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Biomechanics and Postural Control Characteristics in Low Back Pain Subgroups During Dynamic Task

Amjad Shallan

LOMA LINDA UNIVERSITY
School of Allied Health Sciences
in conjunction with the
Faculty of Graduate Studies

Biomechanics and Postural Control Characteristics in Low Back Pain Subgroups
During Dynamic Task

by

Amjad Shallan

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Each person whose signature appears below certifies that this dissertation in his/her opinion is adequate, in scope and quality, as a dissertation for the degree Doctor of Philosophy.

____, Chairperson

Everett Lohman, III, Professor of Physical Therapy

____

Faris Alshammari, Assistant Professor of Physical Therapy, The Hashemite University

____

Noha Daher, Professor of Epidemiology and Biostatistics

____

Robert Dudley, Assistant Professor of Kinesiology, Azusa Pacific University

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ABBREVIATIONS

LBP	Low Back Pain
NSCLBP	Nonspecific Chronic Low Back Pain
MSEBT	Modified Star Excursion Balance Test
AEP	Active Extension Pattern
FP	Flexion Pattern
PL	Posterolateral
PM	Posteromedial
COP	Center of Pressure
MDCS	Multidimensional Classification System
MCI	Motor Control Impairment
FLSP	Flexion Lateral Shift Pattern
PEP	Passive Extension Pattern
MDP	Multi-Directional Pattern
COG	Center of Gravity
BOS	Base of Support
IPAQ-SF	International Physical Activity Questionnaire - Short Form
VAS	Visual Analogue Scale
RMQ	Roland-Morris Disability Questionnaire
TSK	Tampa Scale of Kinesiophobia
ROM	Range of Motion
PPIVM	Passive Physiological Intervertebral Movements
PL	Medio-Lateral

AP	Anterior -Posterior
ANOVA	Analysis Of Variance
BMI	Body Mass Index
SEBT	The Star Excursion Balance Test
PSIS	Posterior Superior Iliac Spine
ASIS	Anterior Superior Iliac Spine
SD	Standard Deviation

ABSTRACT OF THE DISSERTATION

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by

Amjad Shallan

Doctor of Philosophy, Graduate Program in Physical Therapy
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Dr. Everett Lohman, III, Chairperson

Dynamic balance impairments are commonly observed in people with low back pain (LBP). People with LBP have reduced lumbopelvic stability and may exhibit spinal biomechanical and postural control changes during dynamic balance. A limited number of studies are available about the spinal kinematic and postural control changes during dynamic balance in people with nonspecific chronic low back pain (NSCLBP) subgroups. Therefore, the aim of this dissertation was to compare spinal kinematics and postural control between NSCLBP subgroups and healthy individuals during dynamic balance using a modified Star Excursion Balance Test (mSEBT).

Eighteen NSCLBP subjects [9 active extension pattern (AEP), 9 flexion pattern (FP)], and 10 healthy controls were enrolled in this study. All subjects performed mSEBT on their dominant leg in the anterior (ANT), posterolateral (PL), and posteromedial (PM) reach directions. Normalized reach distance, balance parameters, including the center of pressure (COP) displacement and velocity as well as the pelvic, lumbar, and thoracic 3-dimensional kinematics were recorded.

There were significant differences in mean reach distance in both PL and PM directions between AEP and healthy and between FP and healthy subjects. However,

there was no significant difference among the three groups in the anterior reach direction. Kinematic results showed significant differences in both lumbar and thoracic spine regions between AEP and FP and between AEP and healthy in all reaching directions. However, there were no significant differences in spinal kinematics between FP and healthy subjects. In addition, the results showed a significant difference in mean COP velocity in PM direction between AEP and FP subjects, and between AEP and healthy subjects.

The findings in this study highlight the heterogeneity of the individuals with NSCLBP and the importance of identifying the homogenous subgroups. Individuals with AEP and FP experience diminished dynamic balance compared to healthy controls. The thoracic and lumbar spine regions are very important to discriminate between AEP and FP, and between AEP and healthy during dynamic balance. In addition, the findings of this study support the concept of the Multidimensional Classification System (MDCS).

CHAPTER ONE

INTRODUCTION

Low Back Pain

Low back pain (LBP) is considered one of the most complex heterogeneous disorder that affect approximately 36% of the population yearly with approximately 23% of whom will go on to develop chronicity (LBP more than 12 weeks) (Airaksinen et al., 2006). LBP could lead to the disability and affect the quality of life such as decreasing the daily activity level and increasing the risk of missing the work (Katz, 2006). In addition, it considers one of the costliest musculoskeletal disorders in many societies, which cost more than 90 billion dollars in the United States as a direct cost for dealing with LBP disorder (Luo, Pietrobon, Sun, Liu, & Hey, 2004). Therefore, LBP remains one of the highest healthcare priorities for modern societies.

Nonspecific LBP is defined as LBP without specific cause or source of pain, and there is no abnormality or pathoanatomic could be found with radiology (Dankaerts et al., 2009; Luomajoki, Kool, De Bruin, & Airaksinen, 2007). NSCLBP results from various factors which might interact with each other such as psychosocial, biomechanical, environmental, cultural and even genetic factors (Balagué, Mannion, Pellisé, & Cedraschi, 2012). The complexity and the heterogeneity of these factors could be the reason behind establishing inaccurate etiology of NSCLBP (Balagué et al., 2012). Despite the large number of studies related to the treatment of NSCLBP, the overall effect of these interventions is short-term and moderate at best (Foster, Hill, O'Sullivan, & Hancock, 2013; Patel, Friede, Froud, Evans, & Underwood, 2013). The difficulties in finding the effective treatments are attributed to the heterogeneity of NSCLBP individuals (Foster, Hill, & Hay, 2011). Therefore, identifying NSCLBP patient's subgroups will help to increase the possibility of finding long-term prognosis from the therapeutic intervention (Foster et al., 2013).

Subclassification of Non-Specific Chronic Low Back Pain

With the increasing of prioritization to classify people with NSCLBP into homogenous subgroups in research and clinical practice, several classification systems have been introduced. However, there is a disadvantage in many of these classification systems where it mainly focused on a unidimensional factor to classify the NSCLBP. For example, we have classifications based on Patho-anatomical features only (Nachemson, 1999; Petersen et al., 2003); or it classified the NSCLBP based on clinical features (Delitto, Erhard, & Bowling, 1995; R. McKenzie & May, 2003; R. A. McKenzie & May, 1981; Van Dillen et al., 1998; Van Dillen et al., 2003); and some of these classifications used the psychological features only to classify the people with NSCLBP (Bergström, Bodin, Jensen, Linton, & Nygren, 2001; Coste, Paolaggi, & Spira, 1992; Keefe, Bradley, & Crisson, 1990; Klapow et al., 1993; Main, Wood, Hollis, Spanswick, & Waddell, 1992; Ozguler et al., 2002). In addition, NSLBP usually has been classified as acute, subacute, or chronic based on the duration of the symptom (Dunn & Croft, 2006; Von, 1994). However, these classification systems have become used less because they failed to provide us with the full picture of the prognosis or the cause of the individual's LBP experience (Cedraschi et al., 1999; Turk & Rudy, 1988; Von Korff & Dunn, 2008). Therefore, many different approaches have been proposed to classify the people with NSCLBP which consider all contributory factors in NSCLBP (Borkan et al., 2002; P.

O’Sullivan, 2005). One of these approaches is the Multidimensional Classification System (MDCS) (P. O’Sullivan, 2005).

The Multidimensional Classification System for NSCLBP

The Multidimensional Classification System (MDCS) propose three main subgroups for chronic low back pain based on the primary mechanism of pain (Figure 1). The first subgroup is classified based on psycho-social factors as the primary cause of pain which results from forebrain activation which induces the centrally mediated pain response (P. O’Sullivan, 2005). The second subgroup is patients with low back pain from specific pathoanatomical structural changes. The third subgroup includes people with low back pain with maladaptive responses to pain that results from either motor control impairment that results from changes in tissue loading over the time or impairment of movement. Despite the pain of the third subgroup that may be the primarily mechanically driven but the altered psychosocial behaviors may play a role to drive patients into a pattern of on-going pain and disability (Frymoyer, Rosen, Clements, & Pope, 1985; Hodges & Moseley, 2003).

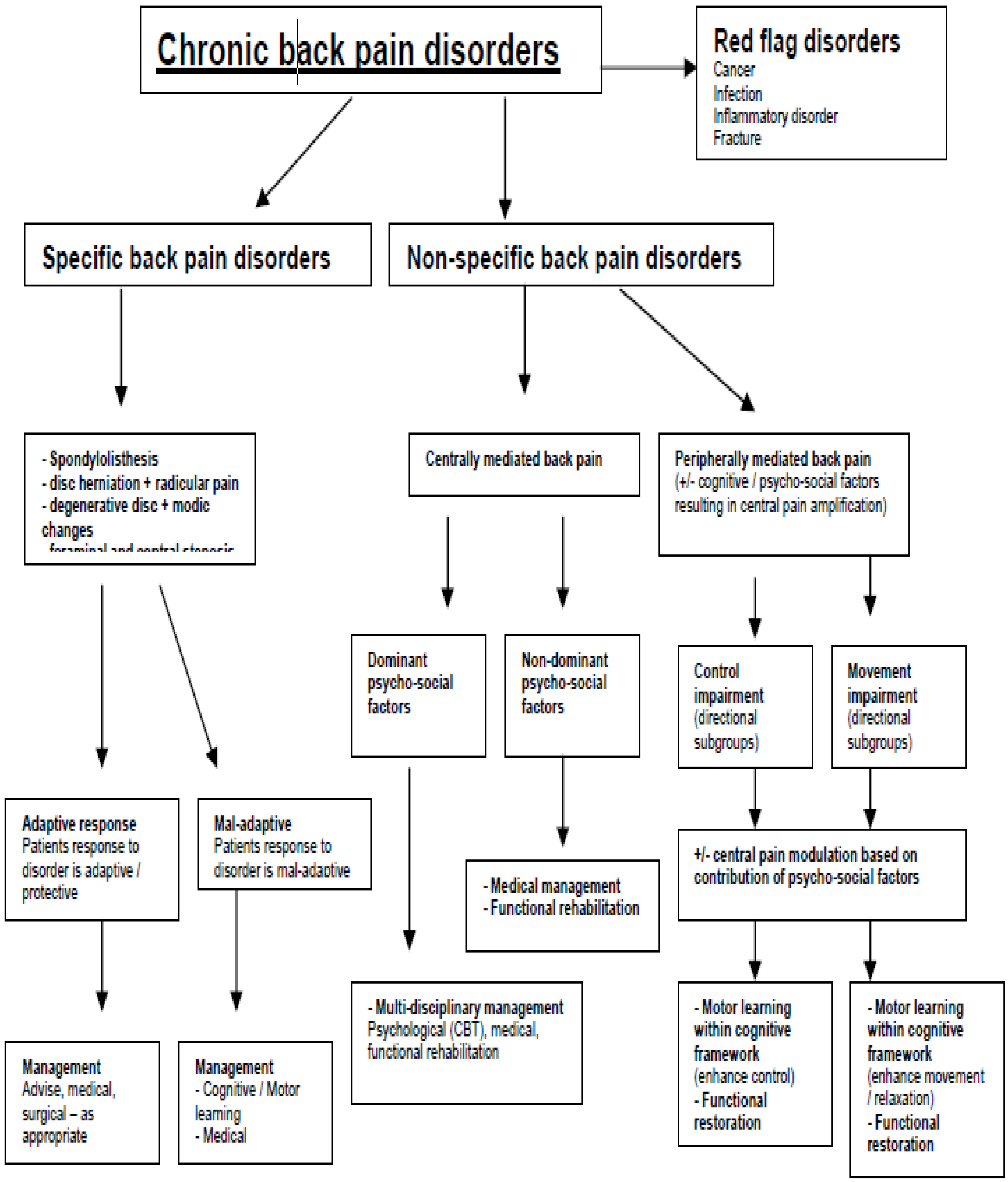

Figure 1: The Multidimensional Classification System (MDCS). (reproduced from O'Sullivan (2006))

Motor Control Impairment

Motor Control Impairment (MCI) is considered to be the most common clinical presentations of CLBP. Individuals with MCI displaying spinal control impairment in the direction of the primary source of pain (P. O'Sullivan, 2005). Individuals with MCI have been shown to display a full range of movement in the direction of pain provocation and they also display a high level of fear avoidance to adopt postures and movement strategies that may enhance the pain. However, the main treatment protocol for those patients are focused on decreasing fear avoidance behavior and enhancing spinal control especially during the performance of functional activities in order to decrease spinal loading and avoid end-range repetitive strain which this would lead to decrease the peripheral nociceptor sensitivity.

MDCS approach identified five MCI subgroups within NSCLBP population: Active extension pattern (AEP), flexion pattern (FP), flexion lateral shift pattern (FLSP), passive extension pattern (PEP), and multi-directional pattern (MDP). A full description of each MCI pattern is given in detail in (Appendix C and D). However, AEP and FP MCI are considered as the most clinical presentation of NSCLBP subgroups. Therefore, many studies have been conducted to distinguish between flexion pattern (FP) and active extension pattern (AEP) in term of physical characteristics in the adult and adolescent populations.

Spinal Kinematics in MCI Subgroups

There are many important functions for the spinal column including: maintaining the upright posture of the body and creating a stable proximal base from which movements in the more distal extremities may occur. Lumbopelvic stability is considered as both dynamic and complex process which involves the active and passive spinal components in addition to the neural control from the central nervous system (Panjabi, 1992).

Impairments of the spine affect postural stability during standing (Silfies, Bhattacharya, Biely, Smith, & Giszter, 2009; van Dieën, Cholewicki, & Radebold, 2003). Deficits in proprioception in the spinal region may lead to postural instability (Silfies et al., 2009). A lack of kinematic coordination between the thoracic and lumbar segments and the pelvis may result in musculoskeletal injuries, mainly with unexpected perturbations (Jones, Henry, Raasch, Hitt, & Bunn, 2012).

FP and AEP patients are proposed to exhibit difficulty adopting neutral postures with a natural lordosis of the spine. AEP individuals are proposed to show more hyper-extended posture in the lumbar spine region while the FP individuals are proposed to habitually assume a more flexed spinal profile (O'sullivan, 2004). The spinal postural differences between MCI subgroups have been investigated previously in static postures (Caffaro et al., 2014; Ham, Kim, Baek, Lee, & Sung, 2010; Hemming, Sheeran, van Deursen, & Sparkes, 2018). The lumbo-pelvic angles differences have evaluated between MCI subgroups (FP and AEP) in usual and slumped sitting (Dankaerts, O'sullivan, Burnett, & Straker, 2006). The results showed no significant differences between healthy controls and heterogeneous (pooled) NSCLBP subjects in a usual sitting. However, when they classified the NSCLBP into homogenous groups (AEP and FP), they found significant differences in the lumbar region between the AEP group and both the FP and healthy groups during usual sitting where AEP subjects adopted more extended lumbar-pelvic postures while the FP subjects adopted more flexed lumbar-pelvic posture. In addition, the results showed that AEP individuals adopted less flexed lower lumbar angle and more anterior sacral tilt compared to both the FP and healthy groups during slumped sitting.

Based on previous literature, spinal kinematics are usually examined during static postures in patients with NSCLBP subgroups with limited information about the segmental spinal kinematics between MCI subgroups during dynamic activities.

Balance and Low Back Pain

Balance and postural control are essential elements in order to direct the movement strategies especially during dynamic functional activities (Guskiewicz, 2011). Balance is defined as the ability of the body to keep the line of gravity within its base of support (Pollock, Durward, Rowe, & Paul, 2000). However, the postural stability is defined as the ability of the human body to maintain a desired postural orientation in response to the changes in the posture from either external or internal sources (Peterka & Loughlin, 2004). The human body usually reacts to any changes in the balance by using muscle activation of a specific muscle.

Postural control is defined as the ability of the body to maintain or return to the balance or equilibrium status (Cavanaugh, Guskiewicz, & Stergiou, 2005). However, balance could be either static or dynamic (Bressel, Yonker, Kras, & Heath, 2007). In static balance, the body keeps the center of gravity (COG) within the fixed base of support (BOS) during standing or sitting on a stable surface while in dynamic balance, the body tries to keep the COG over a moving BOS.

There are many factors contributing to balance and postural control in healthy adults including: vestibular system, visual, and somatosensory input (Mergner, Schweigart, Maurer, & Blümle, 2005). All of these afferent inputs are depending on the central nervous system to process this sensory information and organize the appropriate motor responses.

The human body is linked in a kinetic chain and any movement in this chain will lead to create a postural perturbation (Rivera, 1994). Any changes in the position of the trunk will lead to changes in the position of the center of mass and this will lead to alteration in the postural control and balance (Mok, Brauer, & Hodges, 2004).

There many reactive or predictive strategies have been reported in the previous literature to maintain postural control (Pollock et al., 2000). These strategies may be impaired in individuals with low back pain. For example, several studies found an alteration in trunk somatosensory in people with LBP (Brumagne, Cordo, & Verschueren, 2004; Lamoth, Meijer, Daffertshofer, Wuisman, & Beek, 2006; Leinonen et al., 2003; P. B. O'Sullivan et al., 2003). This alteration in trunk somatosensory lead to deficit in lumbar position sense and increase in the trunk muscle reaction time; which also lead to reduction in the ability of the body to be involved in a sufficient postural stability strategies (Larivière, Forget, Vadeboncoeur, Bilodeau, & Mecheri, 2010; Luoto et al., 1996; Ramprasad, Shenoy, Singh, Sankara, & Joseley, 2010; Taimela, Osterman, Alaranta, Soukka, & Kujala, 1993).

Postural control alterations in people with LBP has been reported in several studies. People with LBP have a higher postural sway compared with healthy people as well as more difficulties in adapting to changing situations (Mientjes & Frank, 1999; Ruhe, Fejer, & Walker, 2011). In addition, many studies found that people with LBP may have balance and postural control deficit even after the LBP has resolved (Bouche, Stevens, Cambier, Caemaert, & Danneels, 2006; van Dieën, Koppes, & Twisk, 2010).

