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The Effect of Limb Movement on the Lumbopelvic Region in People with Low Back Pain

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by

Sara Ann Scholtes

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Abstract of the Dissertation

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Linda R. Van Dillen, P.T., Ph.D., Chairperson

Low back pain (LBP) affects up to 80% of the population at some point in their lifetime. Several models have been proposed to explain the persistent and recurrent course of LBP. In particular, the Movement System Impairment model proposes that lumbopelvic motion that begins soon after the start of an active movement is important to LBP because of its potential contribution to increased frequency of lumbopelvic motion across the day. The purpose of this dissertation is to examine aspects of this model, focusing specifically on lumbopelvic motion during limb movements.

In Chapter 2, we examine whether men and women with LBP differ in the prevalence of movement impairments during standardized clinical tests. We report that a larger proportion of men than women demonstrate early lumbopelvic motion during limb movement tests and movement tests potentially affected by limb tissue stiffness, but not during a movement test unaffected by limb tissue stiffness. In Chapter 3, we examine differences in lumbopelvic motion between people with and people without LBP during two active limb movement tests. We report that, compared to people without LBP,

people with LBP demonstrate a greater magnitude of and earlier lumbopelvic rotation during knee flexion and hip lateral rotation. In Chapter 4, we examine the relationship between lumbopelvic motion during passive and active hip lateral rotation in people with and people without LBP. We report that people with LBP, but not people without LBP, demonstrate a relationship between lumbopelvic motion during passive and active hip lateral rotation. In Chapter 5, we examine how effectively people with and people without LBP modify lumbopelvic motion during active hip lateral rotation following within-session instruction. We report that all people are able to modify lumbopelvic motion during hip lateral rotation, but that people with LBP are less effective at modifying lumbopelvic motion than people without LBP.

The results of this dissertation suggest that lumbopelvic motion during limb movements is important to the course of a LBP problem. Further studies could investigate the factors contributing to lumbopelvic motion during limb movements and intervention strategies to address lumbopelvic motion during limb movements.

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List of Abbreviations

BMI: body mass index

EMG: electromyographic

FABQ: Fear Avoidance Beliefs Questionnaire

GT: greater trochanter

HLR: hip lateral rotation

IC: iliac crest

K: knee

KF: knee flexion

LBP: low back pain

LE: lower extremity

LM: lateral malleolus

MSI: Movement System Impairment

ODI: Oswestry Disability Index

PCA: principal components analysis

PSIS: posterior superior iliac spine

Chapter 1

Background and Significance

Low Back Pain

Low back pain (LBP) is a musculoskeletal condition that affects up to 80% of the population at some point in their lifetime.[5] Although as many as 90% of individuals who initially seek medical consultation for an acute episode of LBP stop seeking medical treatment within 3 months, as many as 75% of these individuals state they are not fully recovered one year later.[2] In addition, many people who experience one LBP episode, will experience additional episodes.[24] The persistent and recurrent course of LBP has led to annual costs associated with LBP estimated to be between 20 and 50 billion dollars.[10] Thus, LBP has both enormous social and economic consequences.

Movement System Impairment Model

Several models have been proposed to explain the course of LBP. One model, the Movement System Impairment (MSI) model, proposes that repetitive movements and sustained postures of the lumbopelvic region in a particular direction contribute to the development, persistence, and recurrence of LBP.[11] The premise of the model is that movements and postures performed repeatedly during daily activities may lead to impairment and eventually injury, particularly if the repeated movements and sustained postures deviate from a biomechanically optimal movement pattern.[11]

A standardized examination for LBP has been developed based on the MSI model. The examination includes assessment of movements and alignments in a number of different positions. The examination includes assessment of trunk movements (e.g. side bending), limb movements (e.g. hip lateral rotation in prone) and combined trunk and limb movements (e.g. forward bending).[20]

One of the primary judgments made by the clinician during assessment of a movement test is the point in the test movement that lumbopelvic motion begins. Sahrmann[11] has proposed that lumbopelvic motion that begins soon after the start of a movement is evidence of a relative flexibility issue. Relative flexibility is described as the tendency of one or more segments to move more readily than other, adjacent segments during a movement.[11] Relative flexibility is proposed to occur because of variations in stiffness of adjacent segments. For example, if the lumbopelvic region were less stiff than the hip, then the lumbopelvic region would be more likely to move early during a hip movement. Relative flexibility is considered important because many daily activities occur in the early to mid ranges of motion rather than end ranges of motion. If a person demonstrates lumbopelvic motion that begins soon after the start of a movement, then the lumbopelvic region may move more frequently across the day, particularly if the person also demonstrates repetitive movements in a particular direction. The increased frequency of lumbopelvic motion may contribute to an increase in lumbopelvic region tissue stress, microtrauma, and ultimately LBP.[7,9] Although relative flexibility has been reported in people with LBP[3,13,17,20,22,23] the mechanisms contributing to relative flexibility have not been extensively investigated.

Limb movement tests are included in the standardized examination for LBP because limb movements result in forces on the lumbopelvic region and, therefore, could contribute to lumbopelvic motion. Limb movements have previously been identified to be important to examine in people with LBP. People with LBP report an increase in symptoms with active limb movements[19] and demonstrate lumbopelvic motion that begins soon after the start of the movement during active limb movement tests.[18,22] Differences in lumbopelvic motion between different subgroups of people with LBP,[17] as well as, between men and woman with LBP have been reported.[3] Van Dillen et al[17] identified differences in symmetry of lumbopelvic motion demonstrated during an active limb movement between two different subgroups of people with LBP. Gombatto et al[3] reported that, compared to women with LBP, men with LBP complete a greater amount of lumbopelvic motion during the early part of a limb movement. Identifying differences in lumbopelvic motion demonstrated during limb movement tests between different subgroups of people with LBP, or between men and women with LBP may help direct classification and intervention of people with LBP. Identifying whether people with LBP demonstrate differences in lumbopelvic motion when compared to people without LBP, however, has not been extensively studied. A number of investigators have reported differences between people with and people without LBP during activities that required movement of both the trunk and the limbs,[8,15,16] but, to our knowledge, only one study has examined differences in lumbopelvic motion during a limb movement test between people and people without LBP.[8]

The standardized examination for LBP based on the MSI model also includes tests assessing the effect on symptoms of modifying a movement impairment observed during a trunk, limb, or combined trunk and limb movement test. The goal of modifying a test movement is to decrease or eliminate lumbopelvic motion in order to decrease symptoms and promote a more biomechanically optimal movement pattern. Clinical data support the importance and effectiveness of modifying lumbopelvic motion during an active movement test. People with LBP report an immediate decrease in symptoms when lumbopelvic motion during a limb movement is manually restricted by the clinician.[23]

With the MSI model, if restriction of lumbopelvic motion during a movement test results in decreased symptoms, the test item would then be prescribed as part of a home program. Prescribing a test item as part of a home program, however, would require the patient to be able to control the lumbopelvic region during the active movement without manual assistance. Case reports highlighting the benefits of using the MSI model to evaluate and treat a person with LBP would suggest that when the model is used to guide intervention, short and long term outcomes are improved.[4,6,23] How quickly or how effectively people are able to modify lumbopelvic motion during an active movement has not been examined.

Purpose of Dissertation

The purpose of this dissertation work is to examine additional aspects of the MSI model, focusing on the role of limb movements. Chapter 2 examines gender differences in the prevalence of early lumbopelvic movement impairments during a number of different active movement tests in people with LBP. Clinical observation and previous data suggest that analysis of gender differences in prevalence of movement impairments across a number of different tests may provide important insight into inherent differences between men and women with LBP. Based on (1) previous work by Gombatto et al[3] reporting that men with LBP complete a greater amount of lumbopelvic motion during the first portion of a limb movement than women with LBP and (2) data suggesting men demonstrate greater active and passive stiffness of the lower limbs than women,[1] we hypothesized that, compared to women, a greater percentage of men would demonstrate early lumbopelvic motion during limb movement tests and movement tests potentially affected by limb tissue stiffness. We also hypothesized that there would be no difference in prevalence of early lumbopelvic motion between men and women in movement tests that are not influenced by limb tissue stiffness. A better understanding of gender differences in movement patterns demonstrated during clinical tests may help refine examination and intervention options for men and women with LBP.

Chapters 3, 4, and 5 examine lumbopelvic motion demonstrated during limb movement tests in people with and people without LBP. Previous data suggest examining lumbopelvic motion demonstrated during limb movements is important to help identify different subgroups of people with LBP,[17] but whether lumbopelvic motion during limb movements is different between people with and people without LBP has not been determined. Chapter 3 examines whether people with and people without LBP demonstrate different patterns of lumbopelvic motion during 2 different limb movement tests identified to be important for classifying people with LBP into subgroups. We hypothesized that, compared to people without LBP, people with LBP would demonstrate earlier and more lumbopelvic motion during both limb movement tests. Identifying differences in lumbopelvic motion demonstrated during a limb movement in people with and people without LBP may provide insight into the importance of lumbopelvic motion during a limb movement to the development and persistent course of a LBP problem. This information may also help refine LBP intervention strategies.

Chapter 4 examines the relationship between lumbopelvic motion demonstrated during an active limb movement test and lumbopelvic motion demonstrated during a passive limb movement test. Clinically, the pattern of lumbopelvic motion observed during a passive limb movement test appears to be similar to the pattern of lumbopelvic motion observed during an active limb movement test. The relationship between the two movements, however, is unknown. Furthermore, because our observations are based on examining people with LBP, it is unknown whether the potential relationship between lumbopelvic motion during a passive and an active limb movement is unique to people with LBP, or whether people without LBP also demonstrate a similar relationship. We hypothesized that how soon the lumbopelvic region moves during passive hip lateral rotation (HLR) would be related to how soon the lumbopelvic region moves during active HLR. Chapter 4 also examines the relationship between how soon the lumbopelvic region moves during active HLR and a number of other subject characteristics, clinical findings, and laboratory findings. Because prior data suggest gender differences in lumbopelvic motion during active limb movements,[3,12,14] we hypothesized that gender would be related to how soon the lumbopelvic region begins to move during active HLR.

Chapter 5 examines how effectively people with and people without LBP are able to modify lumbopelvic motion during an active limb movement test, HLR, following standardized, within-session instructions. Manual restriction by a clinician of the lumbopelvic region during an active limb movement results in an immediate decrease in symptoms.[18,21] How effective people are at decreasing lumbopelvic motion without manual assistance is unknown. We hypothesized that, with instruction, all people would (1) complete a greater amount of HLR prior to the start of lumbopelvic motion and (2) demonstrate less lumbopelvic motion during HLR. We also hypothesized that, compared to people with LBP, people without LBP would demonstrate greater improvements in both variables. Identifying how effectively people can modify a movement pattern may help guide a clinician to provide the most appropriate home program for someone with LBP.

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Chapter 2

Gender-Related Differences in Prevalence of Lumbopelvic Region Movement Impairments in People with Low Back Pain

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ABSTRACT

Study Design: Cross-sectional, secondary analysis.

Objectives: To examine potential gender differences in prevalence of lumbopelvic region movement impairments during clinical tests in a sample of people with low back pain (LBP).

Background: A number of studies have identified factors contributing to differences between men and women in prevalence of lower extremity injuries. Few studies have examined potential gender differences in impairments of people with LBP.

Methods and Measures: Eighty-four males and 86 females (mean +/- SD age, 41.5 +/- 13.3 years) with LBP participated in a standardized examination. Responses from 7 movement tests that examine early lumbopelvic movement were analyzed using chi-square statistics.

Results: A greater proportion of men than women displayed early lumbopelvic movement during the majority of limb movements (3/4) and movements potentially affected by limb tissue stiffness (2/2) ($P<.05$). There were no differences in the proportions of men and women displaying early lumbopelvic movement during a movement presumed to not be affected by limb tissue stiffness ($P>.05$). Similar results were obtained when analyzing only the subsets of subjects who reported an increase in symptoms with a specific test.

Conclusion: Our results provide data to suggest men and women with LBP may move differently in the lumbopelvic region during clinical tests of limb movements and movements potentially affected by limb tissue stiffness. Recognition of gender differences in prevalence of movement impairments is important for improving examination and intervention of people with LBP.

Key Words: limb, lumbar, physical therapy

INTRODUCTION

A number of investigators have focused on examination of biomechanical and neuromuscular factors to explain gender differences in the prevalence of various lower extremity injuries.[5,13,22,27,38,39] There has also been some interest in the study of gender differences in people with other musculoskeletal pain conditions, including people with low back pain (LBP). The primary focus of gender-related studies of people with LBP has been on movement of the lumbopelvic region during functional tasks. Gender differences have been reported in the contribution of hip and trunk movement to lifting style,[16,17] hip and spine movement during a reaching task,[31] and pelvic movement during walking.[28] Recently, gender differences in movement strategies during the clinical test of active hip lateral rotation have also been identified.[9] The results of the Gombatto et al[9] study are of particular interest because the findings suggest that men and women may move differently during standardized clinical tests of movement. A better understanding of possible gender differences in movement of the lumbopelvic region during clinical tests could assist in better directing examination and intervention of people with LBP, with the ultimate goal of improving outcomes.

A standardized clinical examination, based on Sahrmann's conceptual model of LBP,[25] includes a number of clinical tests of trunk, limb, or combined trunk and limb movements.[34] For each test, a judgment is made by the clinician about the presence or absence of a specific movement impairment. Because one of the main assumptions of Sahrmann's model is that early movement of the lumbopelvic region during everyday movements contributes to LBP,[25] a primary judgment made is whether the patient moves his or her lumbopelvic region *early* in the range of the test movement. Similar to other judgments made during clinical tests, making a judgment of early lumbopelvic movement during a clinical test provides a clinically feasible method to gain insight into lumbopelvic movements potentially demonstrated during everyday activities and how the movements relate to a person's LBP symptoms. In particular, the finding of early lumbopelvic movement is considered important to the person's LBP problem because people perform many of their daily activities in early and mid-ranges of joint motion. If a person tends to move the lumbopelvic region early in the range of a test movement, the person has the potential to exhibit similar movement with daily activities, thus increasing the frequency of lumbopelvic movement across the day. The potential result is an increase in lumbar region loading, accumulation of tissue stress because of minimal time off for normal adaptation and recovery,[21] and eventually LBP symptoms.[19]

Although a relationship between the presence of early lumbopelvic movement during clinical tests and early lumbopelvic movements during everyday activities has not specifically been confirmed, there are data to support the proposal that repetition of movement is related to LBP. Performance of repetitive activities such as bending and twisting is a known risk factor for LBP.[2,15,18,23,24,26] Principles of the Physical Stress Theory also would suggest that an increase in frequency of movement of a specific region across the day may contribute to increased stress on biological tissues, leading to injury and eventually pain.[21]

Although data suggest that people with LBP display early lumbopelvic movement with various clinical tests,[6,9,33,36] currently the factors contributing to the early movement are not fully understood. One possible contribution is passive tissue stiffness, which is defined as the ratio of change in passive resistance to change in displacement.[7] If passive stiffness varies in different anatomical regions then the region with less stiffness may move earlier in the range of a test movement than other regions contributing to the movement. For example, during the clinical test of hip lateral rotation in prone, the lumbopelvic region may move early during hip rotation if stiffness of the hip is greater than stiffness of the lumbopelvic region.[9] Investigators have reported that, compared to women, men demonstrate greater active and passive stiffness of the lower limbs.[3,8,11] If tissue stiffness plays a role in early lumbopelvic movement during clinical tests, then potentially men and women may display different movements during testing. Gender differences in limb tissue stiffness and reported gender differences with the clinical test of hip lateral rotation in prone[9] would suggest that potentially men and women may move differently during certain movement tests included in the examination based on Sahrmann's model of LBP.[25] In particular, men and women may move differently during tests that involve limb movement or are potentially affected by limb tissue stiffness.

The primary purpose of this secondary analysis was to examine whether men and women with LBP differed in the prevalence of early lumbopelvic region movement during standardized clinical tests. A secondary purpose was to examine whether these gender differences were present in the subsets of people who reported increased LBP symptoms during individual tests. We hypothesized that, compared to women, a greater percentage of men would demonstrate early lumbopelvic movement during tests of limb movements and tests of movements potentially affected by limb tissue stiffness. We further hypothesized that there would be no gender differences in the prevalence of early lumbopelvic movement during test movements considered to be unaffected by limb tissue stiffness. This analysis is important because a better understanding of gender differences in findings during clinical tests could help to better direct examination and interventions in people with LBP with the goal of improving outcomes.

METHODS

Subjects

The original sample consisted of 188 patients with LBP who were part of a study examining the reliability and validity of examination items proposed to be important for classifying individuals with LBP into subgroups.[34] People were recruited from outpatient physical therapy clinics, through advertisements on posters and in local newspapers, and from family members and friends of patients who had already participated in the study. People between 18 and 75 years of age who had LBP symptoms in either the region of the lower back, proximal lower extremity, or distal lower extremity[29] were eligible for inclusion in the study. People were excluded in the case of pregnancy, severe kyphosis or scoliosis, spinal stenosis, a history of spinal surgery in the last 3 months, more than 1 surgical procedure on the spine, pending spinal surgery, cancer, rheumatoid arthritis, ankylosing spondylitis, neurological disease (for example, multiple sclerosis), or an inability to stand and walk without an assistive device. All patients read and signed an informed consent approved by the Human Studies Committee of Washington University Medical School before participating in the study.

Examination Items

The items of interest were part of a set of physical tests and measures from a standardized clinical examination.[34] The current study focused specifically on a subset of active movement tests. The tests consisted of trunk, limb, and combined trunk and limb movements. With each test, symptoms were assessed (increased, decreased, or remained the same) and judgments of timing of lumbopelvic movement were made. The movement tests were included in the examination to assess impairments of early lumbopelvic movement in the directions of flexion, extension, rotation, flexion and rotation, or extension and rotation. Interrater reliability of the 5 examiners administering the examination items has been previously reported.[34]

Procedures

Patient Selection. The sample was divided into 2 groups based on gender and the groups were compared for equivalence with regard to relevant characteristics. Table 2.1 lists the values for the patient and LBP-related variables for the sample and the results of associated statistical tests of differences. Men and women were different with regard to 2 characteristics. On average, women reported higher Oswestry Disability Index (ODI) scores (mean±SD, Females=27.6±14.9, Males=19.5±14.4) and had higher body mass index (BMI) values (mean±SD, Females=26.9±7.2, Males=24.3±3.8) compared to men.

Because the groups were not equivalent with regard to variables that could pose alternative explanations for any obtained gender differences in prevalence of movement impairments, the data set was reduced. A process was used in which the female cases were iteratively removed beginning with the case with the highest ODI score. After removal of each case, mean ODI scores for the 2 groups were compared. Removal of cases continued until the 2 groups were equivalent with regard to mean ODI scores; 17 cases were removed through this process. A similar process was then used to make the groups equivalent with regard to BMI. Because removal of female cases with high ODI scores also resulted in the removal of female cases with high BMI values, only 1 additional case was removed. A total of 18 female cases were removed from the data set.

Test Items. Seven active movement tests associated with an early lumbopelvic movement impairment were the focus of the current study. Symptoms and movement impairments were assessed with each of the tests. The 7 tests were categorized as (1) limb movements, (2) movements potentially affected by limb tissue stiffness, and (3) a movement presumed to not be affected by limb tissue stiffness. A test was categorized as a limb movement test if the movement involved limb movement without movement of the trunk. For example, hip lateral rotation in prone is categorized as a limb movement test because the test involves only movement of the limb. A test movement was categorized as potentially affected by limb tissue stiffness if the test involved movement of the trunk and limbs and stiffness of limb tissues potentially would affect movement of the lumbopelvic region during the test. For example, both the trunk and the hips move during forward bending and potentially stiffness of the hamstrings may influence the movement. Return from forward bending was categorized as a movement presumed to not be affected by limb tissue stiffness because the test involved trunk and limb movement but tissues of the limb would not influence movement of the lumbopelvic region during the test. The test items, associated impairments, and values for reliability coefficients from the original study are provided in Table 2.2.[34]

The judgment of an impairment during a movement test was made by trained examiners based on operationally defined criteria. The criteria used for deciding on the presence or absence of an impairment during a movement test were developed by a clinical expert and 5 orthopedic physical therapists. The clinical expert in this case was the person who proposed the LBP classification scheme for which the clinical examination was developed. All therapists involved in the development and testing process had a minimum of 5 years of orthopedic physical therapy experience (range: 5-35 years). Training of examiners included (1) studying a manual and watching videotapes that contained all pertinent information for the examination, (2) passing a written examination of the information from the manual, and (3) meeting with the principal investigator to practice and review testing procedures. For tests that involved both trunk and limb movement, the examiner made a judgment about whether the rate of movement of the trunk was greater than the rate of movement of the limb during the first 50% of the test movement. To examine early movement of the lumbopelvic region during limb movement tests, a criterion of 1.28 cm (0.5 inch) or greater movement of the lumbopelvic region during the first 50% of the limb movement was used for the majority of judgments. The criterion of 1.28 cm (0.5 inch) was used because it was considered (1) enough movement of the lumbopelvic region to be clinically significant and (2) to be perceived and judged by trained clinicians. The procedures for the active movement tests have been described in prior publications.[34,35] The operational definitions for responses to individual tests are described in the Appendix.

Data Analyses

Descriptive statistics were conducted on relevant patient and LBP-related characteristics. To examine whether the percentage of people who displayed the early lumbopelvic movement impairment with each test was different for men and women, a Chi-square goodness of fit analysis was conducted on the responses (present versus absent) for each of the 7 movement tests. A Chi-square goodness of fit was conducted on symptom data for each test to examine differences in symptom reproduction between men and women. To examine whether the percentage of people who displayed the early lumbopelvic movement impairment with each test was different for men and women in the subsets of people who reported increased LBP during individual tests, a Chi-square goodness of fit analysis was also conducted on the responses (present versus absent) for each of the 7 tests. The probability level for all testing was set at $P \leq 0.05$.

RESULTS

Patient Characteristics

The final gender-based groups were equivalent with regard to all patient and LBP-related variables of interest ($P > .05$ for all comparisons). Table 2.3 provides the values for each of the variables for the final groups and the associated statistical and probability values.

Groups were also equivalent with regard to symptom reproduction during all of the movement tests ($P>0.05$ for all comparisons).

Impairments

All patients. Table 2.4 provides the percentages of positive responses for the groups of men and women for each of the movement tests. Compared to women, a larger percentage of men displayed early lumbopelvic movement with 3 of the 4 limb movement tests (knee extension in sitting, knee flexion in prone, hip lateral rotation in prone). A larger percentage of men also displayed early lumbopelvic movement with both of the tests potentially affected by limb tissue stiffness (forward bend in standing, rocking back in quadruped). There were no differences in the percentage of men and women displaying early lumbopelvic movement during return from forward bending, the test presumed to not be affected by limb tissue stiffness.

Patients who reported an increase in LBP symptoms. Similar results were obtained in the subsets of patients who reported an increase in symptoms during individual movement tests. Table 2.5 provides the percentages of positive responses for men and women for the subsets of patients with symptoms during each test. Compared to women, a larger percentage of men displayed early lumbopelvic movement with 3 of the 4 limb movement tests (knee extension in sitting, knee flexion in prone, hip lateral rotation in prone). A larger percentage of men also displayed early lumbopelvic movement with forward bend in standing, a movement potentially affected by limb tissue stiffness. There were no differences in the percentage of men and women who displayed early lumbopelvic movement during return from forward bending.

DISCUSSION

The findings from this secondary analysis support the hypothesis that men and women move differently during specific clinical tests. In particular, a greater percentage of men displayed early lumbopelvic movement with a majority of the limb movement tests and tests considered to be potentially affected by limb tissue stiffness. There was no difference, however, in the percentages of men and women displaying early lumbopelvic movement with the test presumed to not be affected by limb tissue stiffness. Additionally, when analyzing the results from only those patients who reported an increase in symptoms with individual movement tests, similar results were obtained. Thus, pain during each test does not appear to be responsible for the differences in movements between men and women. The gender differences in movement during clinical tests are important because they suggest possible differences in the factors contributing to LBP between men and women, and, therefore, the potential need for differences in intervention.

Investigators have previously identified gender differences in movement during functional activities. Marras et al[17] and Thomas et al[31] reported that, compared to women, men move more in the trunk and less in the hips during lifting and forward reaching. These studies focused on gender differences in total motion of the trunk and hips and not on *when* in the test movement trunk and hip motion occurred. Because people perform many of their daily activities in the early and mid-ranges of joint motion, identifying when in the test movement trunk and hip motion occurs could potentially be important. If a person tends to move the lumbopelvic region early in the test movement, then he or she may also exhibit similar movements with daily activities. The proposed result is increased frequency of lumbopelvic movement, potentially contributing to the LBP problem. Investigators have examined trunk and hip motion across a test movement,[4] but to our knowledge, only 1 study has focused specifically on *gender* differences in movement of the lumbopelvic region. Gombatto et al[9] reported that, compared to women, men with LBP completed a larger percentage of their total lumbopelvic motion in the first 60% of hip lateral rotation range of motion. Thus, compared to women, men with LBP appear to be demonstrating the early lumbopelvic movement as described by Sahrmann.[25]

Unique to the current analysis is the investigation of gender differences in lumbopelvic movement across a variety of clinical tests included in a standardized examination. We use the information about how people move during clinical tests to give us insight into how a person may be moving during daily activities. Examining gender differences in lumbopelvic movement across a group of clinical tests performed in a variety of different positions provides us with more information about the generalizability of gender differences across a number of movements instead of just 1 functional movement or clinical test as has been reported previously.[9,17,31] The finding of predictable gender differences across several tests suggests the need for further investigation of gender differences in the factors that contribute to LBP.

One factor that may have contributed to the obtained differences in timing impairments between men and women is greater limb tissue stiffness in men compared to women.

Investigators have reported that, when compared to women, men demonstrate greater active and passive stiffness of the lower limbs.[3,8,11] When performing a limb movement or a movement potentially affected by limb tissue stiffness, increased limb tissue stiffness may offer increased resistance to the movement. As the limb moves, lumbopelvic movement may be induced earlier in the range of motion. For example, if the tensor fascia lata/iliotibial band is stiffer than trunk tissues, lumbopelvic movement may be induced earlier in the movement during hip lateral rotation in prone.

There are other possible factors such as differences in anthropometry, extensibility, strength, and recruitment strategies that may be contributing to the identified gender differences during clinical tests. Because anthropometric values, joint ranges of motion, tissue stiffness, and muscle activity data were not collected, we are unable to assess the contribution of these variables to the gender differences we identified. It is our perspective, however, that these factors likely do not independently influence how people move. Rather, we propose that an interaction of biomechanical and neural control factors contribute to the gender differences in movements of the lumbopelvic region identified in the current set of tests. Future studies could examine the interaction of such variables to the identified gender differences in lumbopelvic movement.

Age is another factor that may influence how people move. Studies have documented a decrease in spine motion associated with aging.[1,10,20,30,32,37] There is the possibility that the impairment measures of interest in the current study could be affected by age-related spine changes. To further examine the potential effect of age on the gender effects obtained in the current study, we divided the sample into 2 equal groups, (1) patients younger than 42 years of age and (2) patients 42 years of age or older. For each group, we conducted a Chi-square goodness of fit analysis on the responses of men and women for each of the 7 movement tests. Overall, there was no systematic effect of age on the responses with each of the movement tests. Similar to the results of the current study, compared to women, a greater percentage of men demonstrated early lumbopelvic movement in the majority of limb movement tests or tests potentially affected by limb tissue stiffness, regardless of age. While the current age division was based on equal group representation, it is possible that influence of age on movement could start at a much later age.

A better understanding of differences in the factors contributing to LBP for men and women will help to better direct examination and intervention, potentially resulting in improved outcomes. Prior clinical results suggest that limiting lumbopelvic movement while encouraging movement in other regions can reduce LBP symptoms and improve short- and long-term outcomes.[12,14,35] However, intervention in these prior studies used general methods to restrict lumbopelvic movement and did not examine whether specific methods of restricting lumbopelvic movement at different points in the range of motion resulted in better outcomes for men or women. Gombatto et al[9] reported that, although women demonstrated later lumbopelvic movement, women did not demonstrate less total lumbopelvic movement than men during hip lateral rotation. If men demonstrate earlier lumbopelvic movement but men and women demonstrate equal amounts of total lumbopelvic movement, then our data would suggest that a strategy of limiting lumbopelvic movement *early* in the range of motion may be more important for men than women. On the other hand, it may be more beneficial for women to limit lumbopelvic region movement later in the range of a test movement. Future research examining gender differences in lumbopelvic movement during limb movement tests and the effect of specific interventions to target timing of lumbopelvic movement is necessary to better understand both contributing factors to LBP as well as appropriate intervention strategies.

One potential limitation of this analysis is the process we used to reduce the data set to minimize the effects of variables that could have posed alternative explanations for the obtained gender differences. Although reducing the data set to equate the groups with regard to ODI scores and BMI values allowed us to examine gender differences in movement impairments without regard for potential alternative explanations, gender differences in ODI scores and BMI values are important characteristics that clinically are often found to be different between men and women. Both of these differences potentially could affect the specific intervention for a person's LBP. Although ODI scores and BMI values are important characteristics to consider in people with LBP, we do not believe the inherent differences in ODI and BMI values affected the outcome of the current study. Initially we analyzed the full data set (N=188) and obtained the same results as those reported in the current study; compared to women, a greater percentage of men demonstrated early lumbopelvic movement during limb movement tests or movement tests potentially affected by limb tissue stiffness. We chose to reduce the data set, however, to examine if the effects persisted when ODI and BMI values were equal for men and women.

A second potential limitation is that the data analyzed were based on clinician judgment and thus may be affected by examiner bias. Although we cannot fully discount the potential bias, there are 2 reasons that suggest a bias was not present, or was at least attenuated, during data collection. First, the data set analyzed was part of a large reliability and validity study to test the use of the examination to classify people with LBP.[34] It is our perspective that the primary concern of the clinicians at the time of data collection was to conduct the examination correctly and make appropriate judgments based on defined criteria and not on identifying gender differences. The criteria for all examiner judgments were operationalized and the reliability of examiners' judgments was found to be clinically acceptable.[34] Second, the current hypotheses were formulated *a posteriori*, thus the examiners likely had no preconceived notions about gender differences in findings with the clinical tests. Although examiners may have had knowledge of gender differences in factors contributing to other musculoskeletal problems, at the time of the original study it was thought that early movement of the lumbopelvic region was an important finding in *all* people with LBP and not gender specific.

A third potential limitation is that the generalizability of the findings may be limited due to the characteristics of the examiners who participated in the original study. The original study was conducted by a group of examiners who were involved in the development of the examination. All of the examiners involved also had knowledge of the theory underlying the choice of examination items. Thus, the data collected for the current analyses were obtained by well trained examiners. The findings may not be as evident or replicable by examiners who are not well trained in observing lumbopelvic movement during the clinical tests. Future studies could focus on training inexperienced examiners in the standardized examination to determine if similar gender differences are identified in people with LBP when newly trained examiners make judgments about lumbopelvic movement during the movement tests described.

Finally, the sample primarily consisted of patients with chronic LBP with ODI scores indicating a minimal level of LBP-related disability. Although there was no difference in chronicity of pain or disability level between men and women, it is unknown whether or not the findings in the current study would also be detected in a sample of people with a more recent incidence of LBP and with higher LBP-related disability levels. Future studies could examine if the gender differences are identified in people with LBP who demonstrate a variety of acuity and disability levels.

CONCLUSION

Overall, a larger proportion of men than women demonstrated early lumbopelvic movement during limb movements tests and movement tests potentially affected by limb tissue stiffness, but not during a movement test considered to be unaffected by limb tissue stiffness. These findings provide some data to suggest gender differences in the prevalence of lumbopelvic region movement impairments, specifically early lumbopelvic movement, and the factors contributing to LBP in men and women. A better understanding of gender differences in movement impairments and the potential contributing factors underlying impairments could lead to improved examination, intervention, and outcomes in people with LBP. Based on the current findings, further investigation of potential gender differences in movement and the factors contributing to such differences may be warranted.

Table 2.1 Characteristics of original sample of people with low back pain (N=188).

Characteristic	Male	Female	Statistical and Probability Values		
			t Value	χ^2 Value	*P* Value
Number of subjects	84	104		2.128	0.145
Mean age ± SD (y)	42.1±12.9	41.8±13.5	0.19		0.854
Mean BMI ± SD (kg/m^2)	24.3±3.8	26.9±7.2	-2.99		**0.003**
Mean pain score ± SD (0-5)	1.7±0.9	1.9±0.8	-1.55		0.124
Location of symptoms (%)					
Low back only	71.4	61.5		6.284	0.099
Low back/proximal lower extremity	11.9	11.5			
Low back/distal lower extremity	6.0	2.9			
Low back/proximal Lower extremity/distal Lower extremity	10.7	24.0			
Number of subjects Reporting decreased motor or sensory function	1	4			
History of previous LBP episodes (%)	80.0	81.4		0.039	0.844
Chronicity (%)					
Acute	7.2	9.7		0.370	0.830
Subacute	19.3	19.4			
Chronic	73.5	70.9			
Mean ODI ± SD (0-100)	19.5±14.4	27.6±14.9	-3.68		**<0.001**

Abbreviations: BMI, body mass index; LBP, low back pain; ODI, Oswestry Disability Index
Boldface indicates a significant effect (*P*<0.05).

Table 2.2 Active movement tests, associated impairments, and reliability statistics from the original reliability study.[34]

Test	Impairment	Value of Reliability Statistics	
		Kappa Coefficient	Percent Agreement
Limb Movement Tests			
Hip abduction/lateral rotation in hook lying	Lumbopelvic rotation in the 1st 50% of the hip motion	.60	88
Knee extension in sitting	Lumbopelvic rotation or lumbar flexion in the 1st 50% of the knee motion	.58	86
Knee flexion in prone	Lumbopelvic rotation or anterior pelvic tilt in the 1st 50% of the knee motion	.76	90
Hip lateral rotation in prone	Lumbopelvic rotation in 1st 50% of the hip motion	.56	83
Movement Tests Affected By Limb Tissue Stiffness			
Forward bend in standing	Rate of lumbar flexion > rate of hip flexion in the 1st 50% of trunk motion	.51	76
Rocking back in quadruped	Rate of lumbar flexion > rate of hip flexion in the 1st 50% of trunk motion	.78	95
Return from forward bend in standing	Rate of lumbar extension > rate of hip extension in 1st 50% of trunk motion	.54	92

Table 2.3 Characteristics of the final sample of people with low back pain (N=170).

Characteristic	Male	Female	Statistical and Probability Values		
			t Value	χ^2 Value	*P* Value
Number of subjects	84	86		0.024	0.878
Mean age ± SD (y)	42.1±12.9	41.0±13.7	0.56		0.573
Mean BMI ± SD (kg/m^2)	24.3±3.8	25.6±5.8	-1.68		0.096
Mean ODI ± SD (0-100)	19.5±14.4	22.3±9.7	-1.44		0.153
Mean pain score ± SD (0-5)	1.7±0.9	1.7±0.6	-0.07		0.942

Abbreviations: BMI, body mass index; ODI, Oswestry Disability Index

Table 2.4 Tests, impairments, percentages of positive responses, and statistical values for judgments of lumbopelvic region impairments in people with LBP (N=170).

Test	Impairment	Male	Female	Statistical and Probability Values	
		Value (%)		χ^2 Value	*P* Value
Limb Movement Tests					
Hip abduction/lateral rotation in hook lying	Lumbopelvic rotation in the 1st 50% of the hip motion	14.3	8.2	1.55	0.213
Knee extension in sitting	Lumbopelvic rotation or lumbar flexion in the 1st 50% of the knee motion	38.1	18.6	7.97	**0.005**
Knee flexion in prone	Lumbopelvic rotation or anterior pelvic tilt in the 1st 50% of the knee motion	45.2	19.8	12.60	**<0.001**
Hip lateral rotation in prone	Lumbopelvic rotation in 1st 50% of the hip motion	66.3	32.6	19.20	**<0.001**
Movement Tests Affected By Limb Tissue Stiffness					
Forward bend in standing	Rate of lumbar flexion > rate of hip flexion in the 1st 50% of trunk motion	54.8	30.2	10.47	**0.001**
Rocking back in quadruped	Rate of lumbar flexion > rate of hip flexion in the 1st 50% of trunk motion	19.0	5.9	6.73	**0.009**
Movement Tests Not Affected By Limb Tissue Stiffness					
Return from forward bend in standing	Rate of lumbar extension > rate of hip extension in 1st 50% of trunk motion	9.5	4.7	1.54	0.215

Boldface indicates a significant effect (*P*<0.05)

Table 2.5 Tests, impairments, number of patients reporting an increase in symptoms, percentages of positive responses in the subset of patients reporting an increase in symptoms, and statistical values for judgments of lumbopelvic region impairments.

Test	Impairment	Male		Female		Statistical and probability values	
		(N)*	(%)†	(N)	(%)	χ^2 Value	*P* Value
Limb Movement Tests							
Hip abduction/lateral rotation in hook lying	Lumbopelvic rotation in the 1^{st} 50% of the hip motion	32	15.6	45	11.1	.38	0.561
Knee extension in sitting	Lumbopelvic rotation or lumbar flexion in the 1^{st} 50% of the knee motion	31	58.1	26	26.9	5.57	**0.018**
Knee flexion in prone	Lumbopelvic rotation or anterior pelvic tilt in the 1^{st} 50% of the knee motion	19	63.2	25	32.0	4.23	**0.040**
Hip lateral rotation in prone	Lumbopelvic rotation in 1^{st} 50% of the hip motion	42	76.2	44	43.2	9.70	**0.002**
Movement Tests Affected By Limb Tissue Stiffness							
Forward bend in standing	Rate of lumbar flexion > rate of hip flexion in the 1^{st} 50% of trunk motion	47	61.7	42	38.1	4.95	**0.026**
Rocking back in quadruped	Rate of lumbar flexion > rate of hip flexion in the 1^{st} 50% of trunk motion	19	31.6	22	13.6	1.92	0.166
Movement Tests Not Affected By Limb Tissue Stiffness							
Return from forward bend in Standing	Rate of lumbar extension > rate of hip extension in 1^{st} 50% of trunk motion	26	15.4	34	8.8	.62	0.433

* Indicates number of patients who reported an increase in symptoms with the test.
† Indicates percentage of patients who reported an increase in symptoms with the test who also demonstrated the impairment.
Boldface indicates a significant effect ($P<0.05$).

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APPENDIX

Description of the 7 active movement tests and operational definitions for movement impairment responses assessed with each test. Movement impairments based on lumbopelvic rotation during the test use a criterion of 1.28 cm (0.5 inch) to determine the presence or absence of an impairment. The criterion of 1.28 cm is based on expert opinion[25] and is considered to be enough movement of the lumbopelvic region to be clinically significant and perceptible by trained clinicians.

Initial Position Standing

All tests in standing are performed while the patient stands with his feet shoulder width apart and his arms positioned at his sides. The examiner is positioned so that the patient's pelvis and lumbar region are at eye level for the examiner.

Test: Active forward bend in standing (Figure 2.1). The patient is instructed to perform a forward bend movement as far as he can and then return to the standing position. The examiner observes the movement of the lumbopelvic region during the forward bending motion from a side view, and assesses the rate of lumbar and hip movement.

Impairment: During forward bend in standing, the rate of movement into lumbar flexion is greater than the rate of movement into hip flexion in the first 50% of trunk motion.

Test: Active return from forward bend in standing (Figure 2.1). The patient is instructed to perform forward bend as far as he can and then return to the standing position. The examiner observes the movement of the lumbopelvic region during the return motion from a side view, and assesses the rate of lumbar and hip movement.

Impairment: During return from forward bend, the rate of movement into lumbar extension is greater than the rate of movement into hip extension in the first 50% of trunk motion.

Initial Position Sitting

All tests in sitting are initiated from a position in which the patient's hips are at a 90° angle of flexion, the femurs are horizontal on the table and positioned in neutral abduction-adduction and rotation and the lumbar region is neutral.

Test: Active knee extension in sitting (Figure 2.2). The examiner places a hand on each side of the lumbar region to palpate tissue spanning from the spinous processes to 5.08 cm (2.0 inches) lateral to either side of the spinous processes. The patient actively extends each knee separately through the range of motion without cueing from the examiner.

Impairment: Lumbopelvic rotation in the first 50% of the knee motion. Rotation of one or more of the lumbar vertebrae or rotation of the pelvis is evidenced by tissue asymmetry, which can be seen and palpated when the subject actively extends either knee. Significant tissue asymmetry is defined as 1.28 cm or greater difference in the prominence of the tissue to either side of the lumbar region at the end of the knee motion.

Initial Position Partial Hook lying

All tests in partial hook lying are initiated from a back lying position in which one lower extremity (LE) is extended while the contralateral LE is positioned in hip and knee flexion and the foot positioned flat on the support surface.

Test: Active hip lateral rotation and abduction in partial hook lying (Figure 2.3). While the examiner palpates the anterior-superior iliac spine on the side opposite the moving LE, the patient actively performs hip abduction and lateral rotation as far as he can and then returns the leg to the starting position.

Impairment: Lumbopelvic rotation in the first 50% of the hip motion. Rotation of the pelvis and lumbar region occurs if, within the first 50% of the available hip abduction-lateral rotation motion, the patient displays 1.28 cm or greater motion of the anterior superior iliac spine contralateral to the moving LE.

Initial Position Prone

All tests in prone are initiated from a face lying position in which the patient's LEs are positioned in neutral adduction-abduction and rotation, arms are positioned at his sides, and the head is positioned in whichever position is most comfortable. The examiner places his hand over the sacrum so that a line through the metacarpophalangeal joints is coincident with the long axis of the sacrum, and the long axis of the hand and sacrum are perpendicular to each other.

Test: Active knee flexion in prone (Figure 2.4). A lower extremity movement in which the patient actively bends each knee separately to 90° of flexion and then returns it to the starting position.

Impairment: Lumbopelvic rotation or anterior pelvic tilt in the first 50% of the knee motion. Using the fingertips of the hand as a visual reference for motion, rotation or anterior tilt of the lumbopelvic region occurs if, within the first 50% of the knee motion, 1.28 cm or greater of motion occurs relative to the starting position.

Test: Active hip rotation in prone (Figure 2.5). A lower extremity movement in which the patient actively laterally rotates each hip separately as far as possible while the knee remains flexed to 90°.

Impairment: Lumbopelvic rotation in the first 50% of the hip motion. Using the fingertips of the hand as a visual reference for motion, rotation of the pelvis and lumbar region occurs if, within the first 50% of the hip motion, 1.28 cm or greater motion occurs relative to the starting position.

Standardized Quadruped Position

A position the patient assumes that includes the following segmental alignments: (1) lumbar region horizontal to supporting surface without lumbar region rotation, pelvic rotation, or lateral pelvic tilt, (2) hip joint angle at 90°, (3) hip joint aligned over knee joint so the hip is in 0° of abduction-adduction, (4) neutral hip rotation, (5) ankles plantar flexed, and (6) shoulders positioned in 90° of flexion. The examiner places a hand on each side of the lumbar region to palpate tissue spanning from the spinous processes to 5.08 cm lateral to either side of the spinous processes.

Test: Active rocking back in quadruped (Figure 2.6). The examiner places a hand around each iliac crest so that the thumbs are pointed toward the midline. A movement then is initiated from the standardized quadruped position, in which the patient flexes his knees, hips, and spine while the hands remain in the starting position, until he is sitting on his heels, resulting in upper extremity flexion.

Impairment: The rate of movement into lumbar flexion is greater than the rate of movement into hip flexion in the first 50% of the rocking back motion. Based on visual information about the lumbar region and hip joint motion during quadruped rocking backward (natural), the subject displays movement toward lumbar flexion in the first 50% of the backward motion.

Figure 2.1 Active forward bend in standing and return from forward bend in standing.

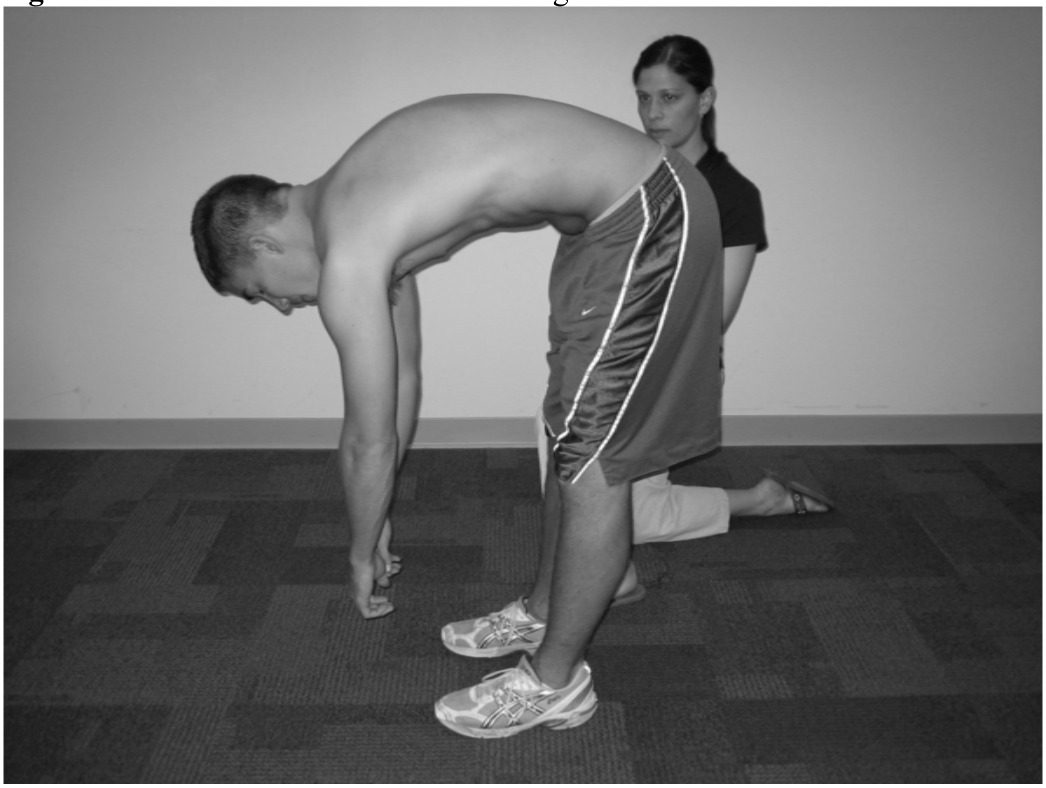

Figure 2.2 Active knee extension in sitting.

Figure 2.3 Active hip lateral rotation and abduction in partial hook lying.

Figure 2.4 Active knee flexion in prone.

Figure 2.5 Active hip rotation in prone.

Figure 2.6 Active rocking back in quadruped.

Chapter 3

Differences in Lumbopelvic Motion between People with and People without Low Back Pain During Two Lower Limb Movement Tests.

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ABSTRACT

Background: Clinical data suggest that active limb movements may be associated with early lumbopelvic motion and increased symptoms in people with low back pain.

Methods: Forty-one people without low back pain who did not play rotation-related sports and 50 people with low back pain who played rotation-related sports were examined. Angular measures of limb movement and lumbopelvic motion were calculated across time during active knee flexion and active hip lateral rotation in prone using a three-dimensional motion capture system. Timing of lumbopelvic motion during the limb movement tests was calculated as the difference in time between the initiation of limb movement and lumbopelvic motion normalized to limb movement time.

Findings: During knee flexion and hip lateral rotation, people with low back pain demonstrated a greater maximal lumbopelvic rotation angle and earlier lumbopelvic rotation, compared to people without low back pain ($P<0.05$).

Interpretation: The data suggest that people with low back pain who play rotation-related sports may move their lumbopelvic region to a greater extent and earlier during lower limb movements than people without low back pain. Because people perform many of their daily activities in early to midranges of joint motion, the lumbopelvic region may move more frequently across the day in people with low back pain. The increased frequency may contribute to increased lumbar region tissue stress and potentially low back pain symptoms. Lower limb movements, therefore, may be important factors related to the development or persistence of low back pain.

Keywords: limb, lumbopelvic motion, low back pain

INTRODUCTION

Limb movements result in forces on the spine and could, therefore, affect the lumbopelvic region. Some investigators have studied the effect of active, voluntary limb movements on the trunk, comparing people with and people without low back pain (LBP). Many of these investigators have focused on postural responses with rapid limb movements in standing, examining anticipatory trunk muscle activity,[3,5,9-12] as well as preparatory trunk and hip movement.[18] Lumbar region and hip joint kinematics have been studied with bending forward in standing and during a few everyday activities in people with and people without LBP.[4,18,20,24,25] The effect of active, voluntary limb movements on lumbopelvic kinematics during standardized limb movement tests, however, has not been extensively studied. These limb movement tests are considered important because clinical data suggest that active limb movements performed during standardized limb movement tests can be associated with (1) early lumbopelvic motion in people with LBP,[23] (2) an increase in LBP symptoms during preferred movement,[31] and (3) a decrease in LBP symptoms[29,33] when lumbopelvic motion is modified during limb movements. In addition, intervention that includes exercise to modify lumbopelvic movement patterns with limb movements appears to contribute to positive short- and long-term outcomes.[8,16,22,35]

Lumbopelvic motion that occurs early during an active, voluntary limb movement is considered to be important because people perform many of their daily activities in early to midranges of joint motion. It has been proposed that, if the lumbopelvic region moves during the early ranges of a limb movement, then the frequency of lumbopelvic motion may be increased across the day. The increased frequency of lumbopelvic motion may contribute to increased tissue stress in the lumbopelvic region,[1] particularly if the lumbopelvic motion is always in the same direction. With time, the increase in stress may contribute to cumulative microtrauma, tissue failure, and the development of LBP symptoms.[1,17] Previously, investigators have reported on differences in timing of lumbopelvic motion between LBP subgroups[28] and between men and women[7] during the active limb movement test of hip lateral rotation in prone. To our knowledge, however, no studies have examined differences in timing of lumbopelvic motion between people with and people without LBP during active, voluntary limb movement tests. Examining differences between people with and people without LBP in timing of lumbopelvic motion may provide insight into the importance of early lumbopelvic motion to the development, persistence, or recurrence of a LBP problem. Furthermore, identifying differences between people with and people without LBP highlights the importance of the previously identified LBP subgroup differences with the test of hip lateral rotation.[7,28]

The purpose of the current study was to examine timing of lumbopelvic motion between people with and people without LBP during two active lower limb movement tests. It was hypothesized that, compared to people without LBP, people with LBP would demonstrate earlier lumbopelvic motion during two active lower limb movement tests performed in prone: knee flexion and hip lateral rotation. Identifying differences in timing of lumbopelvic motion between people with and people without LBP during lower limb movement tests may lead to improved understanding of the factors contributing to LBP and help refine LBP intervention strategies.

METHODS

Subjects

Forty-one subjects without LBP who did not regularly participate in a rotation-related sport and 50 subjects with LBP who regularly (minimum of two times per week) participated in a rotation-related sport were enrolled in the study. Table 3.1 includes subject and LBP-related characteristics of the sample. A rotation-related sport was defined as a sport that required repeated rotation of the trunk and hips to perform most aspects of the activity (e.g. tennis, racquetball). All subjects with LBP associated their symptoms with their sport activity. Subjects were included in the study and assigned to groups based on LBP history and sport participation information provided through a telephone screening process. Subjects were excluded from the study if they verbally reported (1) a history of a spinal fracture or surgery, or (2) a diagnosis by a physician of a spinal deformity, a systemic inflammatory condition, or another serious medical condition. All subjects provided informed consent approved by the Human Research Protection Office of Washington University Medical School prior to participating in the study.

Clinical Measures

Subjects completed self-report measures and participated in a standardized examination based on the Movement System Impairment model of LBP.[21,32,34] The self-report measures included (1) a demographic and LBP history questionnaire, (2) a numeric pain rating scale,[13] (3) the modified Oswestry Disability Index,[6] (4) a racquet sport participation questionnaire, and (5) the Baecke Habitual Activity questionnaire.[2]

Laboratory Measures

Subjects completed the tests of active knee flexion in prone (KF) and active hip lateral rotation in prone (HLR). For KF, the subject was positioned in prone with both lower limbs fully extended and the hips in neutral abduction/adduction and femoral rotation. For HLR, the subject was positioned in prone with both lower limbs in neutral hip abduction/adduction and femoral rotation and the tested lower limb in 90° of knee flexion. When instructed to move, the subject flexed the knee or laterally rotated the hip at a self-selected speed as far as possible and then returned to the initial position. Subjects were given a maximum of 10 seconds to complete each trial. Left and right KF and HLR were performed separately, one time. Kinematic data were collected using a six camera, three-dimensional, motion capture system (EVaRT, Motion Analysis Corporation, Santa Rosa, CA, USA). Reflective markers were placed on landmarks of the trunk, pelvis, and limbs to capture both limb and lumbopelvic motion. The data were collected at a sampling rate of 60 Hz. The static resolution of the motion capture system was 1 mm per cubic meter.

Data Processing

Angular displacement and velocity of movement for the lower leg, thigh, and pelvis were calculated across time. The lower leg segment was defined by a vector from a marker on the lateral knee joint line to a marker on the lateral malleolus. The thigh segment was defined by a vector from a marker on the lateral knee joint line to a marker on the greater trochanter. The transverse plane pelvic segment was defined by a vector from a marker on the right iliac crest to a marker on the left iliac crest. The sagittal plane pelvic segment was defined by a vector from a point at the mid-distance of the right and left iliac crest markers to a marker superficial to the second sacral vertebrae (S2). The knee flexion angle (β) was calculated as the angle between the lower leg segment and a line extending the thigh segment. The hip lateral rotation angle was calculated as the change in angle of the lower leg segment relative to the initial position across time.[7] For both KF and HLR, lumbopelvic rotation (θ) was defined as the change in angle of the transverse plane pelvic segment across time (Figure 3.1). For KF, anterior pelvic tilt (λ) was calculated as the change in angle of the sagittal plane pelvic vector across time (Figure 3.2). Anterior pelvic tilt was not calculated during HLR since expected and observed motion was in the transverse plane. The intraclass correlation coefficients and standard error of the measure for all variables were found to be acceptable. The reliability of measurements from HLR have been previously reported.[7] The reliability statistics for the KF test are reported in Table 3.2.

Motion capture data was filtered using a 4^{th} order, dual pass, butterworth filter with an initial cut-off frequency of 2.5 Hz. After filtering, the start and end points of movement were determined and movement time was calculated. Because subject's were allowed to move at a self-selected speed for each movement test, raw data were filtered at a subject-specific cut-off frequency (fc_{ss})[37] that was calculated by taking the reciprocal of 15% of the period, fc_{ss}=1/.15*(2*movement time).

The start of knee flexion and hip lateral rotation was defined as the point at which angular velocity exceeded 5% of the maximal angular velocity for the lower leg segment. The start of lumbopelvic motion was defined as the point at which angular velocity exceeded 15% of the maximal angular velocity for the pelvic segment. The end of movement for each segment was defined as the point at which the angle reached 99.5% of its maximum.

Dependent Variables

Limb and lumbopelvic kinematics were examined from the start to the maximal angle of the lower limb movement. To index timing of lumbopelvic motion during the limb movement, the difference in time between the start of the limb movement and lumbopelvic motion was calculated. The timing variable was then normalized to limb movement time by dividing the start time difference by the time it took to complete the limb movement.[7,28]

Data Analyses

All statistical analyses were performed with SPSS 15.0 for windows (SPSS Inc., Chicago, IL, USA). Descriptive statistics were calculated for relevant subject characteristics. Chi-square goodness of fit analyses or independent sample t-tests were used to test for differences between groups on relevant subject characteristics. Two-way, repeated measures mixed-model analysis of variance tests were conducted separately on all dependent variables for the KF and HLR tests. The main and interaction effects of group (No LBP, LBP) and side (Right, Left) were examined. Because body mass index (BMI) and velocity of limb movement could potentially affect the dependent variables of interest, analysis of covariance tests were also conducted including BMI and velocity as covariates. The significant group effects remained evident; therefore, the results are reported for the analysis of variance tests only. Because there were no significant interaction effects for any of the dependent variables, data for right and left trials were averaged. If groups did not demonstrate equal variance for a particular dependent variable, an independent samples t-test with equal variances not assumed was conducted. The significance level for all testing was set at $P<0.05$.

RESULTS

There were no differences between people with and people without LBP in sex distribution, age, BMI, or activity level (Table 3.1).

Knee Flexion. Compared to people with LBP, people without LBP demonstrated a greater maximal KF angle. Compared to people without LBP, people with LBP demonstrated a greater maximal lumbopelvic rotation angle and earlier lumbopelvic rotation during KF. There were no differences between groups in magnitude or timing of anterior pelvic tilt during KF (Table 3.3).

Hip Lateral Rotation. There was no difference in maximal hip lateral rotation angle between people with and people without LBP. Compared to people without LBP, people with LBP demonstrated a greater lumbopelvic rotation angle as well as earlier lumbopelvic rotation during HLR (Table 3.3).

DISCUSSION

The purpose of the current study was to examine differences in timing of lumbopelvic motion between people with and people without LBP during two lower limb movement tests. Consistent with our hypotheses, compared to people without LBP who do not regularly participate in rotation-related sports, people with LBP who regularly participate in rotation-related sports demonstrated earlier lumbopelvic motion during KF and HLR. Although we did not hypothesize group differences in lumbopelvic angle during KF or HLR, compared to people without LBP, people with LBP also demonstrated a greater maximal angle of lumbopelvic rotation during both tests.

Lumbopelvic motion that occurs early in the range of an active, voluntary limb movement is considered important because such a finding may provide an index into movement of the lumbopelvic region during everyday activities. Specifically, in people with LBP, these findings suggest that the lumbopelvic region may potentially move more frequently during lower limb movements across the day. Increased frequency of lumbopelvic motion could contribute to increased stress on lumbopelvic region tissues, microtrauma, and eventually LBP.[1,17] The group differences in timing and magnitude of lumbopelvic motion during lower limb movements also suggest that people with LBP may be more mobile in the lumbopelvic region than people without LBP. Increased mobility of the lumbopelvic region has been found to be associated with degeneration of lumbopelvic region tissues.[15] Therefore, the early and increased lumbopelvic motion demonstrated by people with LBP in the current study may be important to the development or persistence of a LBP problem.

Shum et al. compared performance of people with LBP to people without LBP during two different everyday activities: putting on a sock and performing sit to stand. Because of the nature of the activities, the focus was on examining sagittal plane lumbar region and hip joint kinematics and coordination. In both studies, people with LBP demonstrated less lumbar and hip flexion compared to people without LBP during the activity. Interestingly, though, in the study of putting on a sock, motion of the lumbar spine and hip in the transverse and frontal planes was also examined. When compared to people without LBP, people with LBP displayed (1) a greater amount of lumbar spine rotation, and (2) larger peak cross-correlations of lumbar rotation with each of the three hip motions (flexion, lateral rotation, abduction) needed to put on a sock. These findings support our finding of greater lumbar rotation in people with LBP compared to people without LBP when moving the lower limb. Importantly, the findings also suggest that the movement pattern of the lumbopelvic region, i.e., early lumbopelvic rotation, during the two lower limb movement tests in the current study may reflect the movement patterns people with LBP use in everyday activities. In the Shum et al study lumbar rotation was more closely coupled to hip movements needed to put on a sock in people with LBP when compared to people without LBP. Thus, the Shum findings suggest that movement patterns during standardized lower limb movement tests may provide an index of the movement patterns used during everyday activities. It is proposed that the repetition of the lumbopelvic movement patterns used during everyday activities may be important to the development as well as the course of LBP problems.[21]

To our knowledge, only two studies have examined tests in which the intended action is active limb movement with relatively minimal lumbopelvic motion. Van Dillen et al.[28] examined timing of lumbopelvic motion during HLR between two LBP subgroups identified using the Movement System Impairment classification system.[21,34] The majority of subjects in both groups displayed early lumbopelvic rotation during HLR, but people classified into the Rotation with Extension subgroup demonstrated more asymmetrical timing, right versus left, of lumbopelvic motion than people classified into the Rotation LBP subgroup.[28] Gombatto et al[7] examined sex differences in timing of lumbopelvic motion during HLR in a cohort of people with LBP. Compared to women, men with LBP moved through a greater amount of their total lumbopelvic motion during the first 60% of the HLR motion.[7] Although investigating differences in movement between different subgroups of people with LBP is important for refining LBP classifications and interventions for people with LBP, the findings from the two prior studies do not provide information about whether early lumbopelvic motion during a limb movement is a potential contributing factor to LBP. Data from the current study, specifically comparing people with and people without LBP, provide some support for the proposal that early lumbopelvic motion during a limb movement, particularly in the transverse plane, may be relevant to the development or persistence of a LBP problem.

The increased and earlier lumbopelvic motion demonstrated with active limb movements in the current study were specific to motion in the transverse plane. During HLR, it was expected that lumbopelvic motion would occur only in the transverse plane. However, during KF, lumbopelvic motion was expected to occur in both the transverse and sagittal planes. The findings of differences in lumbopelvic motion between people with and people without LBP only in the transverse plane during KF were unexpected. Although we did not hypothesize that the identified differences in lumbopelvic motion would be specific to a particular plane of motion, we do consider such a finding to be important and unique. One might predict that a short or stiff rectus femoris muscle could contribute to pelvic motion in the sagittal plane because the rectus femoris is being stretched across two joints during KF.[14] Although a stiff or short rectus femoris or tensor fascia latae/iliotibial band may also contribute to lumbopelvic motion in the transverse plane, there is no obvious biomechanical explanation for why the lumbopelvic region would move earlier in the transverse plane with knee flexion in the LBP group compared to the group without LBP. The lack of an obvious biomechanically-based explanation, coupled with the early transverse plane motion with two different lower limb movement tests, would suggest that the differences demonstrated in the LBP group may be a result of a learned movement strategy and not just a biomechanical limitation. Such a finding is clinically important because treatment of the early lumbopelvic motion will vary depending on the factors contributing to the identified movement pattern. The current study suggests treatment may require not only stretching of structures that contribute to early movement, but also training to move in the hip or knee while simultaneously limiting movement of the lumbopelvic region during the limb movement.

One potential limitation of the current study is that we examined differences in lumbopelvic motion between people with LBP who perform repeated rotation-related activities and a group of people who do not regularly perform rotation-related activities. It is possible that the early and increased lumbopelvic motion demonstrated by people with LBP who play rotation-related sports is only an adaptation to the sport requirements and does not contribute to the person's LBP problem. However, all LBP subjects included in the current study reported an increase in LBP symptoms associated with their rotation-related sport and during rotation-related tests during the clinical examination.

Additionally, LBP has been reported to be associated with participation in rotation-related sports suggesting the nature of the movements associated with the sport may contribute to the LBP problem.[19,26]

It is unknown whether the findings of the current study would be generalizable to a group of people with LBP who do not regularly perform rotation-related sports. However, it is logical that people who regularly perform other rotation-related activities as part of their leisure-non-sports or work activities may develop similar movement patterns. In support of such a relationship are findings from a secondary analysis of data from people with LBP. In this prior study we found that those who participated in asymmetric leisure activities (sport or leisure non-sport) displayed more rotation-related impairments during a clinical examination than people who participated in symmetric leisure activities. Work-related activities were not examined due to insufficient data.[30] Considering these prior findings and that many everyday activities and jobs require rotation, there may be a significant percentage of people for whom the findings of the current study are relevant. Future studies are necessary to analyze further whether the early lumbopelvic motion during limb movements is found in all people with LBP, regardless of activity.

A second potential limitation is that the generalizability of the data may be limited due to the characteristics of the sample. The LBP group consisted of people with chronic or recurrent LBP who reported a minimal level of disability as indexed by their score on the modified Oswestry Disability Index. It is unknown whether similar results would be found in a group of people with more acute LBP or higher reports of disability. Although we cannot generalize the findings of the current study to a more acute or disabled sample, the people included in the current sample did report an increase in symptoms with rotation-related activities suggesting the excessive or early lumbopelvic motion these people display may be an important contributing factor to the LBP problem regardless of acuity. The sample also was relatively young (range: 18-45 years). Although there is some evidence to suggest that spine mobility decreases with age,[27,36] we have previously reported that age does not appear to affect the prevalence of early lumbopelvic motion demonstrated by people with LBP during clinical tests.[23] It is possible, though, that age could influence the variables reported on in the current study. Future research examining timing of lumbopelvic motion in people with a variety of acuity levels and ages is warranted.

A third potential limitation is the design of the study. Because the study design is cross-sectional, it is unknown whether people in the LBP subgroup developed LBP as a result of the early and increased lumbopelvic motion demonstrated with limb movements, or if the early and increased lumbopelvic motion is a result of the LBP problem. Regardless of the causal relationship, we consider the current findings to be important. Clinical data suggests that altering the lumbopelvic motion demonstrated during limb movements results in decreased LBP symptoms.[16,29,33,35] Thus, regardless of whether the early lumbopelvic rotation we have identified caused the initial LBP problem, the early and increased lumbopelvic motion identified in the current study may contribute to the persistence or recurrence of a LBP problem.

CONCLUSION

The current findings suggest that a greater magnitude of and earlier lumbopelvic motion in the transverse plane during lower limb movements may be important factors contributing to the development or persistence of a LBP problem in people who regularly participate in rotation-related sports. Future work should focus on identifying (1) the factors that contribute to the increased and earlier lumbopelvic motion identified in people with LBP in the current study and (2) whether similar movement patterns are identified in people with LBP who do not participate in rotation-related sports. Identifying contributing factors to examination findings will help to better direct examination and specify interventions for people with LBP.

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Table 3.1 Subject characteristics.

	People without LBP (N=41)	**People with LBP** (N=50)	**95% Confidence Intervals of the Mean Difference**	**Statistical Value, Degrees of Freedom (df), *P*-value**
Sex	M=22, F=19	M=32, F=18	NA	$X^2=0.318$, df=1, $P=0.392$
Age (y)	27.9 (7.4)	28.2 (8.1)	-3.62 - 2.92	$t=-0.208$, df=89, $P=0.836$
Body mass index (kg/m^2)	23.3 (2.8)	24.8 (3.5)	-2.33 - 0.015	$t=-1.961$, df=88, $P=0.053$
Baecke Habitual Activity Questionnaire (3-15)	8.1 (1.3)	8.3 (0.7)	-0.28-0.64	$t=0.783$, df=60.1, $P=0.437$
Modified Oswestry Disability Index (0-100 %)	NA	14.6 (7.6)	NA	NA
Current pain score (0-10)	NA	2.9 (1.7)	NA	NA
Duration of LBP (y)	NA	6.5 (5.4)	NA	NA
Number of acute flare-ups in previous 12 months	NA	7.1 (3.8)	NA	NA

Abbreviation: LBP, low back pain
Values expressed as mean (standard deviation)

Table 3.2 Standard error of the measure and ICC values for variables calculated during right and left knee flexion in prone.

Test Movement	Standard Error of the Measure*	ICC Value
Knee flexion in prone		
Left knee flexion	2.2	0.96
Left lumbopelvic rotation	0.6	0.78
Left anterior pelvic tilt	0.5	0.94
Right knee flexion	2.0	0.96
Right lumbopelvic rotation	0.7	0.70
Right anterior pelvic tilt	0.6	0.91

* Values expressed in degrees

Table 3.3 Means, standard deviations, mean differences, confidence intervals and statistical values for timing and magnitude of knee flexion and hip lateral rotation variables for people with and people without low back pain (LBP).

	People without LBP	**People with LBP**	**Mean Difference**	**95% Confidence Intervals of the Mean Difference**	**Statistical Values, Degrees of Freedom (df), *P*-value**
Knee Flexion Test					
Maximal knee flexion angle	119.95 (9.31)	114.28 (8.60)	5.67 (4.73%)	1.92-9.43	*F*=9.010, df=1, *P*=0.003
Average knee flexion velocity	66.90 (23.36)	60.50 (20.66)	6.40 (9.57%)	-2.82-15.62	*F*=1.901, df=1, *P*=0.171
Maximal lumbopelvic rotation angle	2.32 (1.48)	3.24 (1.73)	0.92 (39.66%)	0.23-1.60	*F*=7.096, df=1, *P*=0.009
Maximal anterior pelvic tilt angle	3.31 (1.90)	3.40 (1.95)	0.08 (2.41%)	-0.72-0.89	*F*=0.041, df=1, *P*=0.840
Timing of lumbopelvic rotation	0.39 (0.33)	0.26 (0.22)	0.13 (33.33%)	0.02-0.25	*t*=2.228, df=66, *P*=0.029
Timing of anterior pelvic tilt	0.26 (0.29)	0.25 (0.21)	0.01 (3.85%)	-0.10-0.10	*F*=0.005, df=1, *P*=0.941
Hip Lateral Rotation Test					
Maximal hip lateral rotation angle	41.59 (6.62)	44.28 (6.38)	2.69 (6.47%)	-0.03-5.40	*F*=3.867, df=1, *P*=0.052
Average hip lateral rotation velocity	23.54 (8.15)	21.40 (8.82)	2.14 (9.09%)	-1.43-5.71	*F*=1.415, df=1, *P*=0.237
Maximal lumbopelvic rotation angle	4.47 (2.55)	5.85 (2.99)	1.38 (30.87%)	0.20-2.55	*F*=5.445, df=1, *P*=0.022
Timing of lumbopelvic rotation	0.31 (0.26)	0.19 (0.14)	0.12 (38.71%)	0.03-0.21	*t*=2.561, df=60, *P*=0.013

Values expressed as mean (standard deviation)

Figure 3.1 Kinematic model with lumbopelvic rotation (θ) calculation. IC = iliac crest.

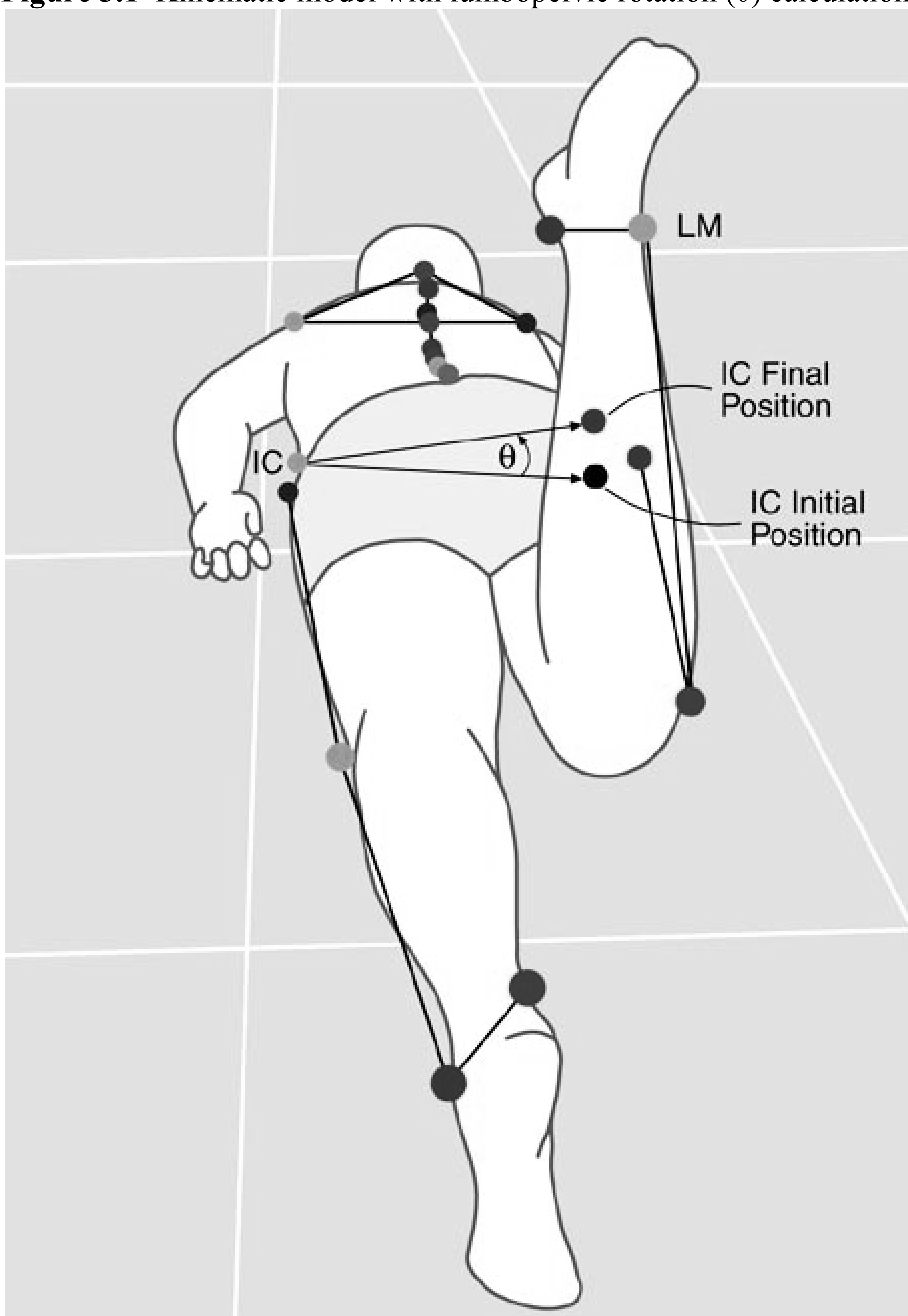
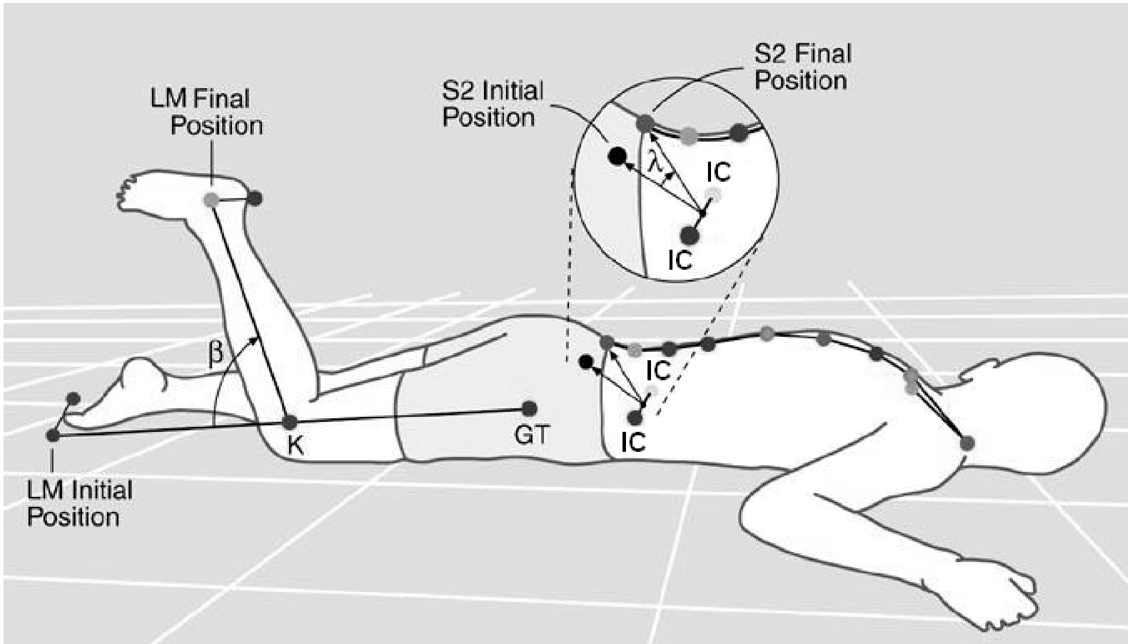


Figure 3.2 Kinematic model with calculations for knee flexion (β) and anterior pelvic tilt (λ). LM = lateral malleolus, K = lateral knee joint line, GT = greater trochanter, IC = iliac crest.



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Chapter 4

The relationship between lumbopelvic motion during a passive and active limb movement in people with and people without low back pain

In Review: Scholtes SA, Norton BJ, Gombatto SP, Van Dillen LR. The relationship between lumbopelvic motion during a passive and active limb movement in people with and people without low back pain. *J Orthop Sports Phys Ther.*

ABSTRACT

Study Design: Cross-sectional, observational study

Objectives: To examine the relationship between lumbopelvic motion during *passive* and *active* hip lateral rotation (HLR) in people with and people without low back pain (LBP).

Background: Clinical observation suggests that the pattern of lumbopelvic motion observed during *passive* HLR is similar to the pattern of lumbopelvic motion observed during *active* HLR.

Methods: Kinematic data were collected while *active* and *passive* HLR were performed in prone. Bivariate correlations were calculated to examine relationships between the amount of *active* HLR completed prior to the start of lumbopelvic motion and (1) the amount of *passive* HLR completed prior to the start of lumbopelvic motion, and (2) a number of other variables of interest. Variables that were correlated significantly ($P<0.05$) were entered into a hierarchical multiple regression analysis.

Results: *People with LBP:* Both the amount of *passive* HLR completed prior to the start of lumbopelvic motion (r=0.834, $P<0.001$) and gender (r=0.786, $P<0.001$) were correlated with the amount of HLR completed prior to the start of lumbopelvic motion during *active* HLR. Together the amount of *passive* HLR completed prior to the start of lumbopelvic motion and gender explained 80% ($P<0.001$) of variance in the amount of *active* HLR completