important predictor of successful treatment outcomes when lumbopelvic manipulation was used. However, Senna and Machaly (2011), as mentioned previously, found that this manipulation also could be effective in patients with CLBP (Senna & Machaly, 2011).

The association between lumbopelvic manipulation and alteration of spinal and abdominal muscle activation has been studied in the literature (Brenner et al., 2007; Raney, Teyhen, & Childs, 2007). This muscle activation was determined via studying muscle thickness. In a case series, Raney, Teyhen, and Childs (2007) studied the association between the lumbopelvic manipulation and the change in lateral abdominal muscle thickness in nine patients who had acute LBP for less than 16 days and did not have symptoms below the knee. The authors studied the muscle thickness of the transverse abdominis muscle and the internal oblique muscle at rest and during the abdominal drawing-in maneuver before and after the application of the lumbopelvic manipulation. The abdominal muscle thickness was measured using rehabilitative ultrasound imaging (RUSI). The authors found that six out of the nine patients demonstrated an increase in the transverse abdominis muscle thickness during the abdominal drawing-in maneuver with changes in thickness ranging from 11.5% and 27.9%. In five of the nine patients, the resting thickness of the transverse abdominis muscle decreased by 11.5% - 25% after the manipulation. Four out of the nine patients demonstrated a reduction of 6.4% - 12.2% in the resting thickness of the internal oblique muscle after the manipulation (Raney et al., 2007).

Brenner et al. (2007) studied the association between spinal manipulation and altered thickness of the MULT muscle in a patient with CLBP who had symptoms for 21 years. The intervention consisted of lumbopelvic manipulation and a L4-5 segment-specific lumbar manipulation. The MULT muscle thickness at the level of L4-5 was measured using RUSI imaging at rest and while the patient was lifting his upper extremities in a prone-lying position. The authors found that the percentage of change of muscle thickness from resting to contraction was 3.6% before the application of spinal manipulation. The percent change increased to 17.2% immediately after the manipulation and to 20.6% at one-day follow-up, which was close to normal percentage change of 22% found in healthy adults (Brenner et al., 2007). The lumbopelvic manipulation seems to be positively associated with improvement of muscle contraction not only in cases with acute LBP, but also with CLBP. However, no cause and effect conclusion can be made due to the small sample size.

Thrust and non-thrust manual therapy techniques may result in similar effects on pain and disability levels (Cook, Learman, Showalter, Kabbaz, & O'Halloran, 2013). Most of the time, it is up to the therapist whether to choose one approach or the other based on the results of the clinical examination. Goldby et al. (2006) compared the long-term effects of a 10-week program of lumbar manual therapy, spinal stabilization exercise, and minimal treatment. In this study, it was up to the treating therapist to select the form of manual therapy. The authors found that patients with CLBP who received manual therapy and those who received stabilization exercises demonstrated a significant reduction in their pain and disability levels at three months, six months and 12 months after the intervention ($p < 0.001$) as compared to minimal treatment (Goldby, Moore,

Doust, & Trew, 2006). A similar study was conducted by Aure et al. (2003) found that patients with CLBP who received manual treatment had significantly lower pain levels and disability levels than patients who received exercise intervention ($p < 0.01$; Aure, Nilsen, & Vasseljen, 2003). In this study, therapists were given the option to manipulate or mobilize the lumbar spine, and were also given the option to include manual therapy to the sacroiliac joints. The sacroiliac joint manual therapy included ventral or dorsal rotational techniques with patients in a prone lying position and a side-lying position, respectively (Aure et al., 2003). In summary, the therapists' clinical reasoning in selecting manual therapy techniques or other forms of treatment could be an important factor to achieve favorable outcomes for patients with CLBP. In addition, these patients often present with various symptoms and dysfunctions. A thorough physical examination may be warranted to assist therapists' clinical decision-making in selecting an appropriate treatment.

Hip Manual Therapy

As mentioned previously in this review, manual therapy has shown to be effective in decreasing pain and improving function in CLBP if it is applied to areas other than the lumbar spinal regions. For example, manual therapy to hips has been effective in decreasing symptoms and improving physical function in patients with CLBP. In a case series, Burns et al. (2011) examined the effects of hip manual therapy combined with exercises on eight patients with CLBP. Different hip manual therapy techniques were used such as long-axis distraction thrust manipulation, supine caudal non-thrust manipulation, supine anterior-posterior non-thrust manipulation, and prone posterior-to-anterior non-thrust manipulation in addition to exercises that were designed to improve

the mobility of the lumbopelvic area. It was concluded that five of the eight patients showed improvement in their disability levels, which was estimated as 24.4% reduction in the OSW scores (Burns, Mintken, Austin, & Cleland, 2011). However, because this was a case series, the results cannot produce a casual-effect relationship. Randomized controlled trials are needed to validate these findings in a larger sample. To our knowledge, there have been no studies that have examined the effects of thrust or non-thrust manual therapy on endurance or fatigability of the back and hip muscles in patients with CLBP.

Summary

CLBP is a common musculoskeletal condition among adults in the U.S. CLBP has been found to be associated with decreased endurance and increased fatigability of spinal and hip muscles, especially the lumbar paraspinal muscles, GMAX muscles and GMED muscles. Evidence has shown that the EMG median frequency collected during the modified Sørensen test is a valid and reliable tool to objectively measure the fatigability of back and hip muscles in asymptomatic adults and in adults with LBP. It has been speculated that weakness and increased fatigability of back and hip muscle may lead to abnormal loading on the passive structures of the spine, therefore causing CLBP. Lastly, although the effects thrust manipulation on the pain and disability levels have been examined in adults with CLBP, there are no studies that have examined the effects of thrust manual therapy, specifically the lumbopelvic manipulation, on the fatigability of back and hip muscles.

CHAPTER III

METHODS

Evidence has shown that back and hip muscle fatigability can be altered in patients with chronic low back pain (CLBP) (Himmelreich, Vogt, & Banzer, 2008; Hultman et al., 1993; Kankaanpää, Taimela et al., 1998; Paquet et al., 1994). In addition, moderate evidence supports the use of lumbopelvic manipulation for acute LBP and CLBP (Cibulka, 1992; Erhard et al., 1994; Senna & Machaly, 2011). No studies have examined the effectiveness of lumbopelvic manipulation on the back and hip muscle fatigability in patients with CLBP.

The primary purpose of Phase I of this study was to examine the immediate effects of lumbopelvic manipulation on the muscle fatigability level of the lumbar multifidus (MULT), gluteus maximus (GMAX), and gluteus medius (GMED) muscles compared to a placebo intervention in patients with CLBP. The secondary purpose of Phase I was to examine the immediate effects of lumbopelvic manipulation on pain level measured by the VAS as compared to a placebo intervention in patients with CLBP. The primary purpose of Phase II was to examine the one-week carry-over effects of lumbopelvic manipulation on muscle fatigability level of the MULT, GMAX, and GMED muscles compared to a placebo intervention in patients with CLBP. The secondary purpose of Phase II was to examine the carry-over effects of lumbopelvic manipulation on pain level measured by VAS as compared to a placebo intervention in patients with CLBP.

Research Design

This study was a mixed-design, randomized controlled trial (RCT) with two independent variables, one between-subject factor (group) and one within-subject factor (time). The independent variable of group had two levels: manipulation group and placebo group. For Phase I, the independent variable of time had five levels (baseline, immediately after intervention, 15 minutes after intervention, 30 minutes after intervention, and 45 minutes after intervention). For Phase II, the independent variable of time had three levels (baseline, three days after the intervention, and one week after intervention). The dependent variables included the fatigability of the bilateral MULT, GMAX, and GMED muscles and the pain level.

Participants

Participants were recruited from the Dallas-Fort Worth area via flyers and word of mouth. The procedure of study, along with the possible risks and benefits were explained to the participants. Each participant was asked to sign a consent form approved by the Institutional Review Board. Approval was obtained from the Texas Woman's University–Dallas prior to beginning the study (see Appendix D). The study was registered on ClinicalTrials.gov with the registration number of NCT01861418.

To determine the number of participants required for this study, a power analysis was performed using G*power 3.1.3 with a significance level of 0.05, power level at 0.80, and the effect size at 0.20. The power analysis suggested a minimum of 32 participants were required for a 2x5 ANOVA repeated measure, with 16 participants in each group to achieve a power level of 0.80.

Men and women between the ages of 20 to 60 with complaints of LBP for at least six months were recruited from outpatient physical therapy clinics in the Dallas-Fort Worth area. Individuals older than 60 years were excluded as those individuals are at higher risk for other conditions such as arthritis, osteoporosis, and spinal stenosis. These conditions may have influenced their performance of the fatigue testing for this study.

Individuals younger than 20 years were excluded as the presence of CLBP in this age range could yield to serious pathology and the likelihood of having CLBP of musculoskeletal origins was low (Hollingworth, 1996; Kujala, Taimela, Oksanen, & Salminen, 1997). Therefore, participants younger than age 20 and those who are older than age 60 were excluded from this study. An additional exclusion criterion was LBP level less than 1.8 cm on the VAS because this pain level was the minimal clinical important difference (MCID) for this scale in patients with CLBP (Hägg et al., 2003). The additional exclusion criteria included: (1) any serious spinal condition such as tumor, fracture, or infection, (2) signs of nerve root compression (i.e. diminished deep tendon reflexes, loss of sensation or loss of strength in a lower extremity, or positive straight-leg-raise test $\leq 45°$ as this could be a sign of severe disc herniation), (3) structural deformity such as scoliosis, (4) spondylolisthesis, (5) ankylosing spondylitis, (6) spinal stenosis, (7) osteoporosis, (8) previous surgery to the back or the hip, (9) current pregnancy or pregnancy within the past 6 months, and (10) the patient's inability to tolerate the testing or the treatment position (Senna & Machaly, 2011).

Investigators

Three investigators participated in carrying out this research study. Investigator #1, the primary investigator (PI) for this study, was a PhD student in physical therapy, a

licensed physical therapist for two years in the United States, and had one year's clinical experience in Saudi Arabia. Investigator #1 had received manual therapy training, including the manipulation technique that was used in this study. Investigator #1 performed the clinical examination and delivered the intervention to the participants in this study. Investigators #2 and #3 were two entry-level doctoral physical therapy (DPT) students who assisted in the EMG data collection and the data analysis in this study. Prior to beginning the study, the DPT students had received up to eight hours of training to standardize the procedures for EMG data collection and processing.

Instruments

Electromyographic Equipment

A 16-channel Delsys electromyographic (EMG) system (see Appendix E) with wireless surface electrodes (Delsys Inc, Boston, MA) was used to determine the fatigability level of the MULT, GMAX, and GMED muscles. The full bandwidth of the EMG unit is 20 to 450 Hz with a gain of 1,000. The EMG signal was recorded at a sampling rate of 1,000 Hz. Each surface electrode unit had a pair of active electrodes separated by a 1-cm distance. EMG median frequency has been used to measure the endurance of back and hip muscles (Biedermann et al., 1990; Clark et al., 2003; Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008; Kankaanpää, Taimela et al., 1998), and has been shown to be a good indicator of back muscle fatigue during isometric back extension (Mannion & Dolan, 1994). Coorevits et al. (2008) reported that EMG median frequency had good test-retest reliability for the MULT muscles (ICC = 0.72) and the GMAX muscles (ICC = 0.73) for healthy adults during a modified Sørensen test. Therefore, their EMG testing protocol was followed in this study. The

EMG median frequency of the above-mentioned three muscles on the painful side was collected seven times: before intervention, immediately after intervention, 15 minutes after intervention, 30 minutes after intervention, 45 minutes after intervention, three days after the intervention, and one week after intervention.

Visual Analogue Scale

A 10-cm VAS was used to determine pain level in this study. The VAS consists of a horizontal line, with the left end representing no pain and the right end representing worst pain ever. Participants were asked to mark their current pain level, worst pain level, and least pain level in the past 72 hours on the VAS immediately before each EMG data collection and the average of the three pain ratings was calculated (Childs et al., 2004) to ensure that they have a pain level of at least 1.8 cm. In addition, the current pain intensity was collected just before each EMG recording. The VAS is described in the literature as one of the best instruments to measure pain intensity (Scott & Huskisson, 1976). Leboeuf et al. (1989) reported that the VAS is reliable to determine LBP intensity when measuring the current pain intensity level ($r = 0.77$), a remembered worst intensity of pain ($r = 0.49$), and a remembered least pain intensity ($r = 0.57$) (Leboeuf et al., 1989; Paungmali et al., 2012). In addition, Paungmali et al. (2012) found that the VAS is a reliable tool to measure non-specific LBP in the lumbopelvic area (ICCs = 0.87-0.96) (Paungmali et al., 2012). The current pain level was collected seven times: before intervention, immediately after intervention, 15 minutes after intervention, 30 minutes after intervention, 45 minutes after intervention, three days after the intervention, and one week after intervention.

Modified Oswestry Disability Questionnaire

The Oswestry Disability Questionnaire (OSW) measures the disability related to LBP. The original OSW described by Fairbank et al. in 1980 consists of 10 items, including pain intensity, lifting, walking, sitting, standing, sleeping, social life, traveling, and sex life. Each item can be scored from 0 to 5 and the total score is multiplied by 2 to get the final percentage of the OSW score. Higher scores indicate greater disability levels (Fairbank et al., 1980). Because the "sex life" item often is left blank most of the time, a modified version of OSW was developed and replaced the "sex life" item with "employment and homemaking" (Fritz & Irrgang, 2001). The modified OSW version (see Appendix A) was used in this study. The modified OSW has been found to be a reliable measure for back pain related disability (ICC = 0.84), and can detect disability improvement and worsening in individuals with LBP with a minimal detectable change (MDC) of 10.5% (Davidson & Keating, 2002). The MCID for OSW is 10% for patients with CLBP (Hägg et al., 2003). Each participant in this study was asked to fill out a modified OSW at the beginning of the study to show the baseline disability level of the participants.

Fear Avoidance Beliefs Questionnaire

The FABQ, which was first described by Waddell et al. in 1993 to assess the level of the fear-avoidance beliefs. The FABQ consists of 16 items (Appendix B). These items can be scored from 0 to 6. The higher score indicates higher levels of fear of pain and higher levels of activity changes to avoid LBP. This questionnaire has two sections: work-related fear avoidance beliefs and fear avoidance beliefs related to physical activity. The FABQ-work consists of seven items that can be scored between 0 and 42. The

FABQ-physical activity consists of four items and can be scored between 0 and 24 (Waddell et al., 1993). The literature has shown that there is an association between the FABQ and work loss as well as disability in patients with CLBP (Crombez et al., 1999; Fritz et al., 2001; Hadjistavropoulos & Craig, 1994). Both the FABQ-work and the FABQ-physical activity were found to be reliable for patients with CLBP (ICC = 0.96, 0.90; MDC = 6.8, 5.4, respectively) (George et al., 2010). The MCID for the FABQ-physical activity was found to be four points. However, no studies yet have determined the MCID for the FABQ-work (George et al., 2004). The FABQ was administered at the beginning of this study show the baseline fear-avoidance level of the participants.

Procedures

Screening and Testing Procedures

Each participant was asked to fill out a medical intake form (see Appendix F). The PI determined their eligibility for the study examined participants. The clinical examination (see Appendix G) included tests to rule out any neurological involvement, abnormal mobility, and sacroiliac joint dysfunction (Cleland, Koppenhaver, Netter, 2011; Magee, 2002). Each participant used the VAS to rate their current, worst and least pain levels in the past 72 hours on the painful side of the back. The average of these three pain ratings was used for later statistical analysis (Childs et al., 2004). If the pain was bilateral or central, the participant was asked to rate their pain level on the side that is the most painful. Each participant was asked to complete the modified OSW (see Appendix A) and FABQ (see Appendix B). Next, each participant was randomly assigned to either a manipulation group or a placebo group. To ensure equal numbers in each group (i.e., 16 each), each participant was asked to pick a sealed envelope which contained a card noted

either “Group A” or “Group B.” Sixteen envelopes for Group A and 16 envelopes for Group B were prepared. Participants who picked “Group A” were assigned to the manipulation group. Participants who picked “Group B” were assigned to the placebo group. For each participant who withdrew from the study, an envelope containing a card indicating their assigned group was put back in the stack of sealed envelopes.

For the EMG recording, the skin over the MULT, GMAX and GMED muscles on the painful side was cleaned with alcohol swabs. If there was excessive hair in these areas, it was shaved. Next, three wireless bipolar EMG surface electrodes were placed on the MULT, GMAX, and GMED muscles bilaterally parallel to the direction of the muscle fibers. For the MULT muscle, the electrode was placed 2 cm away from the second sacral spinous process, just above the level of the posterior superior iliac spines (Figure 1, a) (Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008). For the GMAX muscle, the electrode was placed at the mid-point between the posterior superior iliac spine and the ischial tuberosity (Figure 1, b) (Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008). For the GMED muscle, the electrode was placed at one-third the distance between the greater trochanter and the iliac crest starting from the greater trochanter (see Figure 1c; Rainoldi, Melchiorri, & Caruso, 2004).

Figure 1. From left to right, electrodes placement sites for (a) multifidus (b) gluteus maximus, and (c) gluteus medius muscles.

The EMG median frequency of the MULT, GMAX, and GMED muscles was recorded while participants perform a modified Sørensen test (see Figure 2).

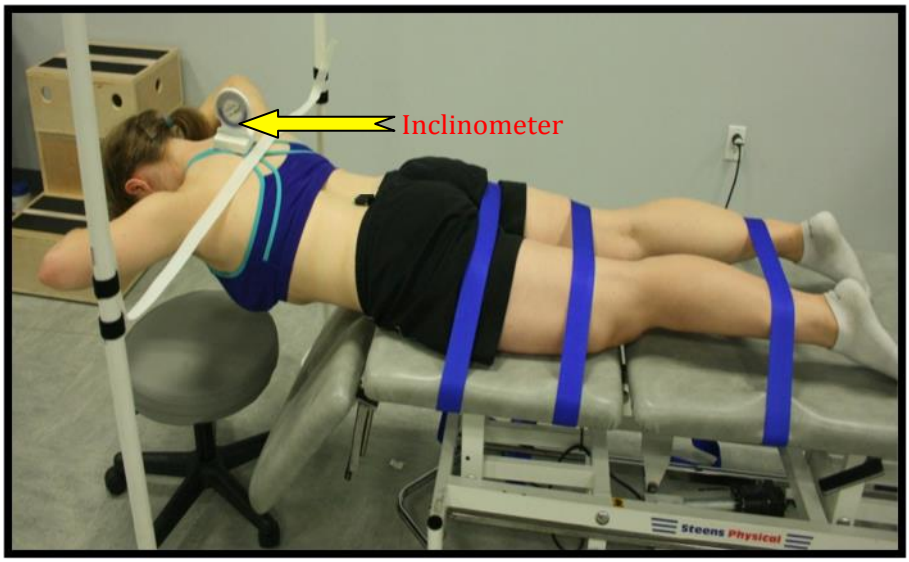

Figure 2. The modified Sørensen test.

Participants were given a practice trial for the modified Sørensen test to familiarize them with the protocol. Next, the first EMG trial for the MULT, GMAX, and GMED muscles was recorded. Following a 15-minute rest, each participant in the manipulation group was treated with a lumbopelvic manipulation and each participant in the placebo group received a pre-manipulation hold. The PI (Investigator #1) performed all interventions. For Phase I of the study, the EMG median frequency for the MULT, GMAX, and GMED muscles was collected again immediately, 15 minutes, 30 minutes, and 45 minutes after intervention. A rest period of 15 minutes was given between each testing session as a 15-minute rest was shown to be enough for muscles to recover after a sustained contraction (Larivière et al., 2003). Each participant was asked to return to repeat the same EMG testing at 3 days and at one week after the first visit for Phase II of the study.

To perform the modified Sørensen test (see Figure 2), participants were asked to lie prone on a treatment table with the bilateral superior borders of anterior superior iliac spines at the edge of the table and the upper body hanging off of the table. Each participant's lower body was stabilized on the table with two belts placed over the hips, just below the knees (Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008). To add more stability, a third belt was placed just above the ankles. During the modified Sørensen test, participants extended their trunk and maintained a trunk horizontal position with their hands touching their forehead, their head in a neutral position, and their elbows out to the side. A rope connected by two vertical stands was placed at the level of the participants' seventh thoracic vertebrae. This rope provided tactile feedback to the participants to encourage them to maintain their body in a horizontal position during the testing procedure (Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008). A fluid-filled bubble inclinometer (Fabrication Enterprises Inc, White Plains, NY; see Figure 2) also was placed over the interscapular area to monitor the trunk position (Latimer et al., 1999). When a participant deviated more than10 degrees from the horizontal position, the participant was asked to extend his/her trunk and keep it in a horizontal position. If the participant could not maintain a horizontal position, the test was ended (Latimer et al., 1999).

Treatment Procedures

The lumbopelvic manipulation (see Appendix C) used in the study has been previously described in the literature (Cibulka, 1992; Erhard et al., 1994; Flynn et al., 2002). Each participant in the manipulation group was asked to lie in a supine position. The PI stood on the opposite side of the LBP. Then, the participant was asked to clasp

his/her hands behind the neck. The PI positioned the participant's trunk in side-bending toward the painful side or away from the PI. The PI reached through the participant's arms with his cranial hand and placed the hand on the participant's upper back. With his cranial hand, the treating PI performed a trunk rotation away from the painful side or toward the PI. The PI reached over the participant's body and placed his other hand (caudal hand) over the anterior superior iliac spine (ASIS) of the participant's painful side. Finally, the PI took up the slack, maintained a pre-manipulation hold position, and asked the participant whether he/she could tolerate that position. If the participant could tolerate the pre-manipulation hold, a verbal permission was obtained from the participant and then the PI proceeded and applied a high-velocity low-amplitude posterior thrust force over the ASIS (Cibulka, 1992; Flynn et al., 2002). For participants in the placebo group, the same procedure was followed except that the PI side-bent and rotated participants' trunks only half way through the range of motion and maintained the pre-manipulation hold position only without applying a high-velocity low-amplitude thrust.

Data Analysis

Participants' demographic data, including age, gender, duration of symptoms, height, weight, body mass index (BMI), disability level, fear-avoidance level and all outcome measures (fatigue rates of the three muscles and pain level) were compared at baseline using independent *t*-tests or chi-square tests to ensure that there were no significant differences between the two groups. The Delsys EMGWorks software (Delsys Inc., Natick, MA) was used to calculate the EMG median frequency for each 1-second window (see Figure 3).

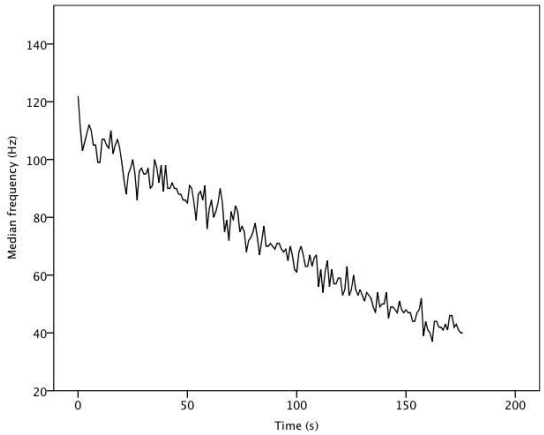

Figure 3. The EMG median frequency power spectrum of a participant.

The EMG median frequency data was then exported to SPSS. Linear regression was performed on the EMG median frequency data to determine the slope and the initial EMG median frequency. Lastly, a normalized value (i.e., fatigability or fatigue rate) was calculated using the following equation:

$$\text{Rate of fatigue (\%/second)} = \left(\frac{\text{EMG median frequency slope}}{\text{EMG median frequency initial}}\right) \times 100 \quad (1)$$

For Phase I of this study, four separate two-way (2x5) ANOVA with repeated measures was performed to compare the EMG median frequency fatigue rates of the three muscles and the VAS scores between groups over five different time points (baseline, immediately after intervention, 15 minutes after intervention, 30 minutes after intervention, and 45 minutes after intervention). If there was a significant interaction, post-hoc 2 (group) x 2 (time) ANOVAs were performed in order to determine where the significant differences occurred. If a significant main effect of time was found, post-hoc pairwise comparisons were performed to determine where the significant differences occurred. The significance level was set at $p = 0.05$ for all statistical analyses.

For Phase II of this study, four separate two-way (2x3) ANOVA with repeated measures was performed to compare the EMG median frequency fatigue rates of the three muscles and VAS data between groups over three different time points (baseline, three days after the intervention, and one week after intervention). If there was a significant interaction, post-hoc 2 (group) x 2 (time) ANOVAs were performed in order to determine where the significant differences occurred. If a significant main effect of time was found, post- hoc pairwise comparisons were performed to determine where the significant differences occurred. The significance level was set at $p = 0.05$ for all statistical analyses.

CHAPTER IV

RESULTS

The primary purpose of Phase I of this study was to examine the immediate effects of lumbopelvic manipulation on the muscle fatigability level of the lumbar multifidus (MULT), gluteus maximus (GMAX), and gluteus medius (GMED) muscles compared to a placebo intervention in patients with chronic low back pain (CLBP). The secondary purpose of Phase I was to examine the immediate effects of lumbopelvic manipulation on pain level measured by the Visual Analogue Scale (VAS) as compared to a placebo intervention in patients with CLBP. The primary purpose of Phase II was to examine the one-week carry-over effects of lumbopelvic manipulation on muscle fatigability level of the MULT, GMAX, and GMED muscles compared to a placebo intervention in patients with CLBP. The secondary purpose of Phase II was to examine the carry-over effects of lumbopelvic manipulation on pain level measured by VAS as compared to a placebo intervention in patients with CLBP.

Participants

Forty participants were recruited from Dallas-Fort Worth area. A total of nine participants were excluded. One participant was excluded due to spinal scoliosis, three due to having neurological signs and symptoms of the lower extremities, and five because they were not able to come at the required testing times in the testing lab due to scheduling conflicts. In addition, four participants did not show up for the last two sessions to complete Phase II of this study. In total, 31 participants completed Phase I of this study

and 27 participants completed Phase II of this study. Figure 4 shows a CONSORT diagram of participants' enrollment and randomization for this study.

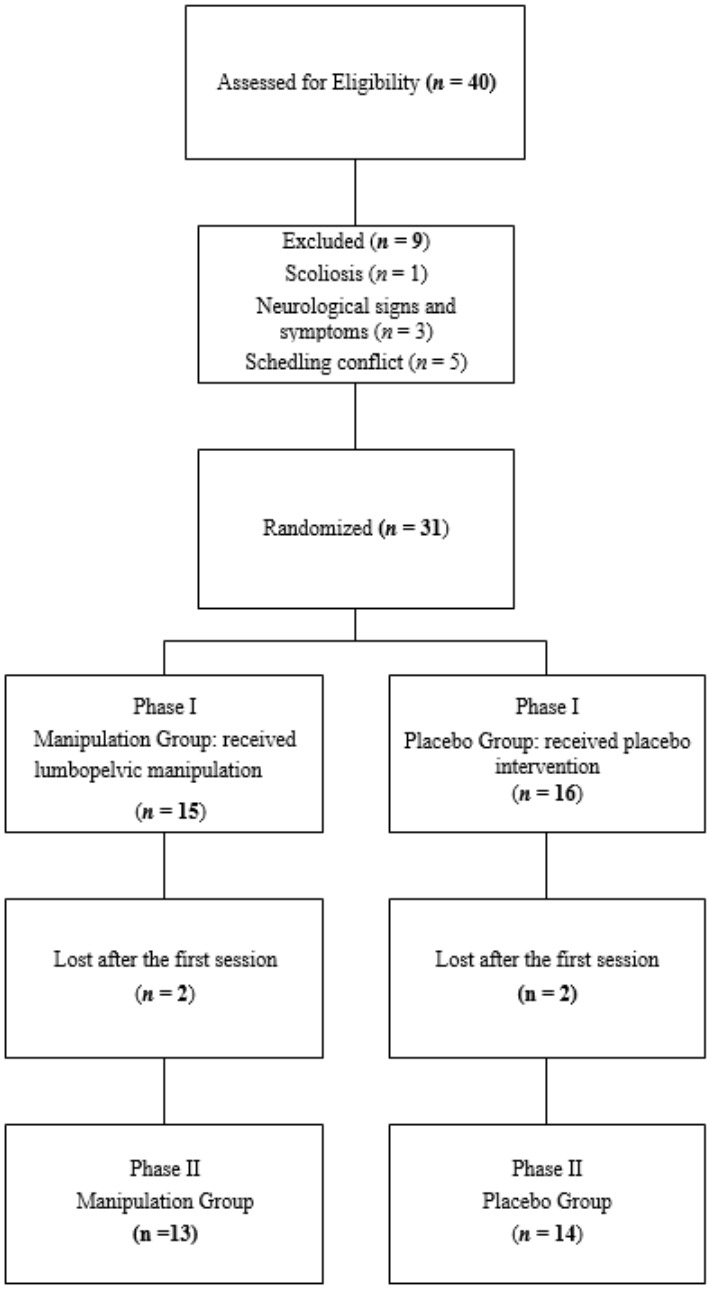

Figure 4. CONSORT diagram of participants' enrollment and randomization.

Phase I Results

Table 1 displays the characteristics of the participants. The participants in this phase were generally young with an average age of 29.7 years. The sample of this phase of the study consisted of more women (n = 21) than men (n = 10). The participants, in general, had mild low back pain with average VAS score of 27 cm on the Visual Analogue Scale (VAS). There was no significant difference in any of the baseline characteristics between participants in the manipulation group and those in the placebo group. However, when comparing the baseline fatigue rates for the three muscles, there was a significant difference in the GMED fatigue rate between groups, with a higher fatigue rate in the placebo group than in the manipulation group.

Table 1

Phase I: Participants' Characteristics and Baseline Fatigue Rates (M ± SD)

	All participants (n = 31)	Manipulation Group (n = 15)	Placebo (n = 16)	p-Value
Age (years)	29.7 ± 8	30.2 ± 10.1	29.3 ± 5.7	0.780
Weight (kg)	75 ± 16.4	78.79 ± 4.8	71.5 ± 13.07	0.224
Height (cm)	168.3 ± 9.3	169.7 ± 10.8	166 ± 7.8	0.408
BMI	26.3 ± 5.1	27.1 ± 5.1	25.6 ± 5.2	0.445
Gender (women/men)	21/10	8/7	1	0.097
VAS pain (cm)	2.70 ± 1.51	3.11 ± 1.47	2.32 ± 1.50	0.155
Duration of pain (months)	47.1 ± 55.4	49.2 ± 50.6	45.2 ± 61.1	0.844
FABQ				
Work	12.4 ± 9.0	13.9 ± 9.2	11.1 ± 8.7	0.397
Physical Activity	10.6 ± 6.2	12.2 ± 6.8	9.1 ± 5.3	0.156
OSW	15.2 ± 9.5	17.2 ± 11.3	13.3 ± 7.4	0.273
MULT fatigue rate	-0.78 ± 0.76	-0.96 ± 0.24	-0.62 ± 0.13	0.240
GMAX fatigue rate	-0.17 ± 0.46	-0.15 ± 0.4	-0.19 ± 0.5	0.783
GMED fatigue rate	-0.42 ± 0.3	-0.31 ± 0.24	-0.52 ± 0.33	0.049*
Sørensen time (s)	58.51 ± 27.66	50.33 ± 20.47	66.18 ±	0.112

Note. * $p < 0.05$. Kg = kilogram, cm = centimeter, VAS = Visual Analogue Scale, BMI = body mass index, FABQ = Fear Avoidance Beliefs Questionnaire, OSW= Modified Oswestry Disability Index, MULT = lumbar multifidus, GMAX = gluteus maximus, GMED = gluteus medius, s = second.

The immediate effects of the intervention on the fatigue rate and the pain level were assessed in Phase I to determine if there was any significant difference between the manipulation group and the placebo group. Therefore, the fatigue rate of the MULT, GMAX, and GMED in addition to the pain level was assessed before the intervention (i.e., baseline), and immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.

EMG Fatigue Rate

The fatigue rate was assessed from the EMG median frequency data according to the equation mentioned in Chapter III (Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008). The EMG fatigue rates of each of the three muscles over five different time points are shown in Table 2.

Table 2

Phase I: Fatigue Rate (M ± SD) for the Three Muscles Across Different Testing Points (% per Second)

	Baseline	Immediately	15 min	30 min	45 min
MULT					
All participants	-0.76 ± 0.66	-0.58 ± 0.33	-0.68 ± 0.35	-0.70 ± 0.38	-0.55 ± 0.65
Manipulation group	-0.80 ± 0.83	-0.58 ± 0.33	-0.70 ± 0.41	-0.67 ± 0.32	-0.44 ± 0.88
Placebo group	-0.73 ± 0.49	-0.58 ± 0.35	-0.66 ± 0.30	-0.73 ± 0.43	-0.65 ± 0.32
GMAX					
All participants	-0.15 ± 0.46	-0.22 ± 0.31	-0.33 ± 0.38	-0.23 ± 0.19	-0.29 ± 0.3
Manipulation group	-0.11 ± 0.41	-0.31 ± .25	-0.40 ± 0.51	-0.20 ± 0.21	-0.39 ± 0.36
Placebo group	-0.18 ± 0.52	-0.14 ± .35	-0.27 ± 0.20	-0.25 ± .18	-0.19 ± 0.21
GMED					
All participants	-0.41 ± 0.29	-0.37 ± 0.26	-0.26 ± .20	-0.30 ± .15	-0.3 ± 0.18
Manipulation group	-0.33 ± 0.25	-0.33 ± 0.28	-0.23 ± .27	-0.26 ± .11	-0.33 ± 0.22
Placebo group	-0.49 ± 0.30	-0.39 ± 0.25	-0.28 ± .11	-0.33 ± 0.17	-0.27 ± 0.15

Note. MULT = Multifidus, GMAX = Gluteus Maximus, and GMED = Gluteus Medius

Figure 5 illustrates the MULT fatigue rates for both the manipulation group and the placebo group. Because Mauchly's test for sphericity was significant ($p < 0.001$), the

homogeneity assumption was not met and therefore, the Greenhouse-Geisser statistics were reported. The ANOVA results showed no significant group by time interaction (p = 0.656). In addition, there was no significant main effect of time on the fatigue rate of the MULT (p = 0.350).

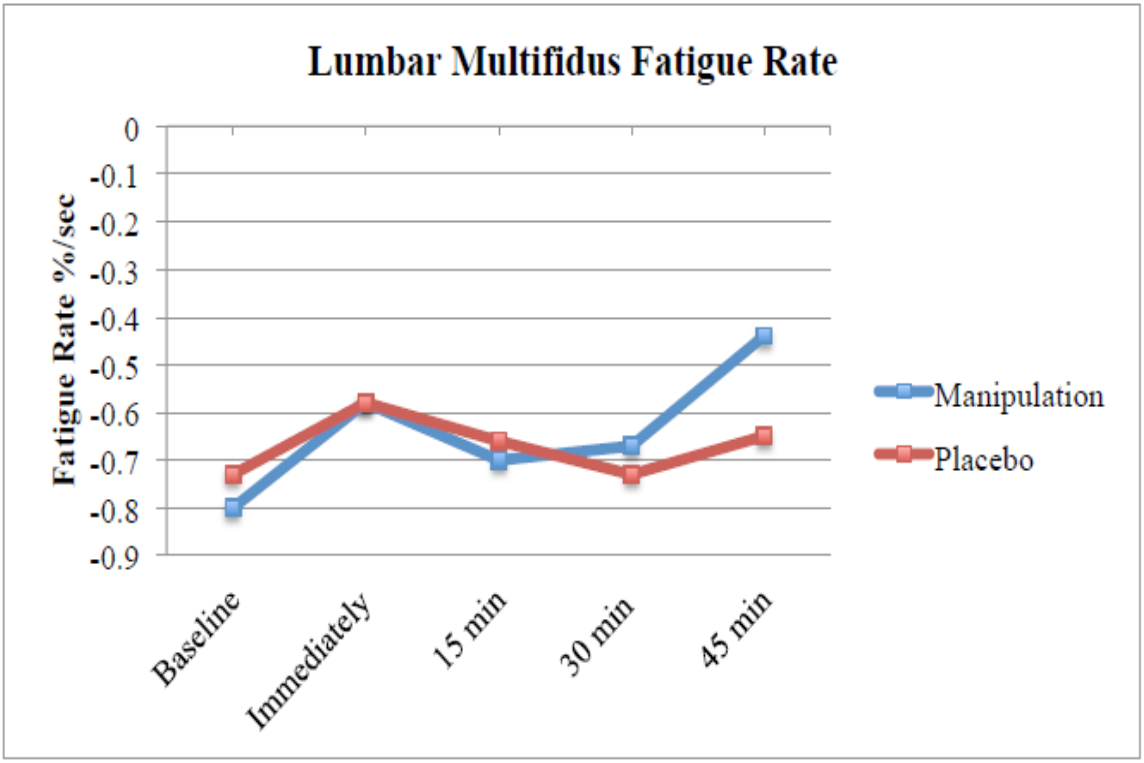

Figure 5. Phase I: fatigue rates of the lumbar multifidus muscle at baseline, immediately following intervention, and 15 min, 30 min and 45 min after the intervention.

Figure 6 illustrates the GMAX fatigue rates for both the manipulation group and the placebo group. Mauchly's test of sphericity was significant (p = 0.00001), indicating that the homogeneity assumption was not met. Therefore, the results of the Greenhouse-Geisser statistics were reported. Similar to the GMAX results, the ANOVA results showed no significant group by time interaction (p = 0.352). Although the manipulation had a noticeable decreased fatigue rate 45 minutes after the intervention, the difference was not statistically significant. In addition, there was no significant main effect of time on fatigue

rate of the GMAX muscle (p = 0.270).

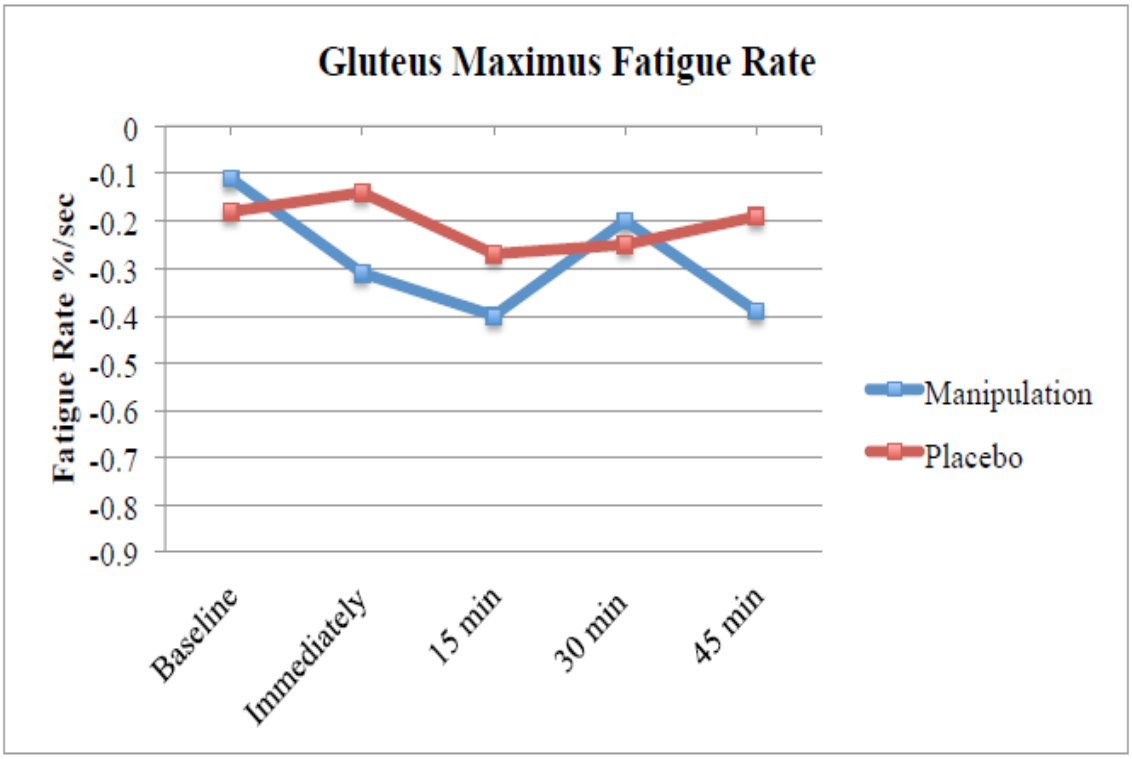

Figure 6. Phase I: fatigue rates of the gluteus maximus muscle at baseline, immediately following intervention, and 15 min, 30 min and 45 min after the intervention.

Figure 7 illustrates the GMED fatigue rates for both the manipulation group and the placebo group. Because Mauchly's test for sphericity was significant (p = 0.0003), the homogeneity assumption was not met and the Greenhouse-Geisser statistics were reported. Similar to the GMAX results, the ANOVA showed no significant group by time interaction (p = 0.430). In addition, there was no significant main effect of the time on the fatigue rate of the GMED (p = 0.100).

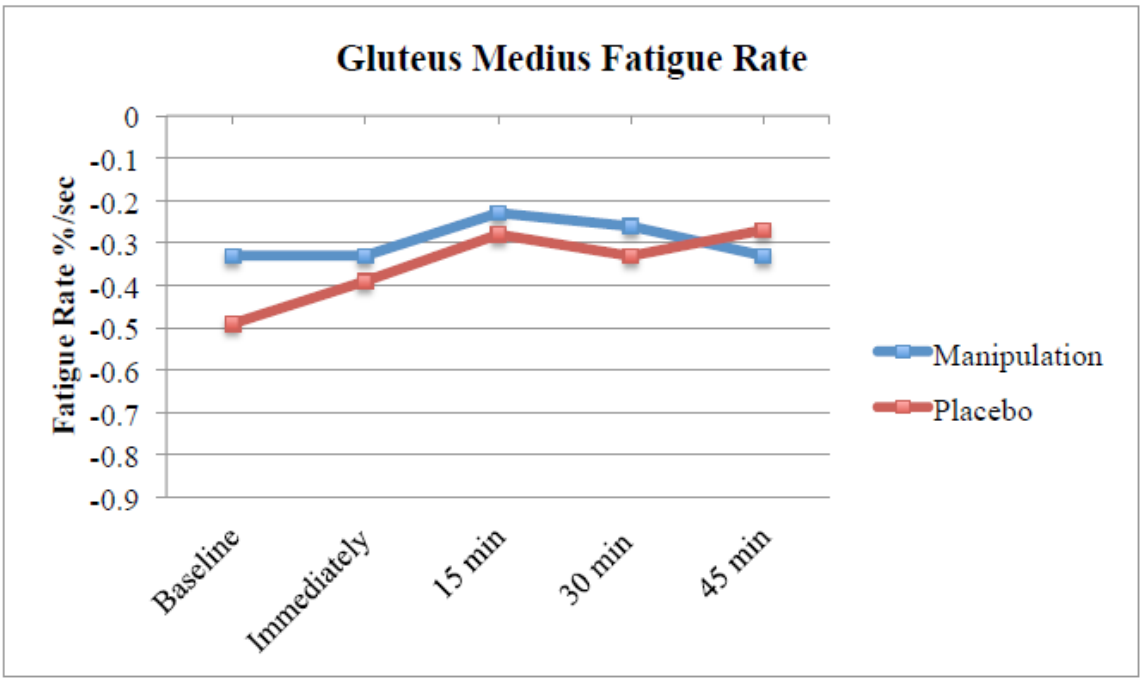

Figure 7. Phase I: fatigue rates of the gluteus medius muscle baseline, immediately following intervention, and 15 min, 30 min and 45 min after the intervention.

Pain Level

The VAS scores were compared to determine the effect of the intervention on the pain level. Table 3 lists the VAS score of all participants. In addition, Figure 8 illustrates VAS scores for both the manipulation group and the placebo group. Because Mauchly's test for sphericity was significant ($p = 0.050$), the homogeneity assumption was not met and the Greenhouse-Geisser statistics were reported. There was a significant interaction between group and time ($p = 0.019$). A post-hoc 2 (group) x 2 (time) was performed and the results showed that the manipulation group had a significantly greater pain reduction than the placebo group between 15 minutes and 30 minutes after the intervention ($p = 0.032$).

Table 3

Phase I: Pain Level (VAS) Across Different Testing Points (M ± SD) (cm)

	Baseline	0 min	15 min	30 min	45 min
All participants	2.70 ± 1.47	2.62 ± 1.49	2.50 ± 1.64	2.40 ± 1.34	2.31 ± 1.37
Manipulation group	3.10 ± 1.50	2.88 ± 1.48	2.83 ± 1.83	2.26 ± 1.49	2.08 ± 1.44
Placebo group	2.32 ± 1.50	2.38 ± 1.51	2.19 ± 1.44	2.53 ± 1.23	2.52 ± 1.31

Note. VAS = Visual Analogue Scale. cm = centimeter.

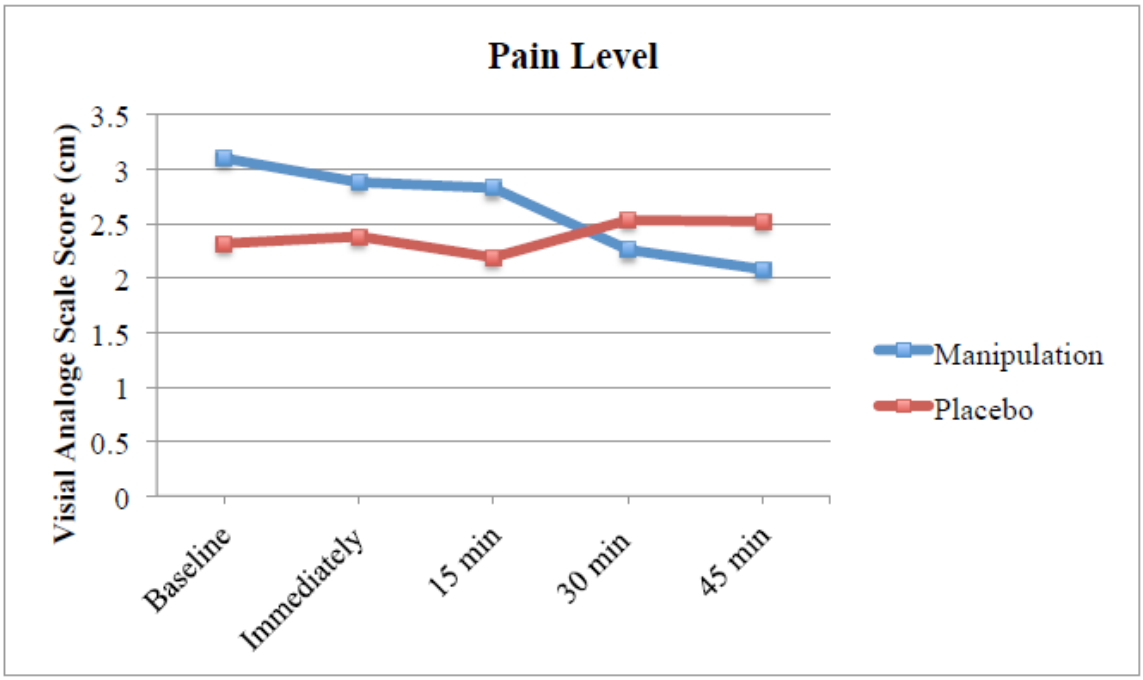

Figure 8. Phase I: Visual Analogue Scale scores at baseline, immediately following intervention, and 15 min, 30 min and 45 min after the intervention.

Phase II Results

Table 4 displays the characteristics of the 27 participants for Phase II of this study. Similar to Phase I, the participants in Phase II were young, with an average age of 29.9 years, and there were more women (n = 20) than men (n = 7). Also, the participants, in general, had mild low back pain with an average VAS score of 2.4 cm. There was no significant difference between participants in the manipulation group and those on the placebo group in any characteristic, except in gender, as there were significantly more

women than men in the placebo group as compared to the manipulation group. As shown in an EMG study, men's paraspinal muscles become fatigued faster than women's (Clark et al., 2003). Therefore, four separate ANCOVAs with repeated measures were performed for the three muscles and the VAS scores using the gender as a covariate. Table 5 shows the fatigue rate of all participants over the three time points in Phase II for each of the three muscles.

Table 4

Phase II: Participants' Characteristics and Baseline Fatigue Rates (M ± SD)

	All participants (n = 27)	Manipulation Group (n = 13)	Placebo Group (n = 14)	p-Value
Weight (kg)	73.8 ± 17.1	78.4 ± 19.6	69.5 ± 13.5	0.190
Height (cm)	167 ± 8.8	169.1 ± 11.3	165.1 ± 5.4	0.265
Age (years)	29.9 ± 8.1	33.1 ± 10.6	28.9 ± 5.2	0.519
BMI	26.3 ± 5.4	27.1 ± 5.4	25.6 ± 5.5	0.468
Gender (women/men)	20/	7/6	13/1	0.021*
VAS pain (cm)	2.49 ± 1.43	2.80 ± 1.31	2.21 ± 1.50	0.291
Duration of pain (months)	52.4 ± 57.6	55 ± 52.2	50 ± 64.1	0.827
FABQ				
Work	13.1 ± 9.5	14.5 ± 10.0	11.7 ± 9.2	0.452
Physical Activity	11.1 ± 6.5	12.8 ± 7.2	9.4 ± 5.5	0.180
OSW	15.7 ± 9.8	18.6 ± 11.6	13.0 ± 7.2	0.141
MULT fatigue rate	-0.80 ± 0.67	-0.88 ± 0.82	-0.73 ± 0.51	0.430
GMAX fatigue rate	-0.23 ± 0.34	-0.23 ± 0.14	-0.23 ± 0.44	0.809
GMED fatigue rate	-0.43 ± 0.32	-0.32 ± 0.27	-0.52 ± 0.35	0.090
Sørensen time (s)	57.92 ± 29.20	49.23 ± 21.01	66 ± 33.94	0.139

Note. * $p < 0.05$. Kg = kilogram, cm = centimeter, VAS = Visual Analogue Scale, BMI = body mass index, FABQ = Fear Avoidance Beliefs Questionnaire, OSW= Modified Oswestry Disability Index, MULT = lumbar multifidus, GMAX = gluteus maximus, GMED = gluteus medius, s = seconds.

Table 5

Phase II: Fatigue Rate (M ± SD) for the Three Muscles Across Different Testing Points (% per Second)

	Baseline	3 days	1 week
MULT			
All participants	-0.80 ± 0.67	-0.74 ± 0.65	-0.74 ± 0.55
Manipulation group	-0.88 ± 0.82	-0.84 ± 0.89	-0.83 ± 0.59
Placebo group	-0.73 ± 0.51	-0.64 ± 0.28	-0.65 ± 0.51
GMAX			
All participants	-0.23 ± 0.34	-0.21 ± 0.16	-0.18 ± 0.20
Manipulation group	-0.23 ± 0.14	-0.28 ± 0.15	-0.28 ± 0.15
Placebo group	-0.23 ± 0.44	-0.16 ± 0.14	-0.10 ± 0.21
GMED			
All participants	-0.43 ± 0.32	-0.25 ± 0.20	-0.31 ± 0.29
Manipulation group	-0.32 ± 0.27	-0.29 ± 0.22	-0.26 ± 0.20
Placebo group	-0.52 ± 0.35	-0.22 ± 0.17	-0.35 ± 0.18

Note. GMAX = gluteus maximus, MULT = multifidus, GMED = gluteus medius.

Figure 9 illustrates the MULT fatigue rates for both the manipulation group and the placebo group. Because Mauchly's test for sphericity was significant ($p = 0.010$), the homogeneity assumption was not met and the Greenhouse-Geisser statistics were reported. The ANCOVA results showed no significant group by time interaction ($p = 0.650$). In addition, there was no significant main effect of time on the fatigue rate of the MULT ($p = 0.326$).

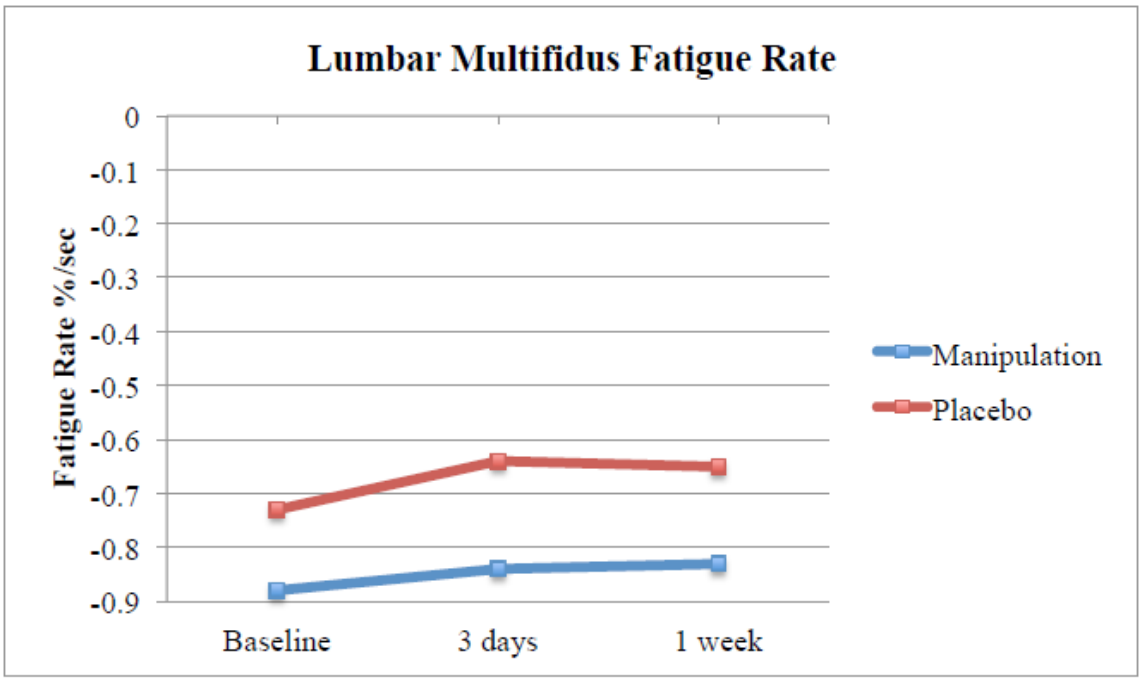

Figure 9. Phase II: fatigue rates of the lumbar multifidus muscle at baseline, and 3 days and 1 week after the intervention.

Figure 10 illustrates the GMAX fatigue rates for both the manipulation group and the placebo group. Because Mauchly's test for sphericity was significant ($p = 0.007$), the homogeneity assumption was not met, and the Greenhouse-Geisser statistics were reported. The ANCOVA results showed no significant group by time interaction ($p = 0.368$). In addition, there was no significant effect of the time on the fatigue rate of the GMAX ($p = 0.344$).

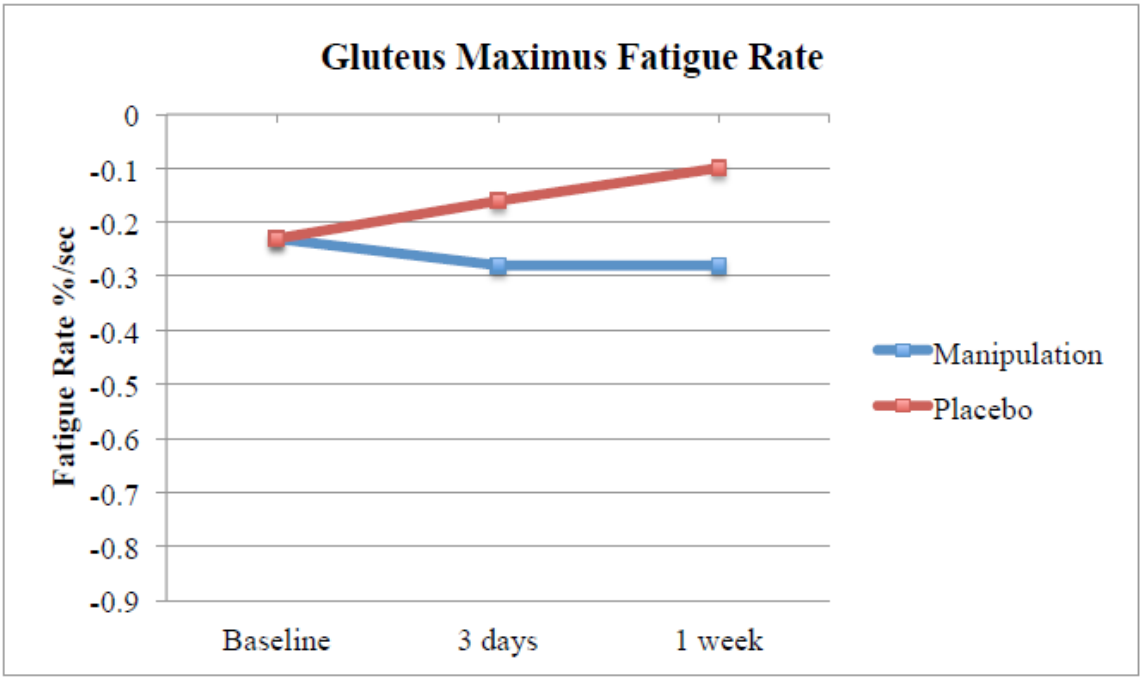

Figure 10. Phase II: fatigue rates of the gluteus maximus muscle at baseline, and 3 days and 1 week after the intervention.

Figure 11 illustrates the GMED fatigue rates for both the manipulation group and the placebo group. Because Mauchly's test for sphericity was significant ($p = 0.005$), the homogeneity assumption was not met, and the Greenhouse-Geisser statistics were reported. The ANCOVA results showed no significant group by time interaction ($p = 0.096$). In addition, there was no significant main effect of time on the fatigue rate of the GMED ($p = 0.188$).

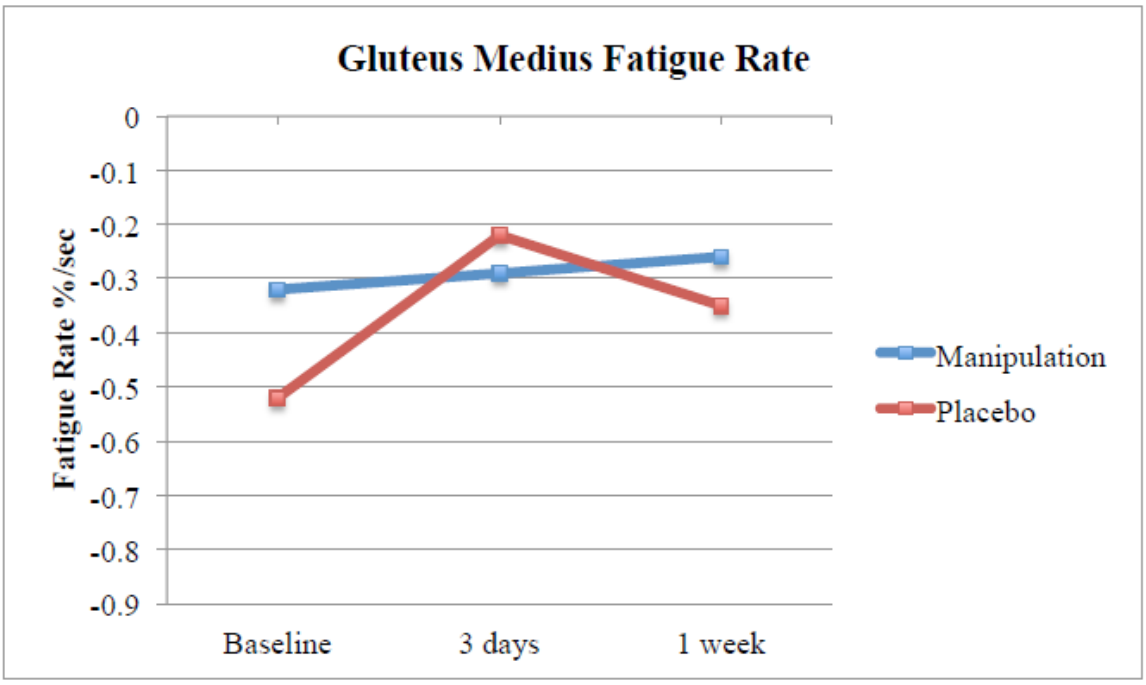

Figure 11. Phase II: fatigue rates of the gluteus medius muscle at baseline, and 3 days and 1 week after the intervention.

Pain Level

The VAS scores were compared between groups to determine the short-term effect of the intervention on the pain level three days after the intervention and one week after the intervention. Table 6 lists the VAS score of all participants. In addition, Figure 12 illustrates VAS scores for both the manipulation group and the placebo group. Because Mauchly's test for sphericity was not significant ($p = 0.057$), the homogeneity assumption was met. The ANCOVA results showed no significant interaction between group and time ($p = 0.263$). However, there was a significant main effect of time ($p = 0.049$), and post-hoc pair-wise comparison showed that all participants had significantly greater reduction in pain level at three days after intervention ($p = 0.019$) and one week after the intervention ($p < 0.001$) compared to the pain level at baseline, but no difference in pain level between three days and one week after the intervention ($p = 1.000$).

Table 6

Phase II: Pain Level (VAS) Across Different Testing Points (M ± SD) (cm)

	Baseline	3 days	1 week
All participants	2.49 ± 1.43	1.52 ± 1.34	1.35 ± 1.48
Manipulation group	2.80 ± 1.31	1.57 ± 1.40	0.95 ± 1.00
Placebo group	2.20 ± 1.51	1.47 ± 1.34	1.73 ± 1.77

Note. VAS = Visual Analogue Scale. cm = centimeter

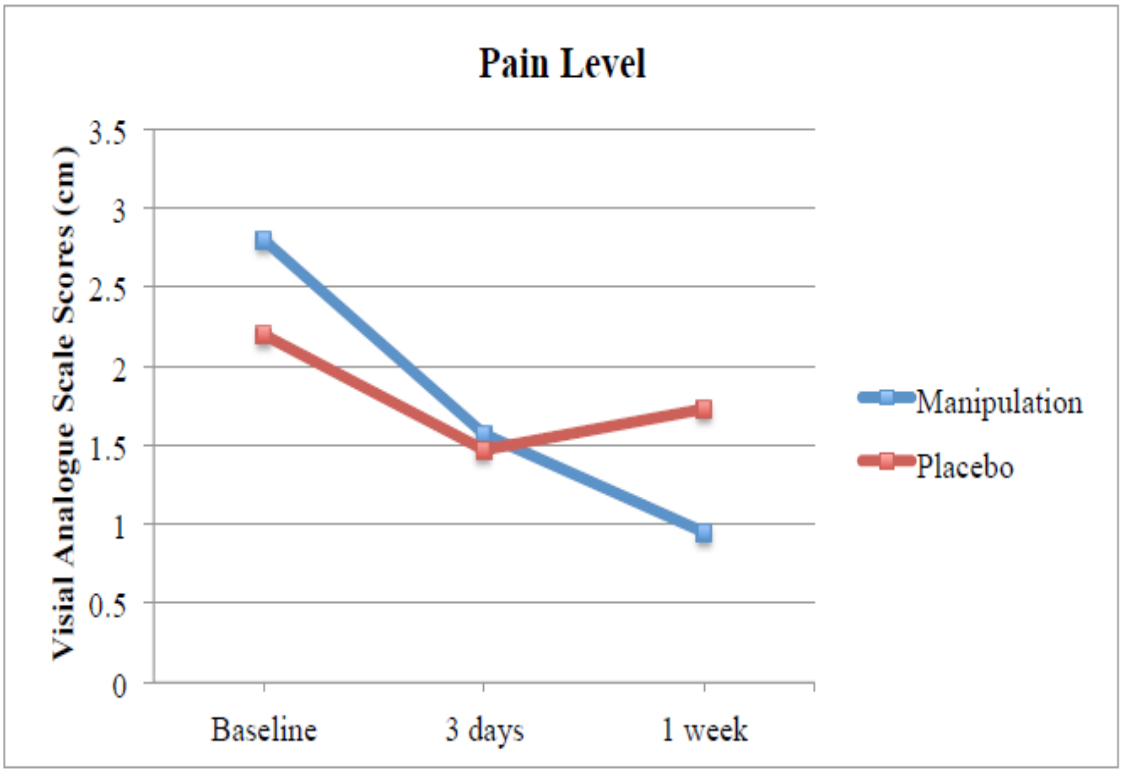

Figure 12. Phase II: Visual Analogue Scale scores at baseline, and 3 days and 1 week after the intervention.

CHAPTER V

DISCUSSION

The primary purpose of Phase I of this study was to examine the immediate effects of lumbopelvic manipulation on the muscle fatigability level of the lumbar multifidus (MULT), gluteus maximus (GMAX), and gluteus medius (GMED) muscles compared to a placebo intervention in patients with CLBP. The secondary purpose of Phase I was to examine the immediate effects of lumbopelvic manipulation on pain level measured by the VAS as compared to a placebo intervention in patients with CLBP. A total of 31 participants completed Phase I of the study. Participants were randomized into two groups: a manipulation group and a placebo group. Participants in the manipulation group received a single lumbopelvic manipulation whereas participants in the placebo group received a pre-manipulation hold only.

The primary purpose of Phase II was to examine the one-week carry-over effects of lumbopelvic manipulation on muscle fatigability level of the MULT, GMAX, and GMED muscles compared to a placebo intervention in patients with CLBP. The secondary purpose of Phase II was to examine the one-week carry-over effects of lumbopelvic manipulation on pain level measured by VAS as compared to a placebo intervention in patients with CLBP. Twenty-seven of 31 participants from Phase I of the study completed Phase II. This chapter discusses hypothesis testing and results, as well as limitations of the study.

Phase I

Hypothesis 1 and 2

Hypothesis 1. *Participants with CLBP who receive lumbopelvic manipulation would demonstrate a decrease in the fatigability level of the MULT, GMAX, and GMED muscles more than those who receive a placebo intervention immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.*

Hypothesis 2. *All participants with CLBP would demonstrate a significant decrease in the fatigability level of the MULT, GMAX, and GMED muscles immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.*

The ANOVA results revealed no significant difference between participants with CLBP who received the lumbopelvic manipulation and those who received a pre-manipulation hold with regard to the fatigability rate of the MULT, GMAX, and GMED across time. Therefore, Hypothesis 1 was rejected and the null hypothesis was retained. This indicates that the lumbopelvic manipulation has no immediate effect on the fatigability rate of the MULT, GMAX, and GMED muscles compared to the placebo intervention immediately after the intervention, 15 minutes, 30, minutes, and also 45 minutes after the intervention in adults with CLBP. In addition, the ANOVA results showed no significant main effect of time on the fatigue rate of these three muscles. Therefore, Hypothesis 2 was rejected and the null hypothesis was retained. This indicated that all participants with CLBP, regardless of the type of manual therapy intervention they received, did not demonstrate any significant changes on the fatigue rate of the MULT, GMAX, and GMED muscles immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention as compared to baseline.

Although the pain scores in this study showed that the manipulation group had a significantly greater pain reduction than the placebo group between 15 minutes and 30 minutes after the intervention, the lumbopelvic manipulation did not have the same effect on the fatigue rates of the MULT, GMED, and GMAX muscle. On the contrary, using ultrasound imaging, improved muscle contraction of the transversus abdominis was observed immediately following the same lumbopelvic manipulation in patients with low back and leg pain (Gill, Teyhen, & Lee, 2007; Raney et al., 2007). In addition, Motealleh et al. (2016) demonstrated a significantly increased EMG activity of the vastus medialis, vastus lateralis and GMED muscles immediately after a lumbopelvic manipulation as compared to a sham manipulation in athletes with patellofemoral pain syndrome (Motealleh, Gheysari, Shokri, & Sobhani, 2016). Increased EMG activity or muscle contraction following a manipulation can be attributed to a possible neurophysiological mechanism in which structures at the manipulated segment such as joint mechanoreceptors, proprioceptors, and free nerve endings are activated by the manipulation, thus facilitating alpha motor neuron and muscle activity (Pickar, 2002).

However, the results of this dissertation study did not support this neurophysiological mechanism. The disagreement could be because manual therapy, manipulation or placebo manual therapy might not cause enough neurophysiological effects to change a prolonged endurance test result, such as the modified Sørensen test.

With regard to the fatigue rates of the MULT and GMED muscles, both groups seemed to have decreased fatigue rates over time, especially at 45 minutes after the intervention. However, the difference was not statistically significant, possibly due to the small sample size (n = 31) in this study. At the beginning of this study, an a priori power

analysis showed a minimum of 32 participants would be required to ensure adequate power of 0.80. However, the results of the statistical analysis in the MULT and GMED fatigue rates revealed small effect sizes (partial $\eta^2 = 0.02$ and 0.03) and low powers (1-$\beta = 0.11$ and 0.23). Therefore, it is doubtful that a larger sample size would have resulted in a significant finding.

The average fatigue rate for the MULT muscle in this study was -0.80 %/second for the manipulation group and -0.73 %/second for the placebo group at baseline. These fatigue rates were higher than the MULT fatigue rate (-0.59 %/sec) of asymptomatic adults found in a pilot study conducted prior to this dissertation study. In addition, the MULT muscle fatigue rate (-0.006 %/second) reported by Coorevits et al. (2005) for adults without low back pain also was lower. It is not surprising to find higher fatigue rates of the MULT muscle in the participants with CLBP. Furthermore, Mannion and Connolly (1997) found a fatigue rate (-0.53 %/second) of the lumbar erector spinae muscles in adults with acute low back pain using the same equation for the fatigue rate calculation. The discrepancy in the fatigue rates between Mannion and Connolly's study and this dissertation study could be partly due to acuteness of low back pain and partly due to the size of the lumbar erector spinae being much larger than the MULT in Mannion and Connolly's study is.

The average fatigue rate of the GMAX muscle in this study was -0.11 %/second for the manipulation group and -0.18 %/second for the placebo group. These fatigue rates were higher than the GMAX fatigue rate (-0.08 %/second) of asymptomatic adults found in the pilot study. Similarly, the GMAX muscle fatigue rate (-0.002 %/second) reported by Coorevits et al. (2005) for adults without low back pain was much lower than those of

the participants with CLBP in this dissertation study. Kankaanpää, Taimela, et al. (1998) also reported the fatigue rates of the GMAX muscles in both patients with CLBP and asymptomatic controls. Although the direct comparison between studies cannot be made because a different normalization equation with a different unit was used in Kankaanpää, and Taimela et al.'s study, the fatigue rates of the patients with CLBP was approximately 50-100% higher than those of asymptomatic individuals in Kankaanpää and Taimela et al.'s study (1998). This finding appeared to be in agreement with the GMAX fatigue rate results found in this dissertation study.

When examining the GMED fatigue rate, the participants with CLBP in the manipulation group had an average fatigue rate of -0.32 %/sec and the participants in the placebo group had an average GMED fatigue rate of -0.52%/sec. These fatigue rates were much higher than the GMED fatigue rate (-0.12 %/sec) of asymptomatic adults found in the pilot study. In an EMG study, Marshall, Patel, and Callaghan (2011) also found that those who developed LBP demonstrated a significantly higher fatigue rate of the GMED muscles ($p = 0.03$), as compared to those who did not develop LBP (Marshall et al., 2011).

In this dissertation study, we used a sampling rate of 1,000 Hz. However, during the normalization process, we divided the EMG median frequency data into 1-second intervals and used a linear regression to calculate the initial EMG median frequency as the one used in Coorevits et al.'s study (Coorevits et al., 2005). This 1-second window could be too large, and may have led to losing accuracy for the EMG median frequency. In other studies, the EMG median frequency data was processed using a 0.25-second interval (Sparto et al., 1997) or using 1-second interval with 50% overlap (Kankaanpää,

Taimela, et al., 1998). One may argue that the use of a 0.25-second interval or adding 50% overlap for a 1-second interval could have yielded a more accurate representation of the EMG median frequency. However, the participants with CLBP in Phase I of this study took 58.1 seconds to complete the modified Sørensen test and those in Phase II of the study took 57.9 seconds. Therefore, the use of a 1-second interval should be sufficient, as indicated in Coorevits et al.'s study (Coorevits et al., 2005).

In addition, we asked participants to perform the modified Sørensen test five times within an hour, and this may have caused fatigue effects, thus possibly affecting the results of the study. Larivière et al. (2003) found that 10 minutes and 15 minutes were enough recovery times for back extensors following a sustained back extension (Larivière et al., 2003). However, in an EMG study, 9 minutes of rest was found inadequate for recovering from performing a fatigue trial of the modified Biering-Sørensen test (Wang-Price, Almadan, Stoddard, & Moore, 2017). Therefore, a 15-minute rest period was given between the two modified Sørensen tests to ensure recovery of those muscles. However, a fatigue effect still could have affected the performance of the modified Sørensen tests.

Hypothesis 3 and 4

Hypothesis 3. *Participants with CLBP who receive lumbopelvic manipulation would demonstrate a greater reduction in pain level than those who receive a placebo intervention immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.*

Hypothesis 4. *All participants with CLBP would demonstrate a significant decrease in pain level immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention.*

The ANOVA results showed a significant difference on the pain level between participants with CLBP who received a lumbopelvic manipulation and those who were given a placebo intervention over time. Post-hoc tests revealed that participants who were treated with a lumbopelvic manipulation had a significant reduction in pain level as compared to those with CLBP who received a placebo intervention between 15 minutes and 30 minutes after the intervention. Therefore, Hypothesis 3 was accepted, and the null hypothesis was rejected. This suggests that the lumbopelvic manipulation significantly improved the pain level after 15 minutes of the intervention in participants with CLBP. Pain reduction immediately after a lumbopelvic manipulation has been reported in athletes with patellofemoral pain syndrome (Motealleh et al., 2016). However, the immediate effect of lumbopelvic manipulation on low back pain has not yet been reported.

Nevertheless, the reduction in pain level was only from 2.83 cm to 2.26 cm on the Visual Analogue Scale (VAS). Although the reduction in pain level was statistically significant in the manipulation group as compared to the placebo group, this difference might not be clinically significant as the minimal clinical important difference (MCID) for this scale is 1.8 cm in patients with CLBP (Hägg et al., 2003). In addition, the ANOVA results showed no significant main effect of time on the pain level. Therefore, Hypothesis 4 was rejected and the null hypnosis was retained. This indicates that the pain level of all participants with CLBP, regardless of their group assignments, did not have any significant change immediately, 15 minutes, 30 minutes, and 45 minutes after the intervention as compared the pain level to baseline. However, this comparison is not important, as a significant interaction of pain over time was found.

Phase II

Hypothesis 1 and 2

Hypothesis 1. *Participants with CLBP who receive lumbopelvic manipulation would demonstrate a decrease in the fatigability level of the MULT, GMAX, and GMED muscles more than those who receive a placebo intervention three days and one week after the intervention.*

Hypothesis 2. *All participants with CLBP would demonstrate a significant decrease in the fatigability level of the MULT, GMAX, and GMED muscles three days and one week after the intervention.*

Similar to the results in Phase I, the ANCOVA results revealed no significant difference in the fatigue rates of the MULT, GMAX, and GMED muscles between participants who were treated with the lumbopelvic manipulation and those who were given a placebo intervention at three days and one week after the intervention. Therefore, Hypothesis 1 was rejected and the null hypothesis was retained. This result indicates that the lumbopelvic manipulation did not have a short-term carry-over effect on the fatigue rates of those muscles over the course of one week after the intervention. In addition, the results of ANCOVA revealed no significant main effect of time on the fatigue rates of the MULT, GMAX, and GMED. Therefore, Hypothesis 2 was rejected and the null hypothesis was retained. This implies that all participants with CLBP, regardless of the intervention they received, did not have any significant changes in the fatigue rates of the MULT, GMAX, and GMED muscles over the course of one week after the intervention. Given that no significant immediate changes after intervention were found in Phase I, the non-significant finding for the short-term carry-over effect was not surprising. Although

the pain scores in this study showed that all participants had significant pain reduction between three days and one week after the intervention, the intervention did not have a similar effect on muscle fatigability to that which was reported in Phase I.

Hypothesis 3 and 4

Hypothesis 3. *Participants with CLBP who receive lumbopelvic manipulation would demonstrate a greater reduction in pain level than those who receive a placebo intervention three days and one week after the intervention.*

Hypothesis 4. *All participants with CLBP would demonstrate a significant decrease in pain level three days and one week after the intervention.*

The ANCOVA results for Phase II showed no significant difference in pain level between the manipulation group and placebo group across time. Therefore, Hypothesis 3 was rejected and the null hypothesis was retained. This implies that the lumbopelvic manipulation did not have any significant effect on the pain level at three days and at one week after the intervention as compared to a placebo intervention in participants with CLBP. However, the ANCOVA results showed a significant main effect of time on the pain level at three days and one week after the intervention. Therefore, Hypothesis 4 was accepted and the null hypothesis was rejected. This result suggests that all participants with CLBP, regardless of whether they were treated with the lumbopelvic manipulation or a placebo treatment, had significant changes in pain level at three days and one week after the intervention.

The finding of pain reduction was in disagreement with the previous study (Senna & Machaly, 2011) which showed, at 1-month follow-up, that 12 sessions of lumbopelvic manipulations combined with exercises resulted in a significantly greater pain reduction

as compared to 12 sessions of sham manipulation combined with exercises. In Senna and Machaly's study (2011), participants not only received multiple lumbopelvic manipulation sessions but also received exercises. In contrast, a single lumbopelvic manipulation session, as performed in this dissertation study, might not be enough to generate treatment effect on CLBP. In addition, Senna and Machaly's study (2011) had a longer follow-up time as compared to the one-week follow-up time in this study. By examining the VAS pain scores for Phase II of this study, the manipulation group seems to have a greater reduction in pain level after one week of the intervention as compared to the placebo group. However, this difference between the two groups was not statistically significant. Therefore, a longer follow-up period may be needed to measure a significant effect. As discussed in Phase I, although the difference was statistically significant between 3 days after intervention (1.52 cm) and one-week after intervention (1.25 cm), the difference (0.27 cm) was not clinically meaningful as the MCID for VAS is 1.8 cm (Hägg et al., 2003).

Limitations

This study has several limitations. The power analysis that was performed before starting this study required a minimum of 32 participants in order to show a significant effect of the treatment. However, due to difficulty in recruiting participants, only 31 participants completed Phase I of this study. In addition, four participants did not complete Phase II of this study. Therefore, only 27 participants completed Phase II of the study.

As discussed earlier, the participants in this dissertation study had low-to-moderate pain level. In addition, the participants In Phase I of this study had an average

disability level of 15 on the Modified Oswestry Disability Index (OSW) indicating a relatively low disability level. Similarly, the average score of those participants on the work subscale of the Fear Avoidance Beliefs Questionnaire (FABQ) was 12, and the average score on the physical activity subscale of the FABQ was 10, indicating low fear-avoidance level. The participants in Phase II also had a low disability level with an average of 15.7 on the OSW, and low fear-avoidance level with the FABQ work subscale score being 13.1 and the FABQ physical activity subscale score being 11.1. Therefore, the results of this study can only be generalized to those patients with CLBP and with low disability levels. The results may have been different with patients with more severe symptoms.

However, participants with a moderate or moderate-to-high level of pain may not be able to complete the modified Sørensen test or tolerate the lumbopelvic manipulation. Spinal manipulation has been shown to be more effective when patients with low back pain meet specific criteria (Childs et al., 2004; Flynn et al., 2002). For this dissertation study, the inclusion criteria for the current study did not classify patients into groups other than general non-specific CLBP. The results of this study might have been different if only those participants who met the criteria identified in Flynn et al.'s study (2002) were included. In addition, participants might not have reached the maximum fatigue level while performing the modified Sørensen test. Although participants were instructed to hold the test position of the modified Sørensen test as long as possible, participants may have stopped the test before reaching the maximum fatigue level. This might have altered the fatigability data in this study.

Conclusion

The study showed that the lumbopelvic manipulation had no immediate or carry-over effects on the fatigue rates of the back and hip muscles in adults with CLBP. Although lumbopelvic manipulation seemed to significantly decrease the pain level at 15 minutes after the intervention, this difference did not exceed the MCID of VAS, thus may not be meaningful to the patients' progress. Future studies should consider the effects of treatment options such as strengthening exercises on the fatigability level of the back and hip muscle in more homogenous subgroups of patients with CLBP.

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APPENDIX A

The Modified Oswestry Disability Questionnaire (OSW)

Modified Oswestry Low Back Pain Questionnaire

This questionnaire has been designed to give your therapist information as to how your back pain has affected your ability to manage in everyday life. Please answer every question by placing a mark in the **one** box that best describes your condition today. We realize you may feel that 2 of the statements may describe your condition, but **please mark only the box that most closely describes your current condition.**

Pain Intensity

0 I can tolerate the pain I have without having to use pain medication.
1 The pain is bad, but I can manage without having to take pain medication.
2 Pain medication provides me with complete relief from pain.
3 Pain medication provides me with moderate relief from pain.
4 Pain medication provides me with little relief from pain.
5 Pain medication has no effect on my pain.

Personal Care (e.g, Washing, Dressing)

0 I can take care of myself normally without causing increased pain.
1 I can take care of myself normally, but it increases my pain.
2 It is painful to take care of myself, and I am slow and careful.
3 I need help, but I am able to manage most of my personal care.
4 I need help every day in most aspects of my care.
5 I do not get dressed, wash with difficulty, and stay in bed.

Lifting

0 I can lift heavy weights without increased pain.
1 I can lift heavy weights, but it causes increased pain.
2 Pain prevents me from lifting heavy weights off the floor, but I can manage if the weights are conveniently positioned (eg, on a table).
3 Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned.
4 I can lift only very light weights.
5 I cannot lift or carry anything at all.

Walking

0 Pain does not prevent me from walking any distance.
1 Pain prevents me from walking more than 1 mile.
2 Pain prevents me from walking more than 1⁄2 mile.
3 Pain prevents me from walking more than 1⁄4 mile.
4 I can only walk with crutches or a cane.
5 I am in bed most of the time and have to crawl to the toilet.

Sitting

0 I can sit in any chair as long as I like.
1 I can only sit in my favorite chair as long as I like.
2 Pain prevents me from sitting for more than 1 hour.
3 Pain prevents me from sitting for more than 1⁄2 hour.
4 Pain prevents me from sitting for more than 10 minutes.
5 Pain prevents me from sitting at all.

Standing

0 I can stand as long as I want without increased pain.
1 I can stand as long as I want, but it increases my pain.
2 Pain prevents me from standing more than 1 hour.
3 Pain prevents me from standing more than 1⁄2 hour.
4 Pain prevents me from standing more than 10 minutes.
5 Pain prevents me from standing at all.

Sleeping

0 Pain does not prevent me from sleeping well.
1 I can sleep well only by using pain medication.
2 Even when I take pain medication, I sleep less than 6 hours.
3 Even when I take pain medication, I sleep less than 4 hours.
4 Even when I take pain medication, I sleep less than 2 hours.
5 Pain prevents me from sleeping at all.

Social Life

0 My social life is normal and does not increase my pain.
1 My social life is normal, but it increases my level of pain.
2 Pain prevents me from participating in more energetic activities (e.g., sports, dancing).
3 Pain prevents me from going out very often.
4 Pain has restricted my social life to my home.
5 I have hardly any social life because of my pain.

Traveling

0 I can travel anywhere without increased pain.
1 I can travel anywhere, but it increases my pain.
2 My pain restricts my travel over 2 hours.
3 My pain restricts my travel over 1 hour.
4 My pain restricts my travel to short necessary journeys under 1⁄2 hour.
5 My pain prevents all travel except for visits to the physician/therapist or hospital.

Employment/Homemaking

0 My normal homemaking/job activities do not cause pain.

1 My normal homemaking/job activities increase my pain, but I can still perform all that is required of me.

2 I can perform most of my homemaking/job duties, but pain prevents me from performing more physically stressful activities (e.g., lifting, vacuuming).

3 Pain prevents me from doing anything but light duties.

4 Pain prevents me from doing even light duties.

5 Pain prevents me from performing any job or homemaking chores.

APPENDIX B

Fear Avoidance Beliefs Questionnaire

Fear-Avoidance Beliefs Questionnaire (FABQ)
Waddell et al (1993) Pain , 52 (1993) 157 - 168

Here are some of the things which other patients have told us about their pain. For each statement please circle any number from 0 to 6 to say how much physical activities such as bending, lifting, walking or driving affect or would affect *your* back pain.

	Completely disagree			Unsure			Completely agree
1. My pain was caused by physical activity……..	0	1	2	3	4	5	6
2. Physical activity makes my pain worse……	0	1	2	3	4	5	6
3. Physical activity might harm my back……..	0	1	2	3	4	5	6
4. I should not do physical activities which (might) make my pain worse	0	1	2	3	4	5	6
5. I cannot do physical activities which (might) make my pain worse…...	0	1	2	3	4	5	6

The following statements are about how your normal work affects or would affect your back pain

	Completely disagree			Unsure			Completely agree
6. My pain was caused by my work or by an accident at work……	0	1	2	3	4	5	6
7. My work aggravated my pain……	0	1	2	3	4	5	6
8. I have a claim for compensation for my pain……	0	1	2	3	4	5	6
9. My work is too heavy for me……..	0	1	2	3	4	5	6
10. My work makes or would make my pain worse……..	0	1	2	3	4	5	6
11. My work might harm my back……..	0	1	2	3	4	5	6
12. I should not do my normal work with my present pain…….	0	1	2	3	4	5	6
13. I cannot do my normal work with my present pain……...	0	1	2	3	4	5	6
14. I cannot do my normal work till my pain is treated……..	0	1	2	3	4	5	6
15. I do not think that I will be back to my normal work within 3 months.	0	1	2	3	4	5	6
16. I do not think that I will ever be able to go back to that work……...	0	1	2	3	4	5	6

Scoring
Scale 1: fear-avoidance beliefs about work – items 6, 7, 9, 10, 11, 12, 15.
Scale 2: fear-avoidance beliefs about physical activity – items 2, 3, 4, 5.

Source: Gordon Waddell, Mary Newton, Iain Henderson, Douglas Somerville and Chris J. Main, A Fear-Avoidance Beliefs Questionnaire (FABQ) and the role of fear-avoidance beliefs in chronic low back pain and disability, *Pain*, 52 (1993) 157 – 168, 166.

APPENDIX C

The Lumbopelvic Manipulation and the Placebo Intervention

The lumbopelvic manipulation (left) and the placebo intervention (right).

APPENDIX D

Institutional Review Board (IRB) Approval

TWU
TEXAS WOMAN'S UNIVERSITY
DENTON DALLAS HOUSTON

Institutional Review Board
Office of Research and Sponsored Programs
P.O. Box 425619, Denton, TX 76204-5619
940-898-3378 FAX 940-898-4416
e-mail: IRB@twu.edu

February 19, 2013

Mr. Mohammad Almadan

Dear Mr. Almadan:

Re: Effects of Lumbopelvic Manipulation on Neuromuscular Activity of Back and Hip Muscles in Adults With Chronic Low Back Pain (Protocol #: 17224)

Your application to the IRB was reviewed and approved on 2/19/2013. This approval is valid for one (1) year. The study may not continue after the approval period without additional IRB review and approval for continuation. It is your responsibility to assure that this study is not conducted beyond the expiration date.

Any modifications to this study must be submitted for review to the IRB using the Modification Request Form. Additionally, the IRB must be notified immediately of any unanticipated incidents. If you have any questions, please contact the TWU IRB.

A request to close the study file must be submitted to the IRB at the conclusion of the study. If using a consent form, copies of the signed informed consent are to be submitted with this request before the study file can be closed.

The Institutional Review Board is pleased to acknowledge your sense of responsibility for ethical research. If you have any questions concerning this review, please contact me at (214) 689-6571 or email cbailey2@twu.edu.

Sincerely,

Catherine Bailey

Dr. Catherine Bailey, Chair
Institutional Review Board - Dallas

cc. Dr. Ann Medley, School of Physical Therapy - Dallas
Dr. Sharon Wang, School of Physical Therapy - Dallas
Graduate School

APPENDIX E

Delsys Trigno EMG System


1
PATENTED

APPENDIX F

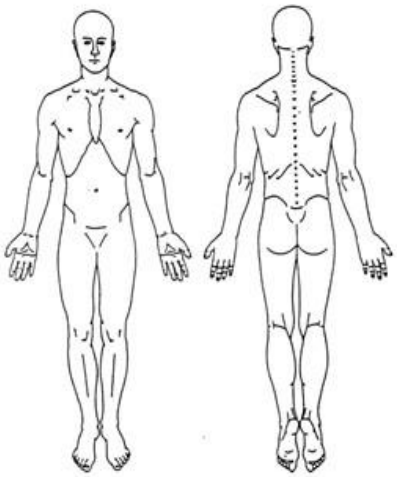
The Medical Intake Form

Basic information:

Last name: First Name: Date: Gender: M F

- o Heart problems
- o Osteoporosis
- o High/low blood pressure
- o Chest pain/ palpitation
- o Depression
- o Tuberculosis
- o Thyroid problems
- o Kidney problems
- o Asthma / bronchitis / pneumonia
- o Stroke
- o Cancer
- o Joint replacement/ repair
- o Severe headaches
- o Poor balance / recent falls
- o Dizziness / vertigo / blackouts
- o Spondylolithesis
- o Shortness of breath
- o Gout
- o Rheumatoid arthritis
- o Anemia
- o Latex allergy
- o Liver problems
- o Fever
- o Circulation problems
- o Spondylitis
- o Seizers
- o Night pain
- o Current fracture
- o Weight loss
- o Currently pregnancy
- o AnkylosingSpondylitis

Please mark your pain on the body diagram



How long have you had low back pain? _____

Is the pain Intermittent / constant?

Have you had a recent episode of low back pain? Yes No

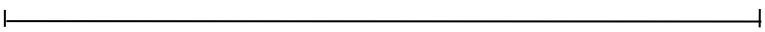
If yes, when? _____

How long? _____

Was the pain constant or intermittent?

Which side does it hurt the most? R L

How do you rate your pain in the past 72 hours (3 days) ?



No pain Extreme pain

Do you have any symptoms below the knees? Yes No

Do you have any parasthesia/ pin and needle sensation or numbness? Yes No

Do you currently have any current knee/ hip injury or problem? Yes No

Have you ever been treated with spinal manipulation? Yes No

APPENDIX G

Clinical Examination

Dermatomal testing of lower extremities

For each level, light touch using two pieces of cotton was performed to compare the sensation for the skin area associated with each nerve root level between the right and left side.

Level	Area
L1	Groin, over the trochanter
L2	Back, The front aspect of thigh to knee
L3	Back, anterior aspect of thigh and knee, medial lower leg.
L4	Lateral thigh, lateral side of the leg, dorsum of the foot, big toe
L5	Posterior and lateral aspects of the thigh, lateral side of the leg, dorsum of the foot, medial side of the sole, 1^{st}-3^{rd} toes.
S1	Posterior thigh and leg, 4^{th}-5^{th} toes, lateral side of foot, planter side of the foot,
S2	Lateral aspect of the leg, knee, heel

Myotomal testing of lower extremities:

The examiner placed each joint in the resting or neutral position and applied a resisted isometric force. Each contraction lasted for five seconds and the testing performed on both sides simultaneously when possible to compare sides. Each test was performed three times to check for fatigable weakness which is indicative of nerve root compression.

Level	Test
L1-2	Resisted hip flexion: while the patient was in supine lying, the examiner placed the tested hip at 30 - 40 degrees of flexion, and knee in 90 degrees of flexion and produced a caudal force at distal femur proximal to the knee.
L3	Resisted knee extension: While the participant was in supine lying, the examiner supported the tested knee in 25 – 35 degrees of flexion with one hand and applied a downward force to the mid-shaft of the tibia.
L4	Resisted ankle dorsiflexion: The participant was asked to place his/her ankle at 0 degrees of ankle dorsiflexion. The examiner produced a caudal force at the dorsum of the foot.
L5	Resisted toe extension: the examiner asked the participant to hold the big toes in neutral position. Then, the examiner applied a caudal pressure to the dorsal aspect of both big toes.
S1	Resisted ankle plantarflexion: The participant was asked to position the

	ankle at 0 degrees of ankle plantarflexion. The examiner applied a cranial force to the planter aspect of the foot. Resisted ankle eversion: Ankle eversion was tested in a similar manner with the resistance applied toward inversion. Resisted hip extension: The participant was lying prone. The examiner flexed the knee of the tested leg to 90 degrees and lifted the thigh slightly from the examination table. The examiner applied pressure to the distal thigh toward the examination table. Resisted knee flexion: The participant was lying prone. The examiner flexed the knee of the tested leg to 90 degrees and applied a force caudally to the distal end of the tibia.
S2	Resisted knee flexion: The participant was lying prone. The examiner flexed the knee of the tested leg to 90 degrees and applied a force caudally to the distal end of the tibia.

Deep tendon reflex testing:

A reflex hummer was used to assess for abnormal reflexes. The examiner marked the test results as normal, hypo-reflexia, or hyper-reflexia.

Level	Reflex
L3-4	Knee (patellar) jerk: The participant was lying supine. The examiner supported the tested knee in 25 – 35 degrees of flexion with one hand, and tapped the patellar tendon just below the patella with a reflex hummer.
S1-2	Ankle jerk: While the participant was in a seated position, the examiner dorsiflexed the foot to 0 degrees of dorsiflexion, and then tapped the Achilles tendon with a reflex hammer.

Upper motor neurons testing:

Clonus	The examiner held the participant's foot on the planter aspect with one hand and stabilized the tibia with the other. Next, the examiner rapidly dorsiflexed the ankle. The test was considered to be positive if rhythmic contractions at a rate of three to several per second were produced after the rapid passive dorsiflexion.
Babiniski	The examiner ran a pointy object along the planter aspect of the participant's foot. Big toe extension and abduction of the other toes indicated a positive reflex which is a sign of upper motor neuron lesion.

Straight-leg-raising test:

Straight-leg-raising (SLR) test was performed passively by the examiner. While the participant was in lying supine, the examiner medially rotated and adducted the participant's hip. While maintaining the knee in extension, the examiner passively flexed the hip till the participant felt back or leg pain or tissue tightness on the back of the thigh. Sensitizing components such as neck flexion or ankle dorsiflexion were added to the test to elicit the symptoms. Back pain indicated a positive test and could be due to a disc herniation or other central lesions. Leg pain indicated lower extremity pathologies.

Mobility/Instability tests:

Test	Description
Posterior-anterior mobility testing	The participant assumed a prone lying position. The examiner applied a posterior anterior pressure using the hypothenar to the spinous process of each of the lumbar segments. The examiner assessed each segment for hypomobility or hypermobility.

Sacroiliac joint tests:

Test	Description
Distraction test	The participant was asked to assume a supine lying position. The examiner applied a posterior force to both anterior superior iliac spines. The test was considered positive if the test reproduced or increased the symptoms.
Gaenslen Test	The participant was in supine position near the edge of the examination table with one leg hanging off of the table and the other leg flexed toward the chest of the participant. The examiner applied a downward pressure to the hanging leg and a cranial pressure to the flexed leg. The test was considered positive if the test produced or increased the symptoms.
Compression test	The participant assumed a side-lying position with both hips flexed to 45 degrees and both knees to 90 degrees with the affected side up. The examiner then applied a downward force on posterior aspect of iliac crest of the affected side. The test was considered positive if it produced or increased the participant's symptoms.
Thigh thrust test	The participant assumed a supine-lying position with the tested hip flexed to 90 degrees and knee fully flexed. The examiner then placed one hand over the sacrum and applied a posterior force with the other hand on the distal end of the femur. The test was considered positive if it produced or increased the participant's

	symptoms.
Sacral posterior-anterior test	While the participant in prone-lying position, the examiner applied a downward pressure over the sacrum. The test was considered positive if it produced or increased the participant's symptoms.
Long-sit test	While the participant was in a supine-lying position, the examiner assessed the level of the both medial malleoli. Then, the participant was asked to sit up while keeping both knee extended and the examiner assessed the levels of the medial malleoli. The test was considered positive if one leg was short in supine and then it became longer in long-sitting.
Standing flexion test	While the participant was in standing, the examiner checked the level of the posterior superior iliac spines. Then, the participant was asked to bend forward as far as he/she can. The test was considered positive if the posterior superior iliac spine on one side moved more cranially than the other.
Sitting flexion test.	While the participant is in sitting, the examiner checked the level of the posterior superior iliac spines. Then, the participant was asked to bend forward as far as he/she can. The test was considered positive if the posterior superior iliac spine on one side moved more cranially than the other.
Prone knee bend test	While the participant was in prone-lying, the examiner checked the level of the heels. The knees were then passively bent and the heels levels were assessed again. The test was considered positive if the heel level was different in both positions.