Star Excursion Balance Test

Several tools have been used in the previous literature to assess the balance and postural control in people with LBP; however, most of these tools and tests were not suitable to examine the dynamic balance such as the Romberg test or it were very complicated or expensive such as the Neurocom Balance Master (Mientjes & Frank, 1999; Ruhe et al., 2011). In addition, most of these tests were performed under static positions and therefore, it was hard to examine the balance and postural control ability during functional tasks and activities that requiring a wide range of motion (Bressel et al., 2007; Sell, 2012).

The SEBT is a simple tool that was introduced to examine dynamic balance and postural control (Ganesh, Chhabra, & Mrityunjay, 2015). The SEBT shown to be highly reliability in detecting postural control deficits in various musculoskeletal injuries (Appiah-Dwomoh, Müller, & Mayer, 2018; Ganesh, Chhabra, & Mrityunjay, 2015; Ganesh, Chhabra, Pattnaik, et al., 2015). The SEBT consist of eight strips of tape placed at 45° angles to each other including: anterior, anteromedial, anterolateral, medial, posteromedial (PM), posterior, posterolateral (PL), and lateral (Figure 2). Performing the SEBT in each of the eight testing directions challenging the individual's balance in all planes including sagittal, frontal, and transverse planes as well as in combinations of each plane (Gribble, Hertel, & Plisky, 2012).

There are several limitations in using the SEBT. First, performing the SEBT is considered a time-consuming. To perform full SEBT session, you need to practice four warm-up trials and at least three scored trials of all 8 testing directions on each leg. The entire procedure requires the subject to perform 112 repetitions, which is considered a very time-consuming and it could lead to fatigue effects as well as it may reduce the motivation of the person to perform the task (Gribble et al., 2012; Hertel, Miller, & Denegar, 2000). Therefore, Hertel et, al. (2008) found that there is considerable redundancy that exists among the eight directions of the original SEBT and they conclude that ANT, PM, and PL directions most strongly represented the overall performance of the SEBT (Hertel, 2008). Therefore, a modified version of the SEBT (mSEBT) has since been used in several research studies (Bouillon & Baker, 2011; Clagg, Paterno, Hewett, & Schmitt, 2015; Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012; Filipa, Byrnes, Paterno, Myer, & Hewett, 2010; Kinzey & Armstrong, 1998; Overmoyer & Reiser, 2013).

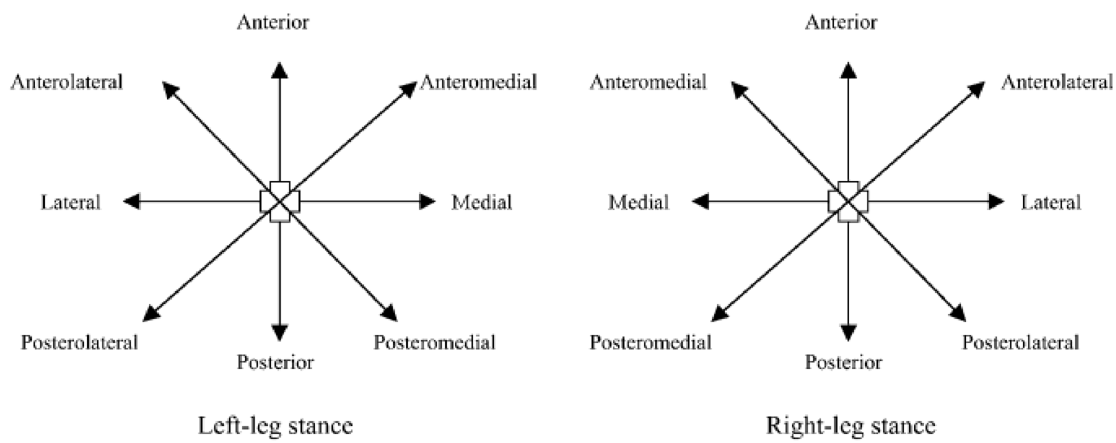

Figure 2. Star Excursion Balance Test reaching directions. Adapted from (Gribble, Hertel, & Denegar, 2007)

Summary of the problem of NSCLBP

NSCLBP is a complex disorder with many of biopsychosocial factors involving in this disorder and classification of NSCLBP into homogenous subgroups is one of the key priorities in back pain clinical practices and the research field (Foster et al., 2011). The MDCS approach considers both physical and psychosocial factors to classify the NSCLBP into homogenous subgroups and it was established evidence-based regarding the spinal kinematics and muscle activity in static postures. However, the information about the spinal kinematics and postural control strategies during the performance of dynamic tasks are limited. Addressing this gap in the literature would help health care providers to develop specific functional interventions to re-educate maladaptive behaviors in MCI subgroups. Therefore, this dissertation aims to further investigate the variability of postural control and spinal movement strategies using the kinematics and COP data in NSCLBP subgroups during the performance of the dynamic functional task.

Purpose

To investigate differences in spine kinematics behavior and postural control variables as well as performance scores produced during performance of the dynamic balance task using mSEBT between the two MCI subgroups of NSCLBP subjects (FP and AEP) and healthy individuals. These purposes were achieved in two studies.

Objectives

1. To compare the differences in dynamic balance among FP, AEP, and healthy controls during performance of mSEBT.

2. To compare the differences in COP parameters among FP, AEP and healthy controls during performance of mSEBT.

3. To examine the kinematic differences in thoracic and lumbar segments, and the pelvis in MCI subgroups (FP and AEP) during dynamic balance using the mSEBT.

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CHAPTER TWO

COMPARISON OF POSTURAL CONTROL BETWEEN INDIVIDUALS WITH AND WITHOUT NONSPECIFIC CHRONIC LOW-BACK PAIN SUBGROUPS BASED ON MULTIDIMENSIONAL CLASSIFICATION SYSTEM

Amjad Shallan[a,b]*, Everett Lohman[a], Faris Al-Shammari[b], Robert Dudley[c], Omar Gharisia[a] , Rana Al-Marzouki[a], Helen Hsu[a], Noha Daher[d]

[a]Department of Physical Therapy, School of Allied Health Professions, Loma Linda University, Loma Linda, California, USA

[b]Department of Physical Therapy, Faculty of Applied Medical Sciences, The Hashemite University, Jordan

[c]Department of Kinesiology, School of Behavioral and Applied Sciences, Azusa Pacific University, Azusa, California, USA

[d]Department of Allied Health Studies, School of Allied Health Professions, Loma Linda University, Loma Linda, California, USA

*Corresponding author: Amjad Shallan, Department of Physical Therapy, Loma Linda University, 24851 Circle Dr, Loma Linda, CA 92354, USA, Tel: 0019092462120; email: ashallan@llu.edu

Abstract

According to previous studies, people with nonspecific low back pain present with static postural control deficiencies. However, limited number of studies are available about the changes in dynamic postural control deficiencies in nonspecific chronic low-back pain (NSCLBP) subgroups. Therefore, the aim of this study was to compare the postural control between NSCLBP subgroups and healthy people during dynamic balance using a modified Star Excursion Balance Test (mSEBT).

Eighteen NSCLBP subjects (9 active extension pattern (AEP), 9 flexion pattern (FP)), and 10 healthy control were enrolled in this study. All subjects performed mSEBT on their dominant leg on a force plate. Normalized reach distance and balance parameters, including the center of pressure (COP) displacement and velocity were recorded.

There were significant differences in mean reach distance in both posterolateral (PL), and posteromedial (PM) reach directions between AEP and healthy ($p<0.001$) and between FP and healthy subjects ($p<0.001$). However, there was no significant differences among the three groups in the anterior reach direction. Also, the results showed no significant differences in mean COP variables (velocity and displacement) between pooled NSCLBP and healthy subjects. However, when we reclassified the subjects into AEP, FP and healthy groups, the results showed a significant difference in mean COP velocity in PM direction between AEP and FP subjects ($p=0.048$), and between AEP and healthy subjects ($p=0.024$).

The findings in this study highlight the heterogeneity of the individuals with NSCLBP and the importance of identifying the homogenous subgroups. Individuals with

AEP and FP experience deficits in dynamic postural control compared to healthy controls. In addition, the findings of this study support the concept of the Multidimensional Classification System (MDCS).

Keywords: Low Back Pain subgroups, Postural control, Center of Pressure, Balance

Background

Low back pain (LBP) is one of the most common musculoskeletal disorders with more than 80% of individuals experiencing LBP at one time in their life (Walker, Muller, & Grant, 2004). The nonspecific chronic low back pain (NSCLBP) is considered one of the most common LBP classifications (Freburger et al., 2009). It is defined as LBP for more than three months without known specific sources of pain and with no evidence of pathoanatomic and abnormality with imaging (Hart, Deyo, & Cherkin, 1995). However, NSCLBP could result from different factors such as biomechanical, psychosocial and genetic factors or the interactions between some or all of them (Balagué, Mannion, Pellisé, & Cedraschi, 2012). In addition, NSCLBP is considered a disabling condition that limits daily activities of the affected people (Vos et al., 2012). Therefore, understanding the mechanism of NSCLBP disorder may help healthcare providers to develop proper interventions.

Postural control is required to safely and effectively perform a wide range of daily activities (Maribo, Schiøttz-Christensen, Jensen, Andersen, & Stengaard-Pedersen, 2012). Postural control is defined as the ability of the human body to keep the center of gravity (COG) within the base of support (Winter, 2009). However, studies have identified postural control changes in people with LBP especially in term of center of pressure (COP) parameters (e.g., COP velocity and displacement)(Mazaheri, Coenen, Parnianpour, Kiers, & van Dieën, 2013; Rainville et al., 2011).

Numerous factors may contribute to postural control alteration in people with NSCLBP (Ruhe, Fejer, & Walker, 2011). Deficit in the neuromusculoskeletal systems such as a reduction in somatosensory input, processing, or motor output have been found to contribute to alterations in postural control in people with NSCLBP (Luoto et al., 1998). In addition, studies revealed that LBP could affect postural stability through numerous co-existing factors such as pain, alteration in movement strategies, and fear of pain (Ruhe et al., 2011).

Different methods are used to detect postural control and dynamic balance deficits. However, many of these methods are complicated and costly (Ruhe, Fejer, & Walker, 2010). The Star Excursion Balance Test (SEBT) is a simple tool that has been used to measure functional and dynamic balance (Ganesh, Chhabra, & Mrityunjay, 2015). The SEBT has been used to detect dynamic balance impairments that may lead to lower extremity injuries (Herrington, Hatcher, Hatcher, & McNicholas, 2009; Linens, Ross, Arnold, Gayle, & Pidcoe, 2014). Recently, several studies have utilized the SEBT to detect dynamic balance impairments in people with LBP (Ganesh, Chhabra, & Mrityunjay, 2015; Ganesh, Chhabra, Pattnaik, et al., 2015). Also, SEBT is considered a challenging task for people with LBP. Therefore, the SEBT may provide clinicians with valuable information regarding postural control impairments and movement strategies in people with LBP (E. K. Appiah-Dwomoh, Müller, & Mayer, 2018). The modified version of the SEBT (mSEBT) is used to reduce the potential fatigue effect and the redundancy among the eight directions in the original SEBT (Hertel, Braham, Hale, & Olmsted-Kramer, 2006). The mSEBT consists of three directions including; the anterior, posteromedial and posterolateral directions. The mSEBT has shown excellent interrater reliability and strong intra-rater and test-retest reliability in detecting dynamic balance impairments (Hertel, Miller, & Denegar, 2000; Kinzey & Armstrong, 1998).

The force plate has been used to quantify the center of pressure (COP) oscillations during static and dynamic postural control in people with LBP (Mazaheri et al., 2013; Ruhe et al., 2011). Despite the large number of studies investigating postural stability in people with LBP, the results have been inconsistence with contradictory findings (Mazaheri et al., 2013; Ruhe et al., 2011). One reason behind these inconsistencies may be related to the complexity and heterogeneity of people with LBP (Mazaheri et al., 2013; Seraj et al., 2019). Therefore, classifying people with NSCLBP into subgroups, according to the type of dysfunction, may be important in order to identify the adaptive postural control strategies within each subgroup (Foster, Hill, & Hay, 2011).

Attempts have been made to classify individuals with NSCLBP (Luomajoki, Kool, De Bruin, & Airaksinen, 2007; O'Sullivan, 2005). One of these classification systems is the Multidimensional Classification System (MDCS)(O'Sullivan, 2005). The MDCS outlined five motor control impairment (MCI) subgroups with the flexion pattern (FP) and active extension pattern (AEP) being the most in the clinical setting (Dankaerts et al., 2009; O'Sullivan, 2006). Based on O'Sullivan (2005), MCI subgroups exhibit full range of motion in the direction of pain provocation. Also, MCI subgroups utilize modifications in body postures and movement strategies to deal with the expected pain (O'Sullivan, 2005).

Previous studies have investigated the physical characteristics between these two MCI subgroups (AEP and FP) and healthy subjects in term of kinematics and muscle activity during static and functional tasks (Hemming, Sheeran, van Deursen, & Sparkes, 2015; Hemming, Sheeran, van Deursen, & Sparkes, 2018; Sheeran, Sparkes, Caterson, Busse-Morris, & van Deursen, 2012). However, there is limited information about postural control and dynamic balance characteristics in these subgroups (Seraj et al., 2019). Therefore, the purpose of this study was to examine postural control and dynamic balance performance between MCI subgroups (FP and AEP) compared to the healthy subjects using the mSEBT.

Methods

Subjects

A total of 28 subjects participated in this study from Loma Linda University Medical Health and the surrounding community. Subjects were recruited using fliers. LBP subjects were included in the study if they were between 18 and 60 years old, have LBP for more than 3 months, and the pain was localized to the low back and/or buttock regions only. The control subjects were healthy individuals who have been free of LBP for at least two years and have similar characteristics to subjects with LBP. The exclusion criteria for both groups were: signs of serious spinal pathology, fracture, malignancy, history of spinal surgery, lower extremity injury in the previous two years, vestibular dysfunction, or balance disorders. In addition, females were excluded from the study if they were breastfeeding or pregnant (self-reported) to avoid potential complications or side effects.

Measurement Procedure

All tests were performed at the Physical Therapy Department in the School of Allied Health Professions, Loma Linda University, CA, USA. Data collection took approximately 60 minutes to complete. The study protocol and procedures were explained to the subjects in details by the primary researcher. After that, all subjects read and signed the informed consent. Then, demographic data such as age, weight, height and dominant leg, defined at the limb used to kick a ball, were obtained prior to the data collection session (Appendix A and B). All subjects completed a medical history questionnaire and the International Physical Activity Questionnaire - Short Form (IPAQ-SF) to measure the physical activity level. Subjects in the LBP groups were asked to report the measures for pain using the Visual Analogue Scale (VAS), disability levels caused by LBP using the Roland-Morris Disability Questionnaire (RMQ) and the presence of pain-related fear of movement using the Tampa Scale of Kinesiophobia (TSK) (Appendix C).

MCI Subgroup Classification

AEP and FP were chosen in this study because of their high prevalence (Dankaerts et al., 2009; O'Sullivan, 2006). To establish MCI subgroups classification (AEP and FP), comprehensive subjective and objective assessments were conducted. In the subjective assessment, the full history of the subject’s low back pain was taken as well as the pain behaviors such as the easing and aggravating postures and activities. In the objective examination, the battery of postures and spinal range of motion (ROM) were observed. In addition, usual standing and sitting, full trunk flexion, extension, and side bending were evaluated. Finally, the Passive Physiological Intervertebral Movements (PPIVM) at, above, and below the provoking lumbar segment were performed to assess the existence of joint hypo-mobility or hypermobility [28]. MCI subgroups (AEP and FP) subjects were examined and classified independently by two physical therapists based on MDCS criteria (O’Sullivan, 2005), and only subjects who had an agreement of both clinicians were included in the study. (Figure 1) illustrates the Flowchart of recruitment procedures for NSCLBP subjects.

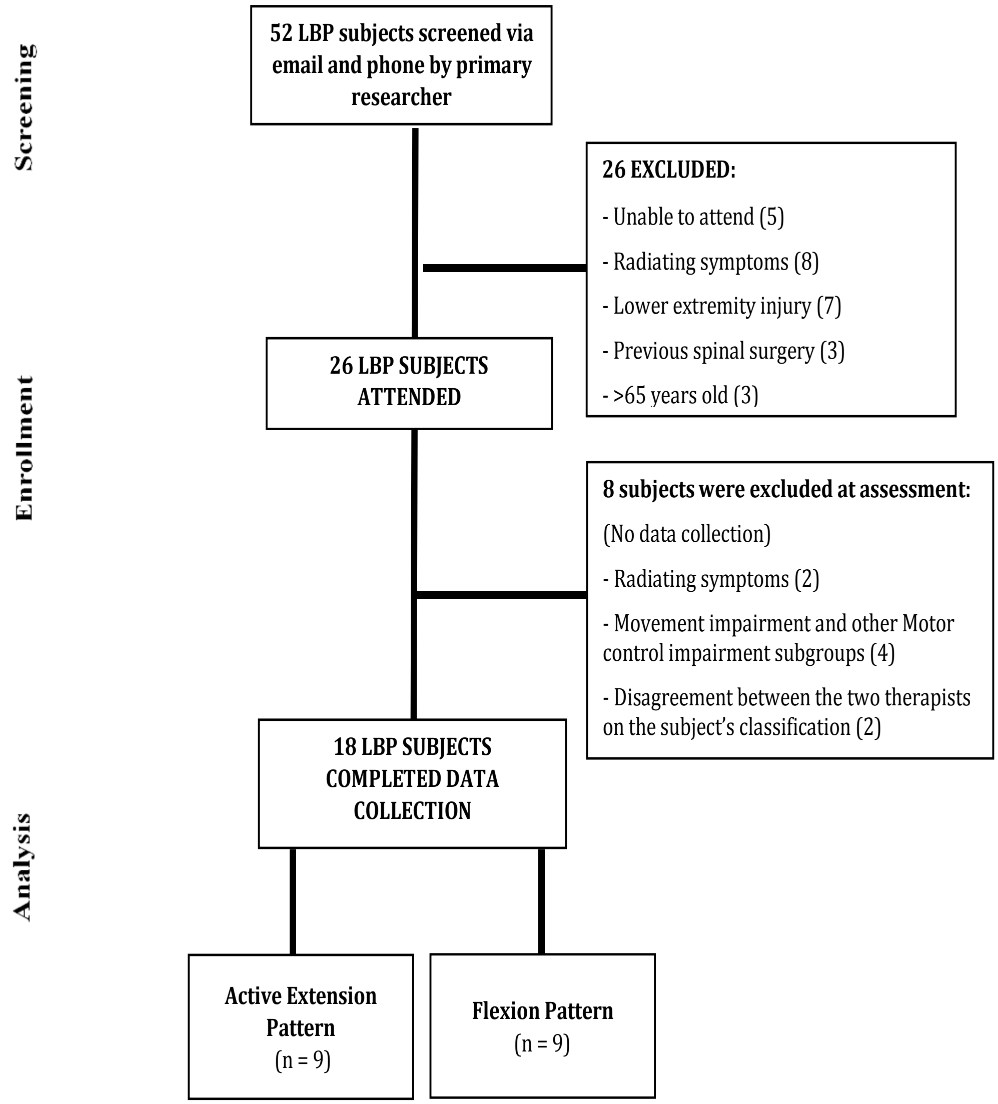

Figure 1. Flowchart of recruitment procedures for low back pain (LBP) subjects

Data Collection Procedures

The mSEBT was used in this study. Three adhesive tape measures with a centimeter scale were adhered to the floor directly above an indwelling force plate to quantify postural sway and COP parameters during each of the mSEBT reach directions. The anterior direction was aligned to the apex and the other two reach directions (PM and PL) were oriented 135o to apex to create a Y shape (E. Appiah-Dwomoh, Müller, Hadzic, & Mayer, 2016).

Verbal and visual demonstration of proper performance of the mSEBT were provided to the subjects. Then, the subjects were instructed to align the lateral malleolus of the dominant leg at the intersection point of the three directions with foot oriented toward the anterior direction with their hands placed on their hips. After that, the subjects were instructed to reach as far as possible with the non-stance leg and pointing with their big toe to the marked tape and return to the starting position (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016). Subjects performed 6 practice trials prior to the actual test trials to minimize the learning effect and to assure performance stabilization (Hertel et al., 2000). Next, the three test trials were recorded in each direction (Anterior, PM and PL) with 15 second rest period between each trial (Hertel et al., 2006). The subjects performed the mSEBT on the force plate without wearing shoes to eliminate the influence of varying footwear (Gribble, Hertel, & Plisky, 2012) (Figure 2). The trial was considered invalid if one of the following situations occurred; the subjects removed their hands off of their hips, the heel of stance limb lost contact with the ground during reaching, the subject put weight onto their reaching foot on the ground, or lost their balance during reach out or return (E. Appiah-Dwomoh et al., 2016). The leg length (from the anterior superior iliac spine to the medial malleolus) was measured with the subject in supine lying (E. Appiah-Dwomoh et al., 2016). This measurement was used in normalizing the mSEBT reach distance for each subject (Gribble & Hertel, 2003). The maximum reaching distance in every direction was normalized as a percentage of the stance limb length using this equation; maximum reach divided by leg length and the results were multiplied by 100. The mean value of normalized reach in each direction was calculated for analysis (E. Appiah-Dwomoh et al., 2016).

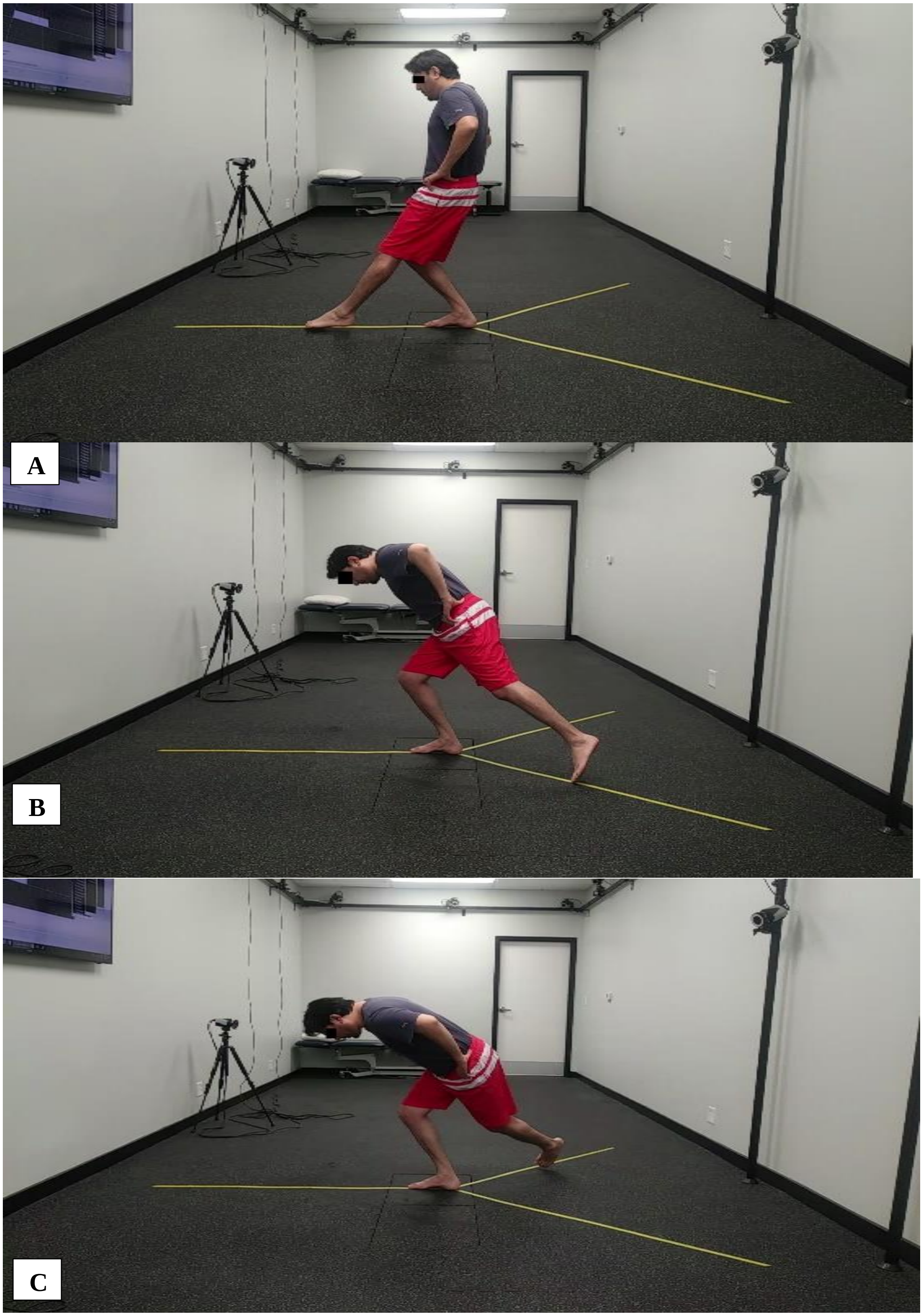

Figure 2. The Modified Star Excursion balance Test. Subject reaches in the (A) anterior, (B) posteromedial, and (C) posterolateral directions.

Data Analysis

A single force plate (AMTI Optima, Watertown, NY, USA) was used to evaluate the postural control parameters. The COP data were sampled at 2000 Hz and force plate movements were described as the following: Antero-posterior movement was represented by the Y-axis, while the medio-lateral movement was represented by the X-axis. Medio-lateral (ML) and anterior-posterior (AP) displacements and velocity of COP were used for analysis. Visual 3D software (C-Motion Inc., Rockville, MD, USA) was used for raw data processing and analysis. COP data was filtered using a fourth order low-pass Butterworth filter with a cut off frequency of 5 Hz.

Statistical Analysis

Data were summarized using mean and standard deviation for quantitative variables and counts (%) for qualitative variables. The normality of continuous variables was examined using Shapiro Wilk's test and Box plots. The characteristics of the subjects were compared among the study groups using chi-square for qualitative variables, and one-way analysis of variance (ANOVA) or independent t-test for quantitative variables.

Mean outcome variables were compared among the three groups (FP, AEP, and healthy) using one-way ANOVA. If the results of the test were statistically significant, post hoc testing using Bonferroni test was conducted. The level of significance was set at alpha=0.05. Statistical analysis was performed using IBM SPSS Software version 25 for Windows (Chicago, IL, USA).

Results

A total of 28 subjects (18 with LBP and 10 healthy) with a mean age of 27.6±3.8 years and body mass index (BMI) 24.3±3.7 kg/m^2 participated in the study. The demographic characteristics of the subjects by the study group are shown in table 1. There was no significant difference in demographic data among the three groups.

There was no significant difference in mean reach distance among the three groups ($F_{2,27}$=1.0, p=0.38, η^2=0.07) in the anterior direction. However, there was a significant difference in the mean reach distance in the PL and PM directions, by study group ($F_{2,27}$=17.6, p<0.001, η^2=0.58, and $F_{2,27}$=9.3, p<0.001, η^2=0.43, respectively). In the PL direction, there was a significant difference in mean reach distance between AEP and healthy (73.4 ±8.4 vs. 90.7 ±5.2, p<0.001), and FP and healthy (75.4 ±7.3 vs. 90.7 ±5.2, p<0.001). Similarly, in the PM direction, there was a significant difference in mean reach distance between AEP and healthy (81.3 ±10.9 vs. 93.3 ±4.5, p=0.018), and FP and healthy (76.7 ±9.8 vs. 93.3 ±4.5, p=0.001). However, there was no significant difference in mean reach distance between AEP and FP in PL and PM directions. (p>0.05, Figure 3)

The results showed no significant differences in mean COP variables (velocity and displacement) between pooled NSCLBP and healthy subjects (Table 2). However, when we reclassified the subjects into AEP, FP and healthy groups, the results showed a significant difference in mean AP COP velocity in PM direction between AEP and FP subjects (71.2 ± 17.2 vs. 56.4 ± 9.3, p=0.048), and between AEP and healthy subjects (71.2 ± 17.2 vs. 55.1± 8.5, p=0.024), (Table 3).

Table 1: Mean (SD) of Baseline Characteristics by Study Group (N=28)

	AEP (n_1=9)	FP (n_2=9)	Healthy (n_3=10)	p-value
Female; n (%)	5 (55.6)	8 (88.9)	7 (70)	0.29
Age (year)	28.8 (5.0)	27.2 (3.6)	26.8 (2.6)	0.51
BMI (kg/m^2)	25.8 (5.0)	23.5 (2.7)	23.8 (3.0)	0.37
Physically active; n(%)	9 (100)	9 (100)	9 (90)	0.76
Pain level	2.8 (1.6)	4.4 (2.0)	-	0.07
TSK	34.9 (8.2)	37.3 (3.7)	-	0.43
RMQ	5.6 (0.9)	5.4 (0.5)	-	0.75

Abbreviations: SD, Standard Deviation; AEP, Active extension pattern; FP, Flexion pattern; BMI, Body mass index; TSK, Tampa Scale for Kinesiophobia; RMQ, Roland-Morris Disability Questionnaire

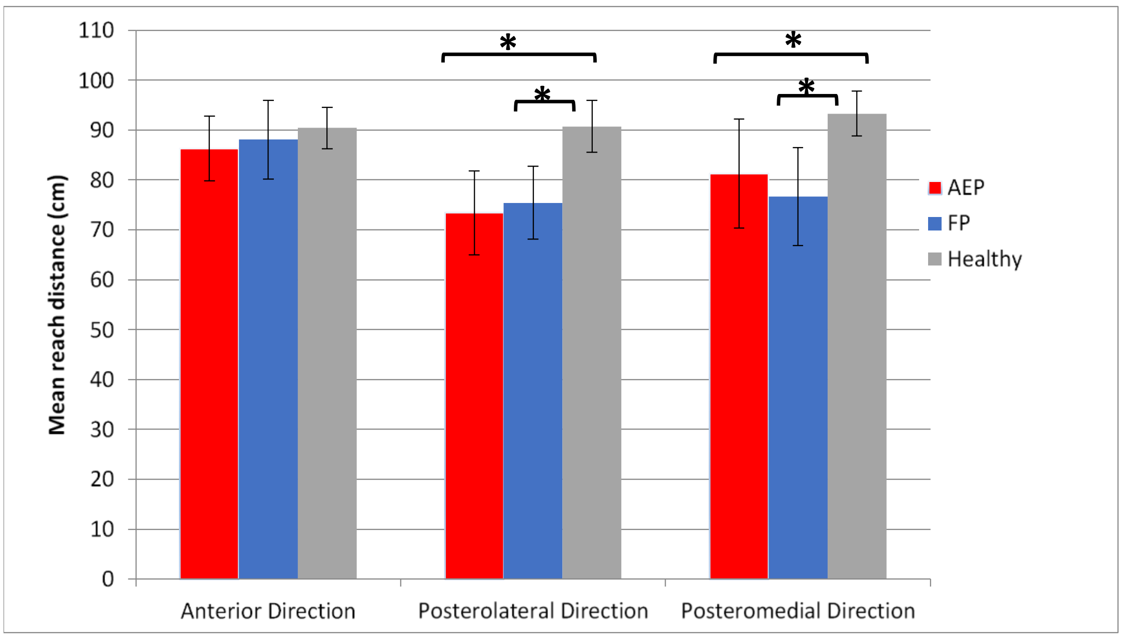

Figure 3. Mean reach distance (cm) by study group (N=28).
Abbreviation: AEP, Active extension pattern; FP, Flexion pattern
* Significant difference ($p < 0.05$). Values are means ± standard deviation.

Table 2. Comparison of COP Displacement (mm) and Velocity (mm/s) between Pooled LBP and healthy subjects

Direction	COP parameter		Pooled LBP (n=18)	Healthy (n=10)	Cohen's	p_value
			Mean ± SD	Mean ± SD	d	
Anterior	Velocity	AP	64.2 ± 15.2	64.8 ± 16.7	0.04	0.930
		ML	40.6 ± 11.8	37.5 ± 6.8	0.30	0.459
	Displacement	AP	245.4 ± 54.2	275.4 ± 59.8	0.54	0.187
		ML	170.8 ± 48.7	192.0 ± 72.6	0.37	0.364
Posterolateral	Velocity	AP	60.1 ± 14.0	62.1 ± 11.6	0.15	0.713
		ML	50.0 ± 12.9	51.3 ± 9.5	0.11	0.786
	Displacement	AP	234.3 ± 65.6	263.3 ± 19.6	0.54	0.096
		ML	216.6 ± 55.5	249.2 ± 79.7	0.51	0.214
Posteromedial	Velocity	AP	63.8 ± 15.4	55.1 ± 8.5	0.66	0.065
		ML	45.6 ± 15.4	46.4 ± 10.9	0.06	0.886
	Displacement	AP	243.6 ± 68.5	263.7 ± 80.5	0.28	0.491
		ML	198.6 ± 66.8	231.1 ± 67.2	0.49	0.230

Abbreviation: SD, Standard Deviation; AP, Anterior- Posterior; ML, Medio-lateral; COP, Center of Pressure

Table 3. Comparison of COP Displacement (mm) and Velocity (mm/s) among the Three Groups

Direction	COP parameter		AEP (n_1=9)	FP (n_2=9)	Healthy(n_3=10)	η^2	p_value
			Mean ± SD	Mean ± SD	Mean ± SD		
Anterior	Velocity	AP	67.2 ± 18.4	61.2 ± 11.4	64.8 ± 16.7	0.026	0.721
		ML	40.7 ± 12.0	40.5 ± 12.3	37.5 ± 6.8	0.021	0.764
	Displacement	AP	244.4 ± 53.2	246.4 ± 58.3	275.4 ± 59.8	0.066	0.425
		ML	160.8 ± 66.2	180.8 ± 20.9	192.0 ± 72.6	0.052	0.515
Posterolateral	Velocity	AP	62.3 ± 17.6	58.0 ± 9.8	62.1 ± 11.6	0.024	0.737
		ML	52.6 ± 12.0	47.5 ± 13.9	51.3 ± 9.5	0.035	0.643
	Displacement	AP	233.2 ±61.6	235.4 ± 73.2	263.3 ± 19.6	0.066	0.425
		ML	221.8 ±53.8	211.4 ± 60.1	249.2 ± 79.7	0.063	0.444
Posteromedial	Velocity	AP	71.2 ± 17.2	56.4 ± 9.3	55.1 ± 8.5	0.285	0.015*
		ML	49.4 ± 15.1	41.8 ± 15.6	46.4 ± 10.9	0.051	0.519
	Displacement	AP	245.9 ± 57.6	241.3 ± 81.5	263.7 ± 80.5	0.019	0.786
		ML	185.4 ± 57.3	211.8 ± 76.3	231.1 ± 67.2	0.081	0.350

Abbreviation: SD, Standard Deviation; AEP, Active extension pattern; FP, Flexion pattern; AP, Anterior- Posterior; ML, Medio-lateral; COP, Center of Pressure; η^2 = effect size. * Significant difference between AEP and FP and between AEP and Healthy, ($p < 0.05$)

Discussion

This study examined the differences in the mSEBT scores in two subgroups of NSCLBP compared with healthy subjects. In addition, it examined the dynamic postural control using the COP parameters during the performance of the mSEBT. The results validate the MCI subclassification and provide more evidence regarding postural control compensatory strategies that may occur in these subgroups of individuals with NSCLBP. To our knowledge, this is the first study to examine the dynamic postural control deficits in people with NSCLBP by subgroups using the modified SEBT.

The results of this study indicated that the reach distances in the PL and PM directions were significantly lower in both AEP and FP groups compared to healthy group. However, there was no significant difference in mean reach distance in the anterior direction among the three groups. Subjects in both AEP and FP subgroups may have a limited pelvic anterior tilt compared to healthy subjects, which leads to decrease in the PL and PM reaching distance (Carpes, Reinehr, & Mota, 2008). Also, reaching in posterior directions in the mSEBT are more challenging compared to anterior reaching due to excessive lumbar lordosis that is required to finish the task which stresses the postural control system in NSCLBP groups to a point that limits the subjects' reach (Behennah, Conway, Fisher, Osborne, & Steele, 2018). In addition, people with NSCLBP are more dependent on visual feedback due to altered proprioceptive input (Mergner, Schweigart, Maurer, & Blümle, 2005). Reaching in posterior direction requires subjects to rely on proprioceptive input and vestibular system to maintain the single leg balance compared to reaching forward where the subjects can use their vision to help.

Therefore, there was no significant difference in reaching forward among groups (Bray & Moseley, 2011).

Another explanation could be related to the pain avoidance behavior in both AEP and FP subjects (O'Sullivan, 2005; Waddell, Newton, Henderson, Somerville, & Main, 1993). Subjects in both MCI groups may anticipate pain during posterior reach which may lead them to avoid performing the task vigorously and consequently this results in poor performance in mSEBT in PM and PL directions compared to healthy subjects (Behennah et al., 2018).

These findings are consistent with the Hooper et al. (2016) study, that found significant differences in reach distances between the LBP subgroups (current LBP vs LBP history) compared to healthy subjects in PL and PM directions but not in the anterior direction (Hooper et al., 2016). On the other hand, Ganesh et al. (2014) found that people with LBP have a significant decrease in reach distances in PM, PL and the anterior directions (Ganesh, Chhabra, & Mrityunjay, 2015). While Appiah-Dwomoh, et al., (2006) did not find any significant differences in any reach directions between healthy athletes and athlete with LBP (E. Appiah-Dwomoh et al., 2016). The inconsistency in the findings of the above studies can be explained by many factors. First, the heterogeneity of the LBP subjects in the previous studies may lead to the differences in the postural stability strategies that each subject used to maintain their balance. In other words, findings in one subgroup of subjects were counteracted by other subgroups when the people with NSCLBP were studied heterogeneously (the washout effect phenomenon) (Fullam, Caulfield, Coughlan, & Delahunt, 2014). Second, LBP subjects' characteristics such as age and physical activities were different which may contribute to these differences in the results (Hemmati, Rojhani-Shirazi, Malek-Hoseini, & Mobaraki, 2017).

Our results showed no significant difference between the pooled NSCLBP and healthy subjects in mean COP measures (displacement and velocity). After subgrouping NSCLBP subjects into FP and AEP groups, the results showed a higher mean COP sway velocity in AEP subjects compared to the FP and healthy subjects in PM direction. This finding confirms the presence of washout effect and establishes the need for studying the homogeneous subgroups of NSCLBP in order to better understand the NSCLBP disorder (Dankaerts, O'sullivan, Burnett, & Straker, 2006).

Our findings support the findings by Seraj et al. (2019), who found no significant differences in postural control variables between the pooled NSCLBP subjects and healthy subjects during lifting task. However, when NSCLBP subjects were classified into AEP and FP, the results revealed that AEP subjects had a significant difference in postural control compared to FP and healthy subjects during lifting task (Seraj et al., 2019).

In our study, AEP subjects had a higher sagittal COP velocity as compared to FP and healthy subjects during PM direction of mSEBT. One of the reasons behind this finding may be the nature of the required task. Reaching in PM direction requires anterior pelvic tilt and stresses lumbar spine resulting in excessive lordosis or hyperextension of lumbar spine. Based on the MCI classification, the standing and extension positions are more likely to aggravate pain in the AEP group as compared to the FP group (O'Sullivan, 2006). According to the pain adaptation model, the normal response of the body is to increase paraspinal muscle activity in the AEP subjects which may increase the load on the trunk structure (Dankaerts et al., 2006). These changes in proprioception and the muscle activity may result in more postural sway velocity in the AEP subjects as compared to the FP and the healthy subjects.

Subjects in the AEP group will tend to move slower in the PM direction as pain-avoidance behavior to finish the task with less pain. Slower movement in the PM direction will result in longer duration of the single leg stance and more activation of the lumbar extensor muscles resulting in fatigue which leads to the increase in body sway (Madigan, Davidson, & Nussbaum, 2006). As noted earlier, the subjects in this study were young. Therefore, the nervous system will have a faster reaction in order to correct body sway, and to maintain stability. According to Newton’s third law, each action has a reaction that is equal in magnitude and opposite in direction. Also, according to the pendulum theory, anterior acceleration will be corrected by posterior acceleration which results in body sway. Since the correction of body sway was fast, we expect that the repeated sway action will be fast as well resulting in the increase in COP sway velocity.

We did not find any significant differences between the FP and the healthy subjects in COP displacement and velocity, suggesting that the FP and the healthy subjects may adopt similar strategies for postural control during the dynamic balance test (Dankaerts et al., 2006). Also, it could be that the mSEBT was not challenging enough to aggravate the pain in the FP group to exhibit different postural control strategies compared to the healthy subjects. In addition, it is expected to have no significant difference in the mean displacement of COP among the groups due to the fact that all subjects were young and physically active (E. Appiah-Dwomoh et al., 2016).

Study Limitations

There were some limitations in this study. First, the sample size was small, future research needs to recruit a larger sample size to investigate the postural stability differences between NSCLBP subgroups. Second, the pain and disability level in NSCLBP subgroups were relatively low. Future studies should investigate subjects with NSCLBP with high levels of pain and disability which may exhibit different postural stability strategies. Third, we did not measure trunk muscle activation or trunk kinematics. This information could help in better understanding of the compensatory movement patterns that each subgroup uses during dynamic balance.

Conclusion

The findings in this study highlight the heterogeneity of the subjects with NSCLBP and the importance of identifying the homogenous subgroups. The findings showed that the dynamic balance and postural control were significantly different between AEP and FP, and AEP and healthy subjects during dynamic balance using the mSEBT. The AEP subjects exhibited more body sway velocity in the posteromedial direction of the mSEBT. However, there were no significant differences observed between FP and healthy subjects, suggesting that FP and healthy individuals may adopt similar postural control strategies during dynamic balance.

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CHAPTER THREE

COMPARISON OF SPINAL KINEMATICS BETWEEN INDIVIDUALS WITH AND WITHOUT NONSPECIFIC CHRONIC LOW-BACK PAIN SUBGROUPS DURING PERFORMANCE OF DYNAMIC BALANCE TASK

Amjad Shallan[a,b]*, Everett Lohman[a], Faris Al-Shammari[b], Robert Dudley [a,c], Mansoor Al-Ameri[a] , Noha Daher[d]

[a]Department of Physical Therapy, School of Allied Health Professions, Loma Linda University, Loma Linda, California, USA

[b]Department of Physical Therapy, Faculty of Applied Medical Sciences, The Hashemite University, Jordan

[c]Department of Kinesiology, School of Behavioral and Applied Sciences, Azusa Pacific University, Azusa, California, USA

[d]Department of Allied Health Studies, School of Allied Health Professions, Loma Linda University, Loma Linda, California, USA

*Corresponding author: Amjad Shallan, Department of Physical Therapy, Loma Linda University, 24851 Circle Dr, Loma Linda, CA 92354, USA, Tel: 0019092462120; email: ashallan@llu.edu

Highlights

- FP and AEP of LBP subgroups had a decreased score in mSEBT PM and PL directions.
- Anterior mSEBT reach distances were not reduced in these two LBP subgroups.
- Regional spinal curvatures were different between AEP and FP during dynamic balance.
- No significant spinal kinematics differences between FP and healthy were observed.

Abstract

Dynamic balance impairments are commonly observed in people with low back pain (LBP). People with LBP have reduced lumbopelvic stability and may exhibit spinal biomechanical changes during dynamic balance. A limited number of studies are available about the spinal kinematic changes during dynamic balance in people with nonspecific chronic low back pain (NSCLBP) subgroups. Therefore, the aim of this study was to compare spinal kinematics between NSCLBP subgroups and healthy individuals during dynamic balance using a modified Star Excursion Balance Test (mSEBT).

Eighteen NSCLBP subjects (9 active extension pattern (AEP), 9 flexion pattern (FP)), and 10 healthy controls were enrolled in this study. All subjects performed mSEBT on their dominant leg in the anterior (ANT), posterolateral (PL), and posteromedial (PM) reach directions. Normalized reach distance and the pelvic, lumbar, and thoracic 3-dimensional kinematics were recorded.

There were significant differences in mean reach distance in both PL and PM directions between AEP and healthy and between FP and healthy subjects. However, there was no significant difference among the three groups in the anterior reach direction. Kinematic results showed a significant difference in the lumbar spine region between pooled NSCLBP and healthy subjects in all reach directions. However, after the classification of subjects with NSCLBP into AEP and FP subgroups, the results showed significant differences in both lumbar and thoracic spine regions between AEP and FP and between AEP and healthy in all reaching directions. However, there were no significant differences in spinal kinematics between FP and healthy subjects.

Individuals with AEP and FP experience diminished dynamic balance compared to healthy controls. The thoracic and lumbar spine regions are very important to discriminate between AEP and FP, and between AEP and healthy during dynamic balance. In addition, the findings of this study support the concept of the Multidimensional Classification System (MDCS).

Keywords: Dynamic balance; non-specific low back pain; kinematics; Star Excursion Balance Test; Thoracic; Lumbar

Introduction

More than 80% of the population experience low back pain (LBP) at one point in their lifetime (Andersson, 1999; Walker, Muller, & Grant, 2004). LBP is considered chronic when pain duration exceeds 3 months (Koes et al., 2010). It accounts for 10% of the cases and represents 70% to 90% of the total LBP cost (Waldburger, Stucki, Balagué, & Wittig, 2001). Symptoms associated with LBP are often recurrent or persistent. LBP subsides spontaneously in 33% of people within three months, however, 65% of individuals with LBP continue to report pain after a year of onset (Itz, Geurts, Van Kleef, & Nelemans, 2013).

Nonspecific low back pain is defined as a LBP without known specific cause of pain and no abnormality can be found with imaging (Hart, Deyo, & Cherkin, 1995; Spitzer, 1987). Non-specific chronic low back pain (NSCLBP) is predominant among people with low back pain (Freburger et al., 2009). NSCLBP is attributed to various factors which might interact with each other such as psychosocial, biomechanical, environmental, cultural, and genetic factors (Balagué, Mannion, Pellisé, & Cedraschi, 2012). Also, NSCLBP is considered a disabling condition that limits daily activities of the affected people (Vos et al., 2012). Therefore, understanding the mechanism of NSCLBP disorder may help healthcare providers to develop proper interventions.

Postural control is necessary to safely perform activities of daily living (Maribo, Schiøttz-Christensen, Jensen, Andersen, & Stengaard-Pedersen, 2012), and is defined as the ability to maintain the center of gravity within the base of support through coordinating body movements (Winter, 2009). Changes in postural control are noted in individuals with LBP and there is an association between the presence of LBP and increased body sway (Rainville et al., 2011). Also, people with LBP have greater difficulty adapting to external stressors that may affect postural control (Mientjes & Frank, 1999).

Different methods are used to determine deficits in postural control. However, these methods are costly and complicated (Ruhe, Fejer, & Walker, 2010). The Star Excursion Balance Test (SEBT) is a simple tool that is used to measure dynamic postural control (Ganesh, Chhabra, & Mrityunjay, 2015). It has been used to detect balance deficits in people with chronic LBP (Ganesh, Chhabra, & Mrityunjay, 2015; Ganesh, Chhabra, Pattnaik, et al., 2015). Also, SEBT is considered a challenging activity to the people with LBP which may provide more information about the kinematic compensatory mechanisms in individuals with NSCLBP (E. K. Appiah-Dwomoh, Müller, & Mayer, 2018). The modified version of the SEBT (mSEBT) is used to reduce the redundancy among the eight directions in the original SEBT and the potential fatigue effect (Hertel, Braham, Hale, & Olmsted-Kramer, 2006). The modified form of SEBT consists of three main directions: the anterior, posteromedial and posterolateral directions (Hertel et al., 2006). The mSEBT has demonstrated excellent interrater reliability, intra-rater and test-retest reliability (Hertel, Miller, & Denegar, 2000; Kinzey & Armstrong, 1998).

A systematic review showed contradictory results regarding the postural stability in patients with LBP (Mazaheri, Coenen, Parnianpour, Kiers, & van Dieën, 2013). The inconsistency could be attributed to the lack of subgroups in those studies. Attempts have been made to classify individuals with NSCLBP (Luomajoki, Kool, De Bruin, & Airaksinen, 2007; O'Sullivan, 2005). One of the classification systems is the

Multidimensional Classification System (MDCS) (O'Sullivan, 2005). The MDCS defined five Motor control impairment (MCI) subgroups within the NSCLBP population (O'Sullivan, 2005). Individuals with MCI utilize modifications in body postures and movement strategies to deal with the expected pain (O'Sullivan, 2005). Based on the MDCS, the most common LBP patterns in MCI subgroups are the Flexion Pattern (FP) and Active Extension Pattern (AEP) (Dankaerts et al., 2009; O'Sullivan, 2006). According to this classification system, in the FP group, spinal flexion aggravates the symptoms while spinal extension eases or alleviates the symptoms. In the AEP group, the converse occurs during spinal extension (O'Sullivan, 2005).

Impairments of the spine affect postural stability during standing (Karlsson & Frykberg, 2000). Deficits in proprioceptive in the spinal region may lead to postural instability (Jo et al., 2011; Silfies, Cholewicki, & Radebold, 2003). A lack of kinematic coordination between the thoracic and lumbar segments and the pelvis may result in musculoskeletal injuries, mainly with unexpected perturbations (Henry, Hitt, Jones, & Bunn, 2006; Sung & Park, 2009). Based on previous literature, spinal kinematics and postural control are usually examined during static postures in patients with NSCLBP (Caffaro et al., 2014; Ham, Kim, Baek, Lee, & Sung, 2010; Hemming, Sheeran, van Deursen, & Sparkes, 2018). Therefore, there is limited information about the segmental spinal kinematics and postural control during dynamic activities. In addition, to the best of our knowledge, no studies have investigated the segmental spinal kinematics differences between NSCLBP subgroups during the dynamic balance test using the mSEBT. Therefore, the purpose of this study was to examine the kinematic differences in thoracic and lumbar segments, and the pelvis in MCI subgroups (FP and AEP) during dynamic balance using the mSEBT.

Methods

Subjects

Twenty-eight subjects were recruited for this study using flyers from Loma Linda University Medical Health and the surrounding community. Low back pain subjects were included in the study if they had non-specific chronic LBP localized in the low back and/or buttock region only, had LBP for at least 3 months, and were between 18 and 60 years of age. The control subjects were healthy individuals without LBP for at least two years and with similar characteristics to those with LBP. Subjects in both groups were excluded if they have signs or symptoms of serious spinal pathology including significant trauma, unexplained weight loss, widespread neurologic changes, history of spinal surgery, fracture or malignancy, lower extremity injury, vestibular or other balance disorders, and females were excluded if they were breastfeeding or pregnant (self-reported). Recruitment procedures for NSCLBP subjects is displayed in Figure 1.

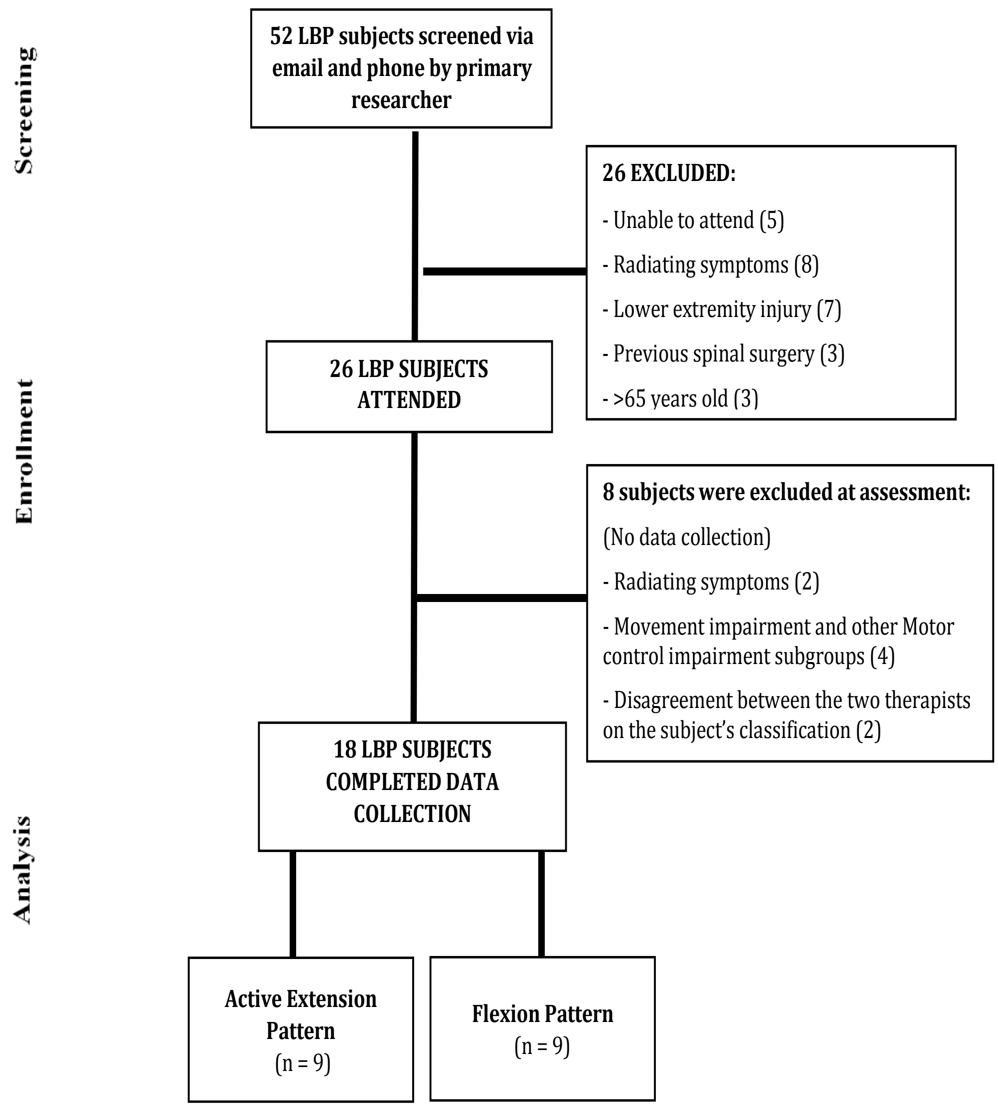

Figure 1. Recruitment procedures for nonspecific chronic low back pain (NSCLBP) subjects

Measurement Procedure

All tests were performed in a single visit at the Physical Therapy Department in the School of Allied Health Professions, Loma Linda University, CA, USA. Data collection took approximately 90 minutes to be completed. All procedures and protocols of the study were approved by the Institutional Review Board at Loma Linda University.

The study protocol and procedures were explained to the subjects in detail by the primary researcher upon the subjects' arrival at the data collection session. Subjects were given the opportunity to ask questions. Subjects were informed of their rights to withdraw from the study at any time without obligations. Following that, a signed informed consent was obtained from subjects before participation in the study.

Demographic data including age, weight, and height were obtained prior to the data collection session. Subjects with LBP were asked to report the measures for pain using the Visual Analogue Scale (VAS), disability using the Roland-Morris Disability Questionnaire (RMQ), and fear of movement using the Tampa Scale of Kinesiophobia (TSK). All subjects completed the International Physical Activity Questionnaire (short form) (IPAQ-SF) to measure their physical activity level.

NSCLBP subjects were examined and classified independently by two physical therapists based on MDCS criteria (O'Sullivan, 2005). FP and AEP subgroups were chosen to be part of this study because of their high prevalence (Dankaerts et al., 2009; O'Sullivan, 2006). Only subjects classified as FP or AEP upon agreement of both therapists were included in the study. To establish NSCLBP classification, comprehensive subjective and objective assessments were conducted. The subjective assessment included a full history of the subject's back pain and pain behavior including the aggravating and easing factors of pain based on the direction of postural changes. The objective assessment included a visual assessment of a sequence of postures and spinal range of motion (ROM). The postures and movement tasks that were evaluated included usual standing, usual sitting, active spinal extension, active spinal flexion, and active spinal bilaterally side flexion. Subjects were asked to assume side-lying position on a treatment table to assess the Passive Physiological Intervertebral Movements (PPIVM) at, above, and below the provoking spinal segment to assess the existence of joint hypomobility or hypermobility (Sheeran, Sparkes, Caterson, Busse-Morris, & van Deursen, 2012).

Data Collection Procedures

Three adhesive tape measures with a centimeter scale were adhered to the floor. The anterior direction was aligned to the apex and the other two reach directions (PM and PL) were oriented 135^o to apex to create a Y shape (E. Appiah-Dwomoh, Müller, Hadzic, & Mayer, 2016). Every subject was given verbal instructions and visual demonstration on how to perform the mSEBT. All subjects performed mSEBT while standing on dominant leg (based on the preferred leg to kick a ball). The subjects were instructed to align the lateral malleolus of the dominant leg at the intersection point of the three directions with their foot oriented in the anterior direction (E. Appiah-Dwomoh et al., 2016). Subjects performed the test without wearing shoes and they were asked to keep their hands on their hips during test performance (Figure 2). Also, the subjects were instructed to reach out as far as they can reach with the non-dominant leg and point with their big toe to the marked tape and return to the starting position (bilateral stand) (Plisky, Rauh, Kaminski, & Underwood, 2006). In order to minimize the learning effect, every subject practiced each direction six times before starting the actual test trials (Hertel et al., 2000). The actual test consisted of three trials in each direction (Anterior, PM and PL) with 10-seconds rest period between trials (Hertel et al., 2006). However, The trial was considered invalid if one of the following occurred: heel of stance leg did not stay in contact with ground during reaching out, the subject put weight onto their reaching foot on the ground, removed their hands from their hips, or lost their balance during reach out and return (E. Appiah-Dwomoh et al., 2016) The maximum reaching distance in every direction was normalized using this equation; maximum reach divided by leg length, multiplied by 100 (E. Appiah-Dwomoh et al., 2016). The leg length (from the anterior superior iliac spine to the medial malleolus) was measured using a tape measure to normalize reach (Gribble & Hertel, 2003).

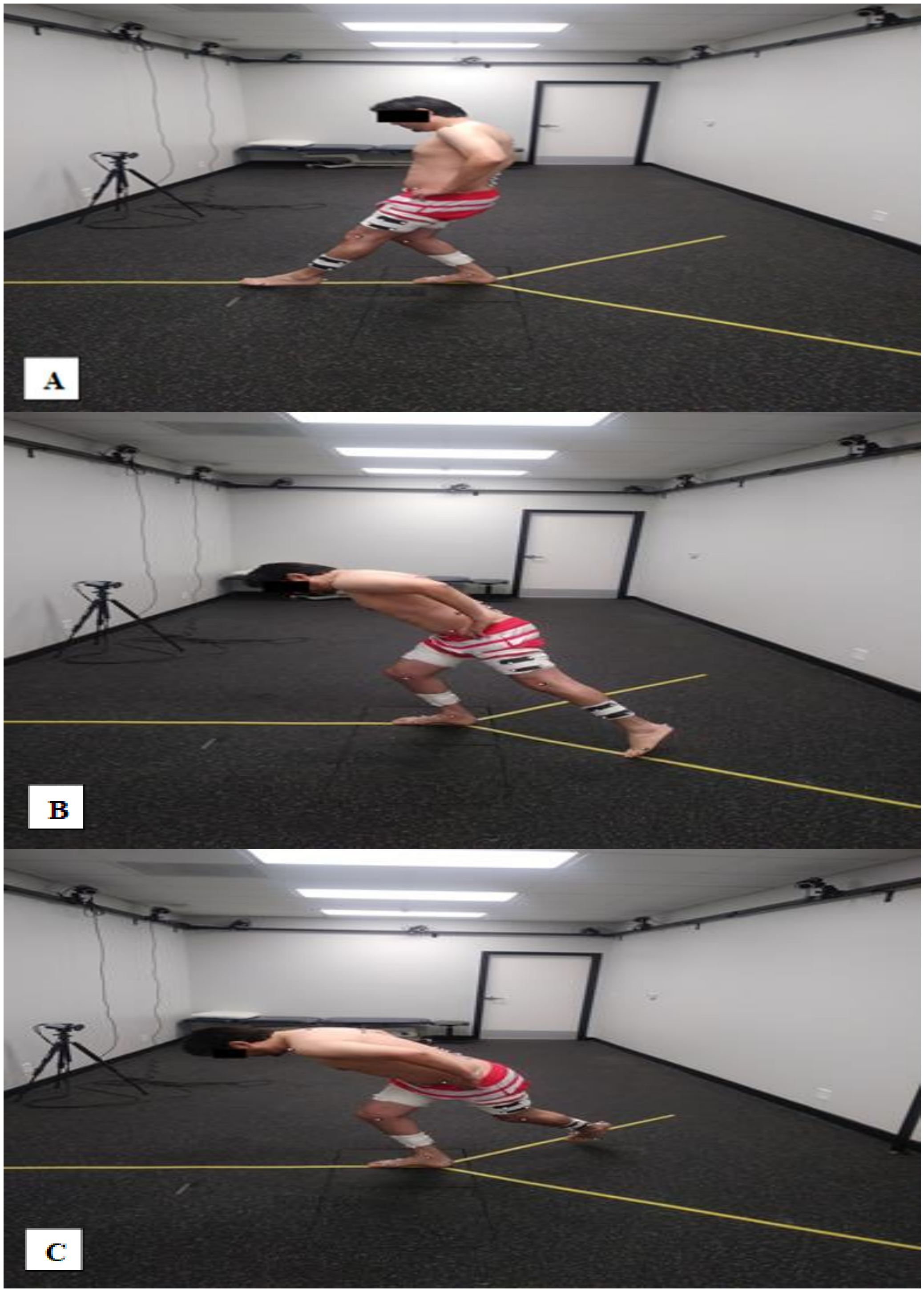

Figure 2. The modified Star Excursion Balance Test. Subject reaches in the (A) anterior, (B) posteromedial, and (C) posterolateral directions

Kinematics Measure

The 18-camera motion analysis system (Miqus M3, Qualisys, Göteborg, Sweden) was used to record marker position data with a sampling frequency of 100 Hz. The anatomical palpations and retroreflective markers placements for all subjects were performed by one physical therapist with 10 years of experience of surface anatomy of the spine. The marker placement was over the following anatomical positions: bilateral posterior superior iliac spine (PSIS), bilateral anterior superior iliac spine (ASIS), bilateral iliac crests, the L5, L3, T12, and T3 spinous processes, 4 cm to the right and left of the L4 and L1 spinous processes, and 6 cm to the right and left of the T7 spinous process (Mazzone, Wood, & Gombatto, 2016). (Figure 3)

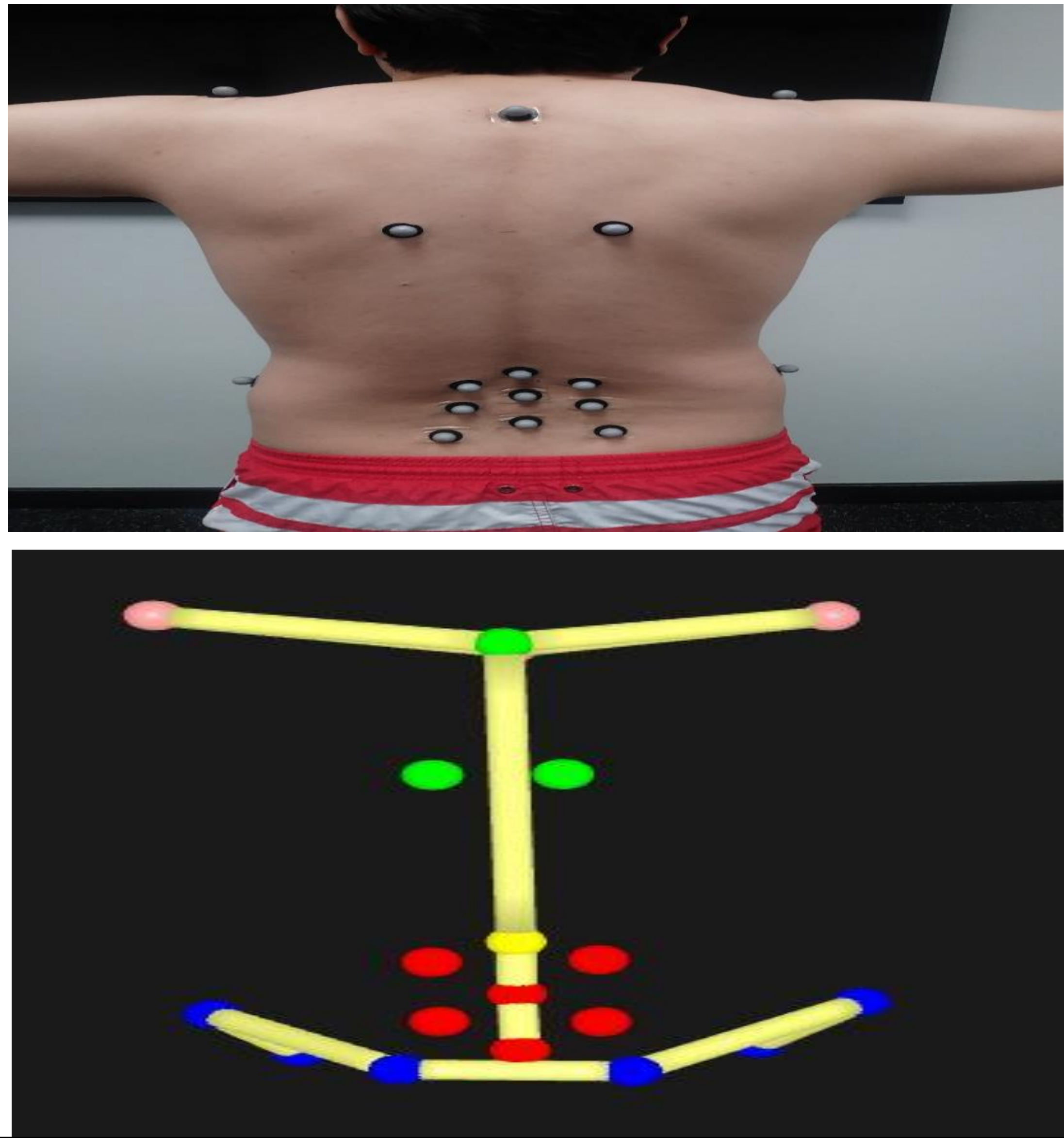

Figure 3. Three-dimensional kinematic model of the spine.
Marker key: L5, L5 spinous process; RL4, 4 cm to the right of the L4 spinous process; LL4, 4 cm to the left of the L4 spinous process; L3, L3 spinous process; RL1, 4 cm to the right of the L1 spinous process; LL1, 4 cm to the left of the L1 spinous process; T12, T12 spinous process; RT7, 6 cm to the right of the T7 spinous process; LT7, 6 cm to the left of the T7 spinous process; T3, T3 spinous process.

Data Analysis

Visual 3D (C-Motion Inc, Rockville, MD) was used to process and analyze the kinematic data. Raw marker data were smoothed using a fourth order Butterworth low pass filter with a cutoff set at 6 Hz and used to calculate joint angles in the sagittal, frontal, and transverse planes The pelvic angle was defined as the angle of the pelvic segment relative to the laboratory, the lumbar angle was defined as the angle of the lumbar segment relative to the pelvis, and the thoracic angle was defined as the angle of the thoracic segment relative to the lumbar segment (Mazzone et al., 2016). A Cardan angle sequence (x-y-z rotation sequence where X represents the medial-lateral axis, y represents the anterior-posterior axis, and z represents the longitudinal axis) was used to calculate joint angles with posterior pelvic tilt, lateral pelvic tilt toward stance leg, and pelvic rotation toward stance leg; spine segment flexion, spine segment side bending toward stance leg, and spine segment rotation toward stance leg to represent the positive values. The maximum joint angle of pelvic, lumbar and thoracic segments in the 3-dimensional planes was taken at the maximal reach point in the three directions, which was also used for data analysis across the three trials.

Statistical Analysis

Large effect sizes were reported in prior SEBT studies in participants with knee and ankle disorders (Gribble, Hertel, & Plisky, 2012; Herrington, Hatcher, Hatcher, & McNicholas, 2009) . Using $\alpha = .05$, power = 0.80, and an effect size f= 0.65, it was determined that a sample of nine participants was required in each group.

Mean and standard deviation for quantitative variables and counts (%) for qualitative variables were used to summarize data. The normality of continuous variables was examined using Shapiro Wilk's test and Box- plots. The frequency distribution of gender by study group was compared using chi-square. A one-way analysis of variance (ANOVA) or independent t-test was conducted to compare means for quantitative variables by study group.

An independent t- test was used to compare mean outcome variables were compared between pooled LBP and healthy subjects. In addition, these variables were evaluated among the three groups (FP, AEP, and healthy) using one-way ANOVA. If the results of the one-way ANOVA were statistically significant, post hoc testing using Bonferroni test was conducted. The level of significance was set at $p \leq 0.05$. Statistical analysis was performed using IBM SPSS Software version 25 for Windows (Chicago, IL, USA).

Results

A total of 28 subjects (18 with NSCLBP and 10 healthy) with a mean age of 27.6±3.8 years and body mass index (BMI) 24.3±3.7 kg/m2 participated in the study. The characteristics of subjects by study group are displayed in table 1. There was no significant difference in the subjects' characteristics among the three groups.

Reach Distance

In the anterior direction, there was no significant difference in mean reach distance among the three groups ($F_{2,27}=1.0$, $p=0.38$, $\eta^2=0.07$). In the PL and PM directions, however, mean reach distance differed significantly by study group ($F_{2,27}=17.6$, $p<0.001$, $\eta^2=0.58$, and $F_{2,27}=9.3$, $p<0.001$, $\eta^2=0.43$, respectively). In the PL direction, there was a significant difference in mean reach distance between AEP and healthy (73.4 ±8.4 vs. 90.7 ±5.2, $p<0.001$), and FP and healthy (75.4 ±7.3 vs. 90.7 ±5.2, $p<0.001$). Similarly, in the PM direction, a significant difference in mean reach distance between AEP and healthy (81.3 ±10.9 vs. 93.3 ±4.5, $p=0.018$), and FP and healthy (76.7 ±9.8 vs. 93.3 ±4.5, $p=0.001$) was observed. However, there was no significant difference in mean reach distance between AEP and FP in PL and PM directions. ($p>0.05$, See Figure 4.)

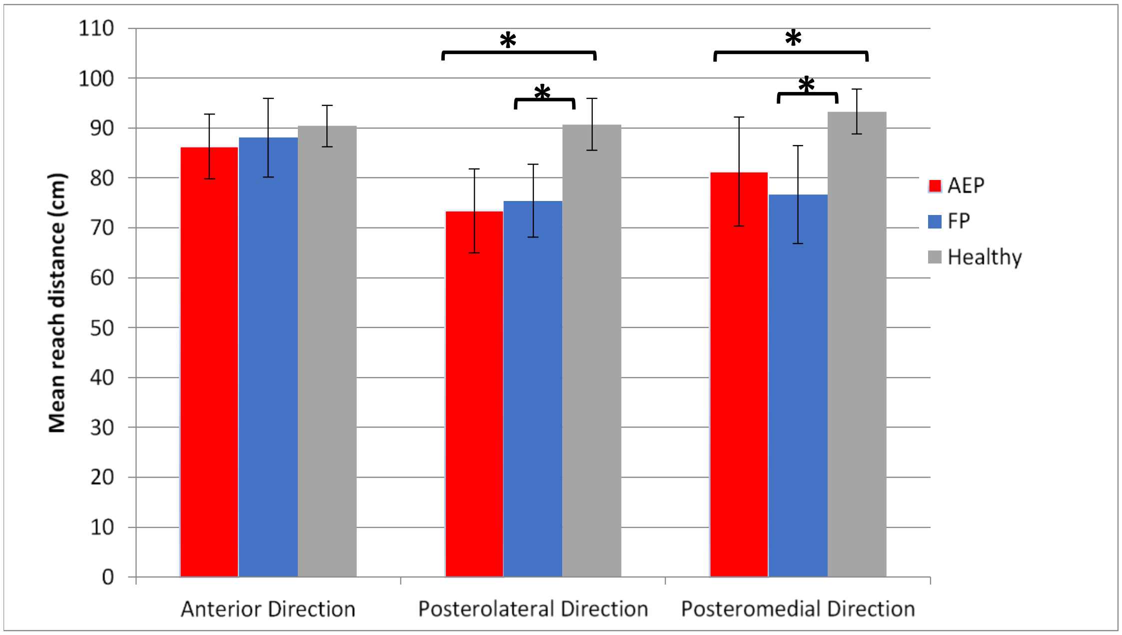

Figure 4. Mean reach distance (cm) by study group (N=28).
Abbreviation: AEP, Active extension pattern; FP, Flexion pattern
* Significant difference ($p < 0.05$). Values are means ± standard deviation.

Spinal Kinematics

Mean (SD) joint and segment angles between the pooled NSCLBP and healthy subjects are shown in Table 2. Mean (SD) joint and segment angles among the three study groups (AEP, FP, healthy) are presented in Table 3, Table 4, and Table 5.

In the anterior direction, there was a significant difference between pooled NSCLBP and healthy subjects in mean sagittal angle of the lumbar spine ($p=0.017$), however, no significant differences were noted in the thoracic spine and pelvic. Upon examining differences among subgroups, a significant difference in mean sagittal angle for both lumbar and thoracic spine ($p<0.001$) was noted. Bonferroni post hoc comparisons revealed that there was a significant difference between the AEP and FP subjects ($p<0.001$ for both lumber and thoracic segments) and between AEP and healthy subjects ($p<0.001$, and $p=0.001$, respectively).

Results from the independent t-test in the PL direction revealed that there was a significant difference between the pooled NSCLBP and healthy subjects in mean sagittal and frontal angle of the pelvis ($p=0.001$), sagittal and axial angle of the lumbar spine ($p=0.007$ and $p =0.002$, respectively), but not in the thoracic spine. When we further analyzed the data based on subgroups, a significant difference in mean sagittal and frontal angle for the pelvis was shown ($p<0.01$). Bonferroni post hoc comparisons revealed that there was a significant difference in mean sagittal and frontal angle for the pelvis between the AEP and healthy subjects ($p=0.016$ and $p=0.01$, respectively), and between the FP and healthy subjects ($p=0.009$ and $p=0.002$, respectively). In the lumbar and thoracic spine, we found a significant difference in mean sagittal angle with PL reaching ($p<0.001$). Further post hoc comparisons revealed that there was a significant difference in mean sagittal angle between the AEP and FP subjects (p<0.001 and p=0.002) and between the AEP and healthy subjects (p<0.001, and p=0.04, respectively).

In the PM direction, there was a significant difference between the pooled NSCLBP and healthy subjects in mean sagittal angle of the pelvis, lumbar, and thoracic spine. (p=0.001, p=0.002, and p=0.031, respectively). When analyzing the data based on subgroups, a significant difference in mean sagittal angle for the pelvic (p=0.003) was found. Bonferroni post hoc comparisons revealed that there was a significant difference between the AEP and healthy subjects (p=0.028) and between the FP and healthy subjects (p=0.004). In the lumbar and thoracic spine, we found a significant difference in mean sagittal angle among the subgroups (p<0.001). Post hoc comparisons showed that there was a significant difference in mean sagittal angle between the AEP and FP subjects (p=0.001) and between the AEP and healthy subjects (p<0.001, and p=0.02, respectively).

Table 1. Mean (SD) of Baseline Characteristics by Study Group (N=28)

	AEP (n_1=9)	FP (n_2=9)	Healthy (n_3=10)	p-value
Female; n (%)	5 (55.6)	8 (88.9)	7 (70)	0.29
Age (year)	28.8 (5.0)	27.2 (3.6)	26.8 (2.6)	0.51
BMI (kg/m^2)	25.8 (5.0)	23.5 (2.7)	23.8 (3.0)	0.37
Physically active; n(%)	9 (100)	9 (100)	9 (90)	0.76
Pain level	2.8 (1.6)	4.4 (2.0)	-	0.07
TSK	34.9 (8.2)	37.3 (3.7)	-	0.43
RMQ	5.6 (0.9)	5.4 (0.5)	-	0.75

Abbreviations: SD, Standard Deviation; AEP, Active extension pattern; FP, Flexion pattern; BMI, Body mass index; TSK, Tampa Scale for Kinesiophobia; RMQ, Roland-Morris Disability Questionnaire

Table 2. Segment angles (degrees) at maximum reach between pooled LBP and healthy subjects (N=28)

Spine Segment		LBP (n_1=18) Mean ± SD	Control (n_2=10) Mean ± SD	Cohen's d	p-value
Anterior Direction					
Pelvic	Sagittal	-17.0 ± 5.2	-16.1 ± 4.6	0.17	0.674
	Frontal	3.1 ± 5.6	6.7 ± 4.9	0.68	0.103
	Transverse	-1.5 ± 11.8	-4.7 ± 14.9	0.25	0.537
Lumbar	Sagittal	-14.7 ± 20.1	2.4 ± 8.4	1.03	0.017*
	Frontal	-2.1 ± 6.3	-2.6 ± 3.3	0.09	0.821
	Transverse	0.4 ± 8.9	3.3 ± 5.1	0.38	0.277
Thoracic	Sagittal	2.1 ± 19.2	-8.7 ± 9.3	0.67	0.054
	Frontal	-0.8 ± 9.9	-1.8 ± 8.7	0.11	0.795
	Transverse	-2.7 ± 12.7	-1.3 ± 10.0	0.12	0.767
Posterolateral Direction					
Pelvis	Sagittal	-41.1 ± 8.7	-52.6 ± 5.5	1.52	0.001*
	Frontal	-16.5 ± 13	-33.7 ± 4.7	1.57	0.001*
	Transverse	15.7 ± 7.8	23.0 ± 14.6	0.70	0.094
Lumbar	Sagittal	-6.7 ± 12.1	5.9 ± 7.9	1.19	0.007*
	Frontal	-1.4 ± 5.6	-3.5 ± 3.6	0.43	0.290
	Transverse	0.6 ± 6.2	6.7 ± 2.8	1.17	0.002*
Thoracic	Sagittal	1.5 ± 13.5	-1.4 ± 11.5	0.23	0.571
	Frontal	-9.5 ± 10.3	-10.7 ± 6.3	0.13	0.751
	Transverse	3.2 ± 19.6	-5.1 ± 12.1	0.48	0.240
Posteromedial Direction					
Pelvis	Sagittal	-41.7 ± 10.2	-55.2 ± 6.1	1.53	0.001*
	Frontal	5.9 ± 9.3	11.6 ± 4.9	0.73	0.081
	Transverse	12.2 ± 11.0	11.9 ± 13.0	0.02	0.957
Lumbar	Sagittal	-8.6 ± 12.0	6.3 ± 8.1	1.40	0.002*
	Frontal	-0.9 ± 4.6	-3.4 ± 3.3	0.60	0.146
	Transverse	0.4 ± 5.6	4.6 ± 4.0	0.83	0.031*
Thoracic	Sagittal	1.7 ± 12.0	-1.4 ± 10.8	0.27	0.508
	Frontal	1.0 ± 8.9	-4.0 ± 8.2	0.60	0.149
	Transverse	-3.4 ± 10.6	-3.1 ± 10.7	0.03	0.934

Abbreviation: SD, Standard Deviation; AEP, Active extension pattern; FP, Flexion pattern.

* Significant difference ($p < 0.05$)

Table 3. Mean± SD of Segment Angles (degrees) at Maximum Reach among the Three Groups (Anterior Direction)

Spine Segment		AEP (n_1=9)	FP (n_2=9)	Healthy (n_3=10)	Effect size	p-value	Post-hoc (Bonferroni test)
Pelvis	Sagittal	-17.7 ± 5.6	-16.3 ± 5.0	-16.1 ± 4.6	0.02	0.771	-
	Frontal	2.6 ± 5.1	3.7 ± 6.4	6.7 ± 4.9	0.10	0.251	-
	Transverse	1.8 ± 10.2	-4.9 ± 12.8	-4.7 ± 14.9	0.06	0.463	-
Lumbar	Sagittal	-17.9 ± 11.6	-0.5 ± 10.0	2.4 ± 8.4	0.59	<0.001*	AEP vs FP/ AEP vs H
	Frontal	-3.2 ± 6.8	-1.1 ± 6.0	-2.6 ± 3.3	0.03	0.701	-
	Transverse	0.0 ± 11.5	0.8 ± 6.0	3.3 ± 5.1	0.04	0.544	-
Thoracic	Sagittal	15.2 ± 18.4	-11.0 ±7.3	-8.7 ± 9.3	0.50	<0.001*	AEP vs FP/ AEP vs H
	Frontal	-1.5 ± 8.8	-0.1 ± 11.5	-1.8 ± 8.7	0.01	0.925	-
	Transverse	-1.5 ± 15.0	-3.9 ± 10.7	-1.3 ± 10.0	0.01	0.879	-

Abbreviation: SD, Standard Deviation; AEP, Active extension pattern; FP, Flexion pattern; H, Healthy
* Significant difference ($p < 0.05$)

Table 4. Mean± SD of Segment Angles (degrees) at Maximum Reach among the Three Groups (Posterolateral Direction)

Spine Segment		AEP (n_1=9)	FP (n_2=9)	Healthy (n_3=10)	Effect size	p	Post-hoc (Bonferroni test)
Pelvis	Sagittal	-41.5 ± 9.1	-40.6 ± 8.8	-52.6 ± 5.5	0.36	0.004*	AEP vs H/ FP vs H
	Frontal	-13.7 ± 16.1	-19.4 ± 10.0	-33.7 ± 4.7	0.40	0.002*	AEP vs H/ FP vs H
	Transverse	14.5 ± 10.0	16.9 ± 5.2	23.0 ± 14.6	0.11	0.226	-
Lumbar	Sagittal	-15.5 ±8.2	2.1 ± 8.5	5.9 ± 7.9	0.59	<0.001*	AEP vs FP/ AEP vs H
	Frontal	-0.9 ± 4.1	-2.0 ± 6.9	-3.5 ± 3.6	0.05	0.521	-
	Transverse	1.1 ± 5.9	0.1 ± 6.8	6.7 ± 2.8	0.25	0.051	-
Thoracic	Sagittal	11.0 ± 7.3	-8.1 ± 11.4	-1.4 ± 11.5	0.39	0.002*	AEP vs FP/ AEP vs H
	Frontal	-11.1 ± 9.1	-7.9 ± 11.6	-10.7 ± 6.3	0.02	0.733	-
	Transverse	4.1 ± 24.3	2.3 ± 15.0	-5.1 ± 12.1	0.05	0.496	-

Abbreviation: SD, Standard Deviation; AEP, Active extension pattern; FP, Flexion pattern; H, Healthy. * Significant difference ($p < 0.05$)

Table 5. Mean± SD of Segment Angles (degrees) at Maximum Reach among the Three Groups (Posteromedial Direction)

Spine Segment		AEP (n_1=9)	FP (n_2=9)	Healthy (n_3=10)	Effect size	p	Post-hoc (Bonferroni test)
Pelvis	Sagittal	-43.5 ± 7.3	-40.0 ± 12.7	-55.2 ± 6.1	0.37	0.003*	AEP vs H/ FP vs H
	Frontal	8.8 ± 7.4	2.9 ± 10.5	11.6 ± 4.9	0.19	0.067	-
	Transverse	8.7 ± 13.9	15.6 ± 6.2	11.9 ± 13.0	0.06	0.471	-
Lumbar	Sagittal	-16.7 ± 9.7	-0.4 ± 7.9	6.3 ± 8.1	0.59	<0.001*	AEP vs FP/ AEP vs H
	Frontal	-0.7 ± 2.8	-1.2 ± 6.1	-3.4 ± 3.3	0.08	0.345	-
	Transverse	1.3 ± 5.7	-0.4 ± 5.6	4.6 ± 4.0	0.16	0.114	-
Thoracic	Sagittal	10.8 ± 4.6	-7.4 ± 9.9	-1.4 ± 10.8	0.44	0.001*	AEP vs FP/ AEP vs H
	Frontal	2.1 ± 6.7	0.0 ± 11.0	-4.0 ± 8.2	0.09	0.319	-
	Transverse	-2.6 ± 10.0	-4.2 ± 11.7	-3.1 ± 10.7	0.00	0.948	-

Abbreviation: SD, Standard Deviation; AEP, Active extension pattern; FP, Flexion pattern; H, Healthy. * Significant difference ($p < 0.05$)

Discussion

This study examined the differences in mSEBT scores in two subgroups of NSCLBP compared to healthy subjects. In addition, it examined the lumber and thoracic spine kinematics during the performance of mSEBT. The results validate the MCI subclassification and provide more evidence regarding the trunk compensatory movements that may occur in these subgroups of individuals with NSCLBP.

The results showed that reach distance differed between MCI subgroups and healthy subjects during dynamic balance performance. The FP and AEP subjects had significantly decreased scores in both the PM and PL reach directions compared to the healthy group. However, there was no significant difference in mean reach distance in the anterior direction among the three groups. These findings are consistent with another study that examined LBP subjects (Hooper et al., 2016). On the other hand, Ganesh et al. (2014) found a significant difference in reaching distance in anterior direction between LBP and healthy subjects (Ganesh, Chhabra, & Mrityunjay, 2015) while Appiah-Dwomoh, et al., (2006) failed to find any significant differences in any directions between healthy athletes and athlete with LBP (E. Appiah-Dwomoh et al., 2016). The inconsistency in the findings of these studies can be explained by many factors. First, differences in the results between these studies may be related to the subjects' classifications or differences in the testing methods (Fullam, Caulfield, Coughlan, & Delahunt, 2014). Second, the two posterior reach directions of mSEBT require more anterior pelvic tilt to accomplish the task (Kang et al., 2015). Our results suggest that subjects in NSCLBP subgroups had a limited anterior pelvic tilt compared with healthy subjects leading to a decrease in the PL and PM reaching distances. Third, the visual system may compensate for any deficits in somatosensory system in people with NSCLBP in the anterior reach (Bove, Nardone, & Schieppati, 2003) since the subjects are able to visualize the movement of limb., However, this is not possible during posterior reach directions (Hooper et al., 2016).

To our best knowledge, this is the first study to compare the spinal kinematics of NSCLBP subgroups during dynamic balance using the mSEBT. Our findings showed significant differences in lumbar spine kinematics between the pooled NSCLBP and healthy groups in the three mSEBT directions, but no significant difference in thoracic spine segment. After subgrouping NSCLBP subjects into FP and AEP groups, the results showed a significant difference in lumbar and thoracic spine kinematics between the AEP group and the FP group in all directions. These findings confirm the washout effect phenomenon and establish the need for studying homogeneous subgroups of NSCLBP in order to understand the kinematics changes in NSCLBP disorder (Dankaerts, O'sullivan, Burnett, & Straker, 2006).

Our findings were in line with those reported by Dankaerts et al., (2006) (Dankaerts et al., 2006). They found a significant difference in the lumbar spine static posture between the AEP and the FP groups. In addition, they found a significant difference between the AEP and the healthy groups in lumbar spine segments during sitting while they did not observe any differences in the lumbar spine segments between the FP and healthy subjects.

In this study, we found that AEP subjects exhibit more lumbar extension posture compared to the FP in all reaching directions. These findings could be attributed to the nature of the required task. The reaching tasks all start in standing, and based on MCI classification, the standing position is more likely to aggravate pain in the AEP group as compared to the FP group (O'Sullivan, 2006). Also, we did not find any significant differences between the FP and the healthy groups in either the lumbar or thoracic regions, suggesting that the FP and the healthy subjects may adopt similar strategies for spinal movement throughout the thoracic and lumbar regions (Dankaerts et al., 2006). In addition, the differences in the thoracic region between MCI subgroups suggest that the AEP subjects may adopt more kyphotic spine posture as compared to the FP subjects (Hemming et al., 2018).

Another reason for the spinal kinematics differences between the FP and the AEP groups during dynamic balance tasks may be due to alterations in the joint position sense and repositioning error (Hodges & Moseley, 2003). In the Sheeran et al., (2012) study, researchers found that the AEP subjects significantly overestimated their neutral lumbar angle compared to the healthy subjects (Sheeran et al., 2012). Also, Byle and Sinnott (Nies & Sinnott, 1991) reported that a variety of individuals with LBP have a significant posterior displacement of the mean position of the COP compared to healthy subjects. They assumed that this posture would lead to relax the spine extensors muscles through increased lordosis. The AEP subjects exhibit a reduced capacity to control spinal extension movement, and usually report increased pain while performing most of the extension-related activities (O’Sullivan, 2005). Therefore, mSEBT forces the lumbar region into more extension resulting in pain provocation and maladaptive movement control in the AEP subgroup. Also, due to the nature of the mSEBT tasks, the AEP subjects experience more pain or fear of pain as compared to the FP and the healthy subjects. According to the pain adaptation model, the normal response of the body is to increase paraspinal muscle activity in the AEP subjects which may increase the load on the lumbar and thoracic spinal structure (Dankaerts et al., 2006). The increase in the muscle activity may result in more lumbar lordosis in the AEP subjects as compared to the FP and the healthy subjects (Dankaerts et al., 2009).

Study limitations

There were some limitations in this study. First, the pain, disability and fear of movement level in NSCLBP subjects were relatively low. NSCLBP with high level of pain, disability and fear of movement may exhibit different spinal kinematics. Second, we did not measure trunk muscle activation and lower extremity kinematics. This information could help in better understanding of the compensatory movement patterns that each subgroup may use during dynamic balance tasks.

Clinical implication

The findings of this study highlight the heterogeneity of the subjects with NSCLBP and the importance of identifying the homogenous subgroups for better selection of the best treatment protocols. This study also confirmed that subjects with motor control impairment have a maladaptive movement behavior in the thoracic spine region during dynamic balance task. Therefore, we recommended the health care providers to incorporate a thoracic spine movement examination during dynamic balance.

Conclusion

Our findings suggest that the regional spinal curvatures are significantly different between AEP and FP subjects, and between AEP and healthy subjects during dynamic balance tasks using the mSEBT. The AEP subjects exhibited more lordotic posture in the lumbar spine and more kyphotic posture in the thoracic spine in all mSEBT directions. The differences in thoracic spine kinematics highlight the importance of involving the thoracic segment during assessment and treatment of dynamic balance in NSCLBP subgroups.

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CHAPTER FOUR

DISCUSSION AND CONCLUSION

No significant differences were observed among the groups in mean questionnaire results for RMQ, TSK or VAS with both NSCLBP subgroups have reported similar level of pain, disability, fear of movement, and physical activity which indicates that NSCLBP subgroups were appropriately matched for these baseline variables.

NSCLBP is a heterogeneous disorder and it is important to study this population under homogenous subgroups in order to understand the mechanisms and the strategies that each subgroup uses during functional and dynamic tasks. LBP results in alteration in balance (Cavanaugh et al., 2005), and a simple tool to measure the dynamic balance in NSCLBP subgroups is needed in the research field and clinical setting. In addition, spinal kinematics and postural control variables may be altered in this population. Therefore, this dissertation aimed to investigate the spinal kinematics and postural control differences in subclassified groups of NSCLBP (AEP and FP) and healthy control group during the performance of dynamic balance task using the mSEBT. This chapter will provide a general discussion and conclusion from the studies included in this dissertation.

In Study-1 of this thesis, we hypothesized that postural control and dynamic balance during performance of mSEBT would be different in AEP subjects. The results supported our hypothesis and showed that there were significant differences in mean reach distance in both posterolateral and posteromedial reach directions between AEP and healthy, and between FP and healthy subjects. Also, there was a significant difference in mean center of pressure velocity in the posteromedial direction between

AEP and FP subjects, and between AEP and healthy subjects. These results supported the MCI subclassification and provide more evidence regarding postural control compensatory strategies that may occur in these subgroups of individuals with NSCLBP.

These findings are consistent with the Hooper et al. (2016) study, that found significant differences in reach distances between the LBP subgroups (current LBP vs LBP history) compared to healthy subjects in PL and PM directions but not in the anterior direction (Hooper et al., 2016). Subjects in both AEP and FP subgroups may have a limited pelvic anterior tilt compared to healthy subjects, which leads to decrease in the PL and PM reaching distance (Carpes, Reinehr, & Mota, 2008). Also, reaching in posterior directions in the mSEBT are more challenging compared to anterior reaching due to excessive lumbar lordosis that is required to finish the task which stresses the postural control system in NSCLBP groups to a point that limits the subjects' reach (Behennah, Conway, Fisher, Osborne, & Steele, 2018). In addition, people with NSCLBP are more dependent on visual feedback due to altered proprioceptive input (Mergner, Schweigart, Maurer, & Blümle, 2005). Reaching in posterior direction requires subjects to rely on proprioceptive input and vestibular system to maintain the single leg balance compared to reaching forward where the subjects can use their vision to help. Therefore, there was no significant difference in reaching forward among groups (Bray & Moseley, 2011).

We found that AEP subjects had a higher COP velocity as compared to FP and healthy subjects during performance of the mSEBT. One of the reasons behind this finding may be the nature of the required task. Reaching in the PM direction requires anterior pelvic tilt and stresses the lumbar spine resulting in excessive lordosis or hyperextension of lumbar spine. Based on the MCI classification, the standing and extension positions are more likely to aggravate pain in the AEP group as compared to the FP group (O'Sullivan, 2006). According to the pain adaptation model, the normal response of the body is to increase paraspinal muscle activity in the AEP subjects which may increase the load on the trunk structure (Dankaerts, O'sullivan, Burnett, & Straker, 2006). These changes in proprioception and the muscle activity may result in more postural sway velocity in the AEP subjects as compared to the FP and the healthy subjects.

In Study-2, we examined the lumbar, thoracic spine and pelvis kinematics during the performance of the mSEBT. Our findings showed a significant difference in lumbar and thoracic spine kinematics between the AEP group and the FP group during performance of the mSEBT.

Consistent patterns of lumbar and thoracic spinal movement have been noted among AEP, FP and healthy subjects during all reaching directions, suggesting that the lumbar region is not only the main key area where NSCLBP AEP and FP subgroups operate differently but also the thoracic spine region movement is contributing to discriminate between AEP and FP subgroups. To our knowledge, this is the first study demonstrate the differences in spinal kinematics during dynamic balance between AEP and FP subgroups.

Our findings were similar with those reported by Dankaerts et al., (2006) (Dankaerts et al., 2006). They found a significant difference in the lumbar spine static posture between the AEP and the FP groups. In addition, they found a significant difference between the AEP and the healthy groups in lumbar spine segments during sitting while they did not observe any differences in the lumbar spine segments between the FP and healthy subjects. In addition, we found that AEP subjects exhibit more lumbar extension posture compared to the FP in all reaching directions. These findings could be attributed to the nature of the required task. The reaching tasks all start in standing, and based on MCI classification, the standing position is more likely to aggravate pain in the AEP group as compared to the FP group (O'Sullivan, 2006).

Conclusion

This dissertation presents several unique contributions to the LBP literature. First, this study was the first to examine mSEBT in homogenous subgroups of NSCLBP (AEP and FP) and compare them to the healthy subjects during performance of dynamic task. In addition, our results showed that reaching distance alone is not enough to show the whole picture of the postural control deficits in NSCLBP subgroups, and it is important to investigate other variables such as spinal kinematics and COP parameters in order to discriminate between AEP and FP subgroups and identify the postural control and kinematics deficits in those population. The studies in this dissertation showed that mSEBT detected dynamic balance deficits in people with MCI subgroups (AEP and FP) . In addition, people in these subgroups adopt a different spinal kinematics strategy than healthy subjects during performance of the mSEBT in all reach directions.

Clinical implication

Several areas considered in this dissertation are relevant for clinical practice. The findings of this study highlight the heterogeneity of the subjects with NSCLBP and the importance of identifying the homogenous subgroups for better selection of the best treatment protocols. In addition, this dissertation confirmed that subjects with active extension pattern have a maladaptive movement behavior in the lumbar and thoracic spine regions during dynamic balance task. Therefore, we recommended the health care providers to focus on changing these abnormalities in spinal curvature to optimize loading response and decrease excessive guarding strategies in muscle and movement avoidance. Also, it is important to involve education aspect in clinician's intervention protocol for these subgroups to eliminate these conditioned movement behaviors.

Limitations of the Study

Several limitations in this dissertation need to be recognized. First, the sample size was small, future research needs to recruit a larger sample size to investigate the postural and spinal kinematics strategies differences between NSCLBP subgroups during dynamic balance task. Second, the pain and disability level in NSCLBP subgroups were relatively low. Future studies should investigate subjects with NSCLBP with high levels of pain and disability which may exhibit different postural stability and spinal kinematics strategies. Third, we examined the postural stability and spinal kinematics for only two of the subgroups proposed by the MDCS (AEP and FP), however, there are other MCI patterns exist such as Passive Extension Pattern (PEP), Flexion Lateral Shift Pattern (FLSP) and Multidirectional Pattern (MDP). To the best of the author's knowledge, no studies have examined postural control and spinal kinematics in the MDP, FLSP or PEP MCI subgroups.

Recommendations for Future Research

Our study investigated the biomechanical attributes of individuals with NSCLBP MCI subgroups and this only reflects on one dimension of NSCLBP disorder. Based on the MDCS, people with NSCLBP have multiple other factors that may influence pain such as beliefs and other psychosocial factors. Therefore, future work should focus on how other dimensions of NSCLBP interact during dynamic balance in order to comprehensively manage the challenge of NSCLBP.

Finally, future studies should focus more in evaluating the impact of targeting subgroup intervention based on Classification Based Cognitive Functional Therapy approaches (Sheeran, van Deursen, Caterson, & Sparkes, 2013; Vibe Fersum, O'Sullivan, Skouen, Smith, & Kvåle, 2013). Therefore, more randomized control studies should be conducted for further support and validate the use of this specific intervention for subclassified MCI NSCLBP populations.

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APPENDIX A

Patient Information Sheet

Data Collection Sheet

PATIENT'S INFORMATION FORM

Participant's ID: .... Date: .... /....../................ Check-in Time: ....: ....

Fist Name: .... Last Name: ....

Age: _______________ **Gender**: M F

Phone Number: ______________________

Email: ____________________________________

Preferred Contact Method: ☐ Phone ☐ Email

Hight: ______________________

Weight: ________________

(Please mark YES or NO)

1. Have you had Low Back Pain that has lasted for more than 3 months until the present? **Yes** **No**
2. Have you had Low Back Pain of equal or greater than 2/10 in the past week? **Yes** **No**
3. Which situation describes your pain over the past 4 weeks the best?
   - 100% of the pain in the low back
   - The pain in the low back, and in the leg(s)
4. Have you had previous extensive spinal surgery (greater than single-level fusion/instrumentation or discectomy)? **Yes** **No**
5. Have you had lower extremities injury within the past 6 months? **Yes** **No**
6. Have you had spinal surgery within the past 6 months? **Yes** **No**
7. Have you had serious spinal pathology (cancer, inflammatory, acute vertebral fracture)? **Yes** **No**
8. Have you been diagnosed with neurological disease? **Yes** **No**

APPENDIX B

Informed Consent Form

LOMA LINDA
UNIVERSITY

INFORMED CONSENT

Title: Non-specific chronic low back pain: comparison of multi-segmental spinal and lower extremity kinematic and muscle activation in subgroups with motor control impairment during performance of dynamic and functional tasks

Principal Investigator: Everett Lohman, III, D.Sc., P.T., OCS, Professor, School of Allied Health Professions

WHY IS THIS STUDY BEING DONE?

The purpose of this graduate student research study is to look at differences in the movement and muscle activation in people with and without low back pain during normal daily activities.

You are invited to be in this study because you are between 18 and 60 years of age and you are healthy or have a localized low back pain in the lower back and/or buttock region for at least 3 months.

You will not qualify if you have any of the following:
Signs of serious spinal pathology including significant trauma, unexplained weight loss and widespread neurologic changes, history of spinal surgery, fracture or cancer, lower extremities injury within the past 3 months and females who are breastfeeding or pregnant.

Approximately 75 subjects will participate at this study. Your participation in this study will be for one visit and for approximately 90-120 minutes to complete.

HOW WILL I BE INVOLVED?

- You will come to Nichol Hall, room A620 or A640 at the Loma Linda University (LLU) to sign the informed consent.
- We will perform a brief assessment to determine your eligibility for the study.
- If you are eligible, your height, weight, age, upper limb length and lower limb length will be recorded.
- You will then be required to complete questionnaires related to your low back pain.
- Healthy subjects will be assigned to the control group, while subjects with low back pain will be assigned to an experimental group.
- Prior to the start of the assessment, you may be asked to change your clothing (for example: males will be asked to wear shorts and females will be asked to wear shorts and sport bra). During data collection, all female participants will be offered a backless vest-top to wear while allowing the markers to remain visible. Changing room and privacy curtains will be provided.

- You will have a number of very light markers attached to the skin to measure your joints movements during performance of different dynamic and functional tasks (such as sit to stand, pick item from the floor, reaching and step up).
-
- Muscle activity and muscle function will also be determined during this session. This will involve placement of electromyography electrodes (noninvasive device that is used to measure the muscle activation) onto the surface of the skin to record muscle activity during the performance of dynamic and functional tasks.
  - Particularly, skin may sometimes need a small patch shaving for the sensors to attach (approximately 2x2cm).
- Then, we will perform muscle strength test for your abdomen and back muscles prior to carrying out the functional tasks testing.
- Finally, you will be asked to perform a range of activities of daily living (such as sit to stand, pick item from the floor, reaching and step up) as well as the dynamic balance test by using star excursion balance test. This measures dynamic balance by challenging you to balance on one leg and reach as far as possible in three different directions.

WHAT ARE THE REASONABLY FORESEEABLE RISKS OR DISCOMFORTS I MIGHT HAVE?

This study poses no greater risk to you than what you routinely encounter in day-to-day life. Participating in this study will may involve the following risks: falling, fatigue/discomfort and breach of confidentiality. One of the testing procedures will require you to stand on one leg. This will put you at minimal risk to fall. The investigator will be standing next to you to minimize this risk. Also, rest time will be given after each activity to minimize fatigue/discomfort.

All records and research materials that identify you will be held confidential. Any published document resulting from this study will not disclose your identity without your permission. Information identifying you will only be available to the study personnel. All subjects will be identified with a numeric code.

WILL THERE BE ANY BENEFIT TO ME OR OTHERS?

Although you may not personally benefit from this study, your participation may help practitioners better understand movements and muscle activation patterns in low back pain patients during performance of dynamic and functional tasks. This will help in the clinical decision-making and will benefit other subjects with similar conditions in the future and will advance the research in this particular area.

WHAT ARE MY RIGHTS AS A SUBJECT?

Your participation in this study is entirely voluntary. You may refuse to participate or withdraw once the study has started. Your decision whether or not to participate or terminate at any time will not affect your future medical standing with the researchers. You do not give up any legal rights by participating in this study. If at any time you feel uncomfortable, you may refuse to answer questions.

WHAT COSTS ARE INVOLVED?

There is no cost to you for participating in this study.

WILL I BE PAID TO PARTICIPATE IN THIS STUDY?

You will receive a $50 gift card for completing the study in full. In order to receive such payment, you may be asked to provide your name and Loma Linda ID number if you are an employee or student.

WHO DO I CALL IF I HAVE QUESTIONS?

Call 909-558-4647 or e-mail patientrelations@llu.edu for information and assistance with complaints or concerns about your rights in this study.

SUBJECT'S STATEMENT OF CONSENT

- I have read the contents of the consent form and have listened to the verbal explanation given by the investigator.
- My questions concerning this study have been answered to my satisfaction.
- Signing this consent document does not waive my rights nor does it release the investigators, institution or sponsors from their responsibilities.
    - I may call Everett Lohman, III, D.Sc. during routine office hours at (909) 558-4632 or Ext. 83171 if I have additional questions or concerns.
- I hereby give voluntary consent to participate in this study.

I understand I will be given a copy of this consent form after signing it.

____________________________ ____________________________

Signature of Subject Printed Name of Subject

____

Date

INVESTIGATOR'S STATEMENT

I have reviewed the contents of this consent form with the person signing above. I have explained potential risks and benefits of the study.

____________________________ ____________________________

Signature of Investigator Printed Name of Investigator

____

Date

APPENDIX C

Questionnaires

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

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

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

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

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

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

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

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

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

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

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

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

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking ➡ ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

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

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

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

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

At A Glance
IPAQ Scoring Protocol (Short Forms)

Continuous Score

Expressed as MET-min per week: MET level x minutes of activity/day x days per week

Sample Calculation

MET levels
Walking = 3.3 METs
Moderate Intensity = 4.0 METs
Vigorous Intensity = 8.0 METs

MET-minutes/week for 30 min/day, 5 days
3.3*30*5 = 495 MET-minutes/week
4.0*30*5 = 600 MET-minutes/week
8.0*30*5 = 1,200 MET-minutes/week

TOTAL = 2,295 MET-minutes/week

Total MET-minutes/week = Walk (METs*min*days) + Mod (METs*min*days) + Vig (METs*min*days)

Categorical Score- three levels of physical activity are proposed

1. <u>Low</u>

- No activity is reported **OR**
- Some activity is reported but not enough to meet Categories 2 or 3.

2. **<u>Moderate</u>**

Either of the following 3 criteria

- 3 or more days of vigorous activity of at least 20 minutes per day **OR**
- 5 or more days of moderate-intensity activity and/or walking of at least 30 minutes per day **OR**
- 5 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum of at least 600 MET-minutes/week.

3. <u>High</u>

Any one of the following 2 criteria

- Vigorous-intensity activity on at least 3 days and accumulating at least 1500 MET-minutes/week **OR**
- 7 or more days of any combination of walking, moderate- or vigorous-intensity activities accumulating at least 3000 MET-minutes/week

Please review the full document "Guidelines for the data processing and analysis of the International Physical Activity Questionnaire" for more detailed description of IPAQ analysis and recommendations for data cleaning and processing [www.ipaq.ki.se].

Tampa Scale for Kinesiophobia

(Miller , Kori and Todd 1991)

1 = strongly disagree
2 = disagree
3 = agree
4 = strongly agree

1. I'm afraid that I might injury myself if I exercise	1	2	3	4
2. If I were to try to overcome it, my pain would increase	1	2	3	4
3. My body is telling me I have something dangerously wrong	1	2	3	4
4. My pain would probably be relieved if I were to exercise	1	2	3	4
5. People aren't taking my medical condition seriously enough	1	2	3	4
6. My accident has put my body at risk for the rest of my life	1	2	3	4
7. Pain always means I have injured my body	1	2	3	4
8. Just because something aggravates my pain does not mean it is dangerous	1	2	3	4
9. I am afraid that I might injure myself accidentally	1	2	3	4
10. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening	1	2	3	4
11. I wouldn't have this much pain if there weren't something potentially dangerous going on in my body	1	2	3	4
12. Although my condition is painful, I would be better off if I were physically active	1	2	3	4
13. Pain lets me know when to stop exercising so that I don't injure myself	1	2	3	4
14. It's really not safe for a person with a condition like mine to be physically active	1	2	3	4
15. I can't do all the things normal people do because it's too easy for me to get injured	1	2	3	4
16. Even though something is causing me a lot of pain, I don't think it's actually dangerous	1	2	3	4
17. No one should have to exercise when he/she is in pain	1	2	3	4

The Roland-Morris Low Back Pain and Disability Questionnaire

Patient name: ______________________________ File #__________ Date:__________

Please read instructions: When your back hurts, you may find it difficult to do some of the things you normally do. Mark only the sentences that describe you today.

- ☐ I stay at home most of the time because of my back.
- ☐ I change position frequently to try to get my back comfortable.
- ☐ I walk more slowly than usual because of my back.
- ☐ Because of my back, I am not doing any jobs that I usually do around the house.
- ☐ Because of my back, I use a handrail to get upstairs.
- ☐ Because of my back, I lie down to rest more often.
- ☐ Because of my back, I have to hold on to something to get out of an easy chair.
- ☐ Because of my back, I try to get other people to do things for me.
- ☐ I get dressed more slowly than usual because of my back.
- ☐ I only stand up for short periods of time because of my back.
- ☐ Because of my back, I try not to bend or kneel down.
- ☐ I find it difficult to get out of a chair because of my back.
- ☐ My back is painful almost all of the time.
- ☐ I find it difficult to turn over in bed because of my back.
- ☐ My appetite is not very good because of my back.
- ☐ I have trouble putting on my sock (or stockings) because of the pain in my back.
- ☐ I can only walk short distances because of my back pain.
- ☐ I sleep less well because of my back.
- ☐ Because of my back pain, I get dressed with the help of someone else.
- ☐ I sit down for most of the day because of my back.
- ☐ I avoid heavy jobs around the house because of my back.
- ☐ Because of back pain, I am more irritable and bad tempered with people than usual.
- ☐ Because of my back, I go upstairs more slowly than usual.
- ☐ I stay in bed most of the time because of my back.

Instructions:

1. The patient is instructed to put a mark next to each appropriate statement.

2. The total number of marked statements are added by the clinician. Unlike the authors of the Oswestry Disability Questionnaire, Roland and Morris did not provide descriptions of the varying degrees of disability (e.g., 40%-60% is severe disability).

3. Clinical improvement over time can be graded based on the analysis of serial questionnaire scores. If, for example, at the beginning of treatment, a patient's score was 12 and, at the conclusion of treatment, her score was 2 (10 points of improvement), we would calculate an 83% (10/12 x 100) improvement.

APPENDIX D

The Multidimensional Classification Approach

(Reproduced from O'Sullivan (2004)

Control Impairment Patterns – Subjective and Objective Criteria

Clinical features of the five control impairment patterns as described by O'Sullivan (2004) (reproduced from Dankaerts et al. (2006))

Control Impairment	Definition	Provocative Postures and Activities	Easing Postures and Activities	Posture and Movement Analysis	Specific Posture and Movement Control Tests
Flexion Pattern	MCI of the lumbar spine with a tendency to flexion strain (loss of segmental lordosis) at the symptomatic segment. Flexion pain disorders are associated with functional loss of motor control into flexion resulting in an excessive abnormal flexion strain.	All flexion-related postures (e.g. slouched sitting) and functional activities (forward bending, cycling) are commonly reported as being painful.	Extension postures/ activities where the lumbar spine is lordosed (e.g. standing, sitting with a lumbar roll, walking).	Tendency to present with a loss of lumbar lordosis during sitting and standing postures. The pelvis is often positioned in posterior pelvic tilt. During all functional tasks the same tendency to have a loss of lordosis at the 'symptomatic level' is noted. Forward bending movements commonly reveal a tendency of an early 'loss of lower lumbar lordosis' (lumbar curve reversal). Similar loss of lordosis is accentuated in other functional tasks like sit- to-stand, squatting and gait. This is associated with an increased lordosis in the upper lumbar and lower thoracic spine.	Inability/ lack of motor control to anterior rotate pelvis and extend lower lumbar spine independent from thorax during above-mentioned aggravating postures/ movements.
Active Extension Pattern	MCI around the lumbar spine with a tendency to hold the lumbar spine actively into extension.	All extension-related postures (standing, erect sitting) and functional activities (carrying out overhead activities, fast walking, running and swimming) are commonly reported as being painful. Also commonly reported as a provocative activity is forward bending (with the key feature here being the tendency to hold the lumbar spine into segmental hyperextension).	Flexion postures/ activities where the lumbar spine is flexed (e.g. crook lying, slouched sitting).	Tendency for the lumbar spine to be actively held into segmental hyper-lordosis at the symptomatic segment during upright sitting and standing postures. During all functional tasks such as sit to stand, squatting and forward bending the same tendency to hyper-lordose at the 'symptomatic segment' is noted. Forward bending movements commonly reveal increased hip flexion and a tendency of a late 'loss of lordosis' (beyond mid range of flexion) or no lumbar curve reversal. Return to neutral from a forward bended position reveals an early hyper-lordosing of the spine at the symptomatic segment.	Inability/ lack of motor control to initiate a posterior pelvic during above-mentioned aggravating postures/ movements.

Flexion/Lateral Shifting Pattern	MCI around the lumbar spine with a tendency to flex and laterally shift at the symptomatic segment.	Reaching and rotating in one direction in association with flexion postures and / or movements.	Relief in extended or lordotic postures, stretching to the opposite side from the shift, shift correction (contra-lateral glide from pelvis).	Similar to the flexion pattern there is a loss of lumbar segmental lordosis at the affected level with the key feature here an associated lateral shift at the lower lumbar spine level. Minimal precipitation of their spine might deviate into a lateral shift position. e.g. the lateral shift is accentuated when standing on the foot ipsi-lateral to the shift. Sagittal spinal movements reveal a tendency to laterally deviate during flexion and this is commonly associated with an arc of pain. Tests like 'sit to stand' usually reveal a typical flexion pattern presentation (see above) plus a tendency towards lateral trunk shift during the movement with increased weight bearing on the lower limb on the side of the shift.	Inability/ lack of motor control to anterior rotate pelvis and extend lower lumbar spine independent from thorax during above-mentioned aggravating postures/movements with an associated lateral deviation
Passive Extension Pattern	MCI around the lumbar spine with a tendency to passively over-extend at the symptomatic segment of the lumbar spine.	Similar to the active extension pattern all extension-related postures (standing, erect sitting) and functional activities (carrying out overhead activities, fast walking, running and swimming) are commonly reported as being painful.	Flexion postures/ activities where the lumbar spine is de-lordosed (e.g. crook lying, slouched sitting).	Tendency for patients to stand into a sway-back posture (thorax posterior to the pelvis) with a segmental hinging at the symptomatic level. Forward bending is often pain free, but on return to neutral they tend to over-extend at the symptomatic level (hinge into extension) and sway pelvis anterior.	Inability/ lack of motor control to extend the thoraco-lumbar spine above the symptomatic segment with a tendency to hinge into extension at this segment.
Multi-directional Pattern	Multi-directional MCI around the lumbar spine	Multi-directional nature of this pattern often reveals pain all weight bearing postures and functional activities.	Difficulty to find relieving positions during weight bearing	Patient may assume a flexed, extended or laterally shifted spinal posture, and may frequently have to alternate them. Excessive segmental shifting and hinging may be observed in all directions, with associated 'jerky' movement patterns and reports of 'stabbing' pain on movement in all directions with observable lumbar erector spinae muscle spasm.	Patients have great difficulty assuming neutral lordotic spinal postures, with over shooting into flexion, extension or lateral shifting postures.

APPENDIX E

Motor Control Subgroups Examination

Functional movement test (observe pain response)	Flexion	Lateral shift (eg. flexion)	Extension (passive)	Extension (active)	Multi-directional
Standing posture	Flattened lumbar lordosis at 'symptomatic' segment	Flattened lumbar lordosis at 'symptomatic' segment Lateral shift	Thorax posterior to pelvis Increased segmental lordosis at 'symptomatic' segment	Thorax anterior to pelvis Increased segmental lordosis at 'symptomatic' segment	Variable
Stabilising strategy	Thoracic ES Upper abdominal	Asymmetrical Thoracic ES, quadratus lumborum, Upper abdominal wall ipsilateral to shift	Upper abdominal wall (RA, EO, upper IO)	Lumbar ES, Psoas +/- LM	Co-contraction / guarding of global trunk muscles
Spinal segment loading	Anterior	Anterior / lateral	Posterior	Posterior	Variable / alternating
Forward bending in standing	Increased flexion at 'symptomatic' segment Extension thoraco-lumbar spine Increased posterior pelvic rotation (+/- arc of pain)	Increased flexion and lateral deviation of 'symptomatic' segment Deviation accentuated in mid range of movement	-	Delayed or loss of reverse lordosis (delayed or absence of flexion relaxation) Hyper-extension of 'symptomatic' segment Excessive anterior pelvic rotation	Increased flexion at 'symptomatic' segment
Return to neutral from forward bending	Extension thoraco-lumbar spine 'symptomatic' segment remains flexed (+/- arc of pain)	Extension thoraco-lumbar spine 'symptomatic' segment remains flexed and deviated (+/- arc of pain)	Tendency to hinge at 'symptomatic' segment and sway pelvis anteriorly on assuming upright position	Tendency to hyperextend 'symptomatic' segment early on return to upright position (+/- arc of pain)	Variable / alternating
Lumbar:hip ratio	3:1	3:1	-	1:3	3:1
COR	Anterior	Anterior / lateral	-	Posterior	Anterior
Extension in standing	Increased extension above 'symptomatic' segment Reduced extension at 'symptomatic' segment	Increased extension above 'symptomatic' segment with lateral deviation Reduced extension at 'symptomatic' segment	Increased extension at 'symptomatic' segment Reduced extension above 'unstable' segment Excessive pelvic sway	Increased extension at 'symptomatic' segment Anterior pelvic rotation	Increased extension at 'symptomatic' segment
Lumbar:hip ratio	1:3	1:3	3:1	3:0	3:1
COR	Anterior	Anterior / lateral	Posterior	Posterior	Posterior
Single leg stand (gait)	-	Lateral shift of thorax +/- trendelenberg	Anterior pelvic sway +/- trendelenberg without sway Internal hip rotation	Posterior pelvic sway Internal hip rotation	Variable / alternating
Squat	Increased flexion at 'symptomatic' segment Posterior pelvic rotation	As with flexion pattern + Lateral deviation	-	Increased extension of 'symptomatic' segment Anterior pelvic rotation	Variable / alternating
Lumbar:hip ratio	3:1				
Sitting	Flexed lower lumbar spine Posterior pelvic rotation Extended thoraco-lumbar spine	As with flexion + deviation	Slumped posture	Lordotic lumbar posture	Variable / alternating
Sit-Stand	Increased flexion at 'symptomatic' segment Extension thoraco-lumbar spine Increased posterior pelvic rotation (+/- arc of pain)	Increased flexion and lateral deviation of 'symptomatic' segment (+/- arc of pain)	Extension 'symptomatic' segment and excessive anterior pelvic sway on assuming erect position	'symptomatic' segment maintained in hyper-lordosis throughout the movement (+/- arc of pain)	Either flexed or extended
Lumbar:hip ratio	3:1	3:1	-	1:3	Variable / alternating

(Reproduced from O'Sullivan (2004)

Specific movement tests (establish pain response and motor control flexibility)	Flexion	Lateral shift (eg. flexion)	Extension (passive)	Extension (active)	Multi-directional
Standing posture correction (test for reduction inloading pain)	Anterior rotation of pelvis Increase lower lumbar lordosis Correct sway	As with flexion + correct deviation	Correct sway posture Extend upper lumbar spine Observe low abdominal reflex	Reduce lordosis / posterior pelvic rotation / relax thorax Correct sway	As indicated
Forward bending correction (for movement pain)	Anterior rotation of pelvis Increase lower lumbar lordosis Flex thoraco-lumbar spine	As with flexion + Correct deviation	–	Enhance posterior pelvic rotation and lumbar flexion Enhance return to neutral with gluteal activation	As with flexion
Backward bending correction (for movement pain)	–	Correct deviation	Reduce sway Enhance extension of upper lumbar spine with control of sway and posterior pelvic rotation to minimise hinging	Enhance posterior pelvic rotation via hips	As with 'passive' extension
Single leg stand correction (for loading pain)	Enhance anterior rotation of pelvis Increase lower lumbar lordosis	Correct deviation with focus on keeping head central with weight transference via hip	Correct postural sway aligning thorax over pelvis	Reduce lordosis / posterior pelvic rotation / relax thorax	As indicated
Squat correction (for loading +/- movement pain)	Enhance anterior rotation of pelvis Maintain lower lumbar lordosis	As with flexion + Correct deviation with focus on keeping head central with weight transference via hip	–	Reduce lordosis / posterior pelvic rotation / relax thorax	As indicated
Sitting correction (for loading pain)	Anterior rotation of pelvis Increase lower lumbar lordosis Relax thorax	As with flexion + correct devaiation	–	Reduce lordosis / posterior pelvic rotation / relax thorax	As indicated
Erect and slump sitting (movement test)	Erect sitting associated with thoraco-lumbar extension. 'symptomatic' segment remains in flexion	As with flexion + deviation	Hyper extension 'symptomatic' segment	Erect sit associated with hyper-lordosis Inability to slump sit	Hyper extension lower lumbar spine
Neutral zone re-positioning test place into neutral lordosis – (a) fully slump and ask to return to neutral position	Tendency to reposition into flexion at 'symptomatic' segment	Tendency to reposition into flexion and deviation	Tendency to reposition into extension	Tendency to reposition into extension	Variable
(b) maintain corrected position and bend forward through the hips	Tendency to flex at 'symptomatic' region	Tendency to flex and laterally deviate at 'symptomatic' region	Tendency to extend at 'symptomatic' region	Tendency to hyperextend lumbar spine	Variable
Sit-stand Place spine in neural lordosis – assess ability to hold spinal position during task (for loading and movement pain)	Tendency to flex at 'symptomatic' region	Tendency to flex and laterally deviate at 'symptomatic' region	Tendency to extend at 'symptomatic' region	Tendency to hyperextend lumbar spine at 'symptomatic' segment	Variable
Sit- stand – single leg (movement test)	-	Excessive lateral shift of thorax over the pelvis when loading the affected side	-	-	-
Anterior / posterior pelvic rotation (supine) (movement test)	Inability to anterior rotate pelvis and extend low lumbar spine independent of thorax	As with flexion + asymmetrical pelvic rotation	Inability to extend thoraco-lumbar spine independent of pelvis	Inability to posterior rotate pelvis and flexion lumbar spine independent of hip flexion	
Lumbo-pelvic lateral rotation independent from hip and thorax (movement test)	–	Inability to rotate lumbo-pelvic region independent of thorax and hip - on side of shift	–	–	As with lateral shift
Prone hip extension (movement test)	–	–	Excessive segmental extension Absence of gluteal activation	Excessive lumbar lordosis and trunk rotation Minimal hip extension	Excessive segmental extension
Four point kneeling Anterior / posterior pelvic rotation (movement test)	Inability to anterior rotate pelvis and extend lumbar spine independent of thorax	As with flexion with associated lateral deviation	Inability to extend thoraco-lumbar spine independent of pelvis and 'symptomatic' segment	Inability to posterior rotate pelvis and flexion lumbar spine	Variable
Lateral leg lower (movement test)	-	Inability to maintain lumbo-pelvic position on side of shift Asymmetrical rotation	Tendency to hyper-extend and rotate lower lumbar spine and flex thoraco-lumbar spine	Tendency to hyper-extend and rotate lumbar spine	Excessive rotation and extension of lumbar-pelvic region

Specific muscle tests (test local muscle system)	Flexion	Lateral shift (eg. Flexion	Extension (passive)	Extension (active)	Multi-directional
Pelvic floor and transverse abdominal wall (supine, prone, side ly, four point kneel, sitting)	Global abdominal wall contraction with tendency to flex lower lumbar spine and posteriorly rotate pelvis (loss of LM co-contraction)	As with flexion + lateral deviation Assymmetrical weakness	Tendency to flex thorax and upper lumbar spine Dominant upper abdominal wall activation Associated breath holding or apical breathing	Tendency to hyperextend lower lumbar spine Anterior pelvic rotation Global bracing of the abdominal wall Breath holding or apical breathing	Variable
Lumbar multifidus with co-contraction with transverse abdominal wall muscles in neutral lordosis (prone, side ly, four point kneel, sitting)	Inability to activate LM Tendency to flexion lower lumbar spine and posteriorly rotate pelvis	Asymmetrical activation of LM Deficit on opposite side to shift	Inability to activate LM above unstable segment	Inability to co-contract LM with TrA in neutral spine position Tendency to hyper-extend lower lumbar spine with dominant ES +/- LM activity	Inability to co-contract in neutral lordosis
Gluteus maximus (prone)	Bilateral weakness	Unilateral weakness	Bilateral weakness	Inner range weakness	Bilateral weakness
Iliopsoas (hip flexion sitting)	Inner range weakness Tendency to posterior rotate pelvis and flex lower lumbar spine	Unilateral inner range weakness Excessive lateral deviation and rotation on side of shift	Inability to maintain upper lumbar lordosis	Over-active psoas Tendency to hyper-extend lumbar spine and anterior rotate pelvis	Variable
Hip flexor length test (Thomas position)	Long 'short hip flexors'	Long 'short hip flexors	Long 'short hip flexors'	Short hip flexors	Long 'short hip flexors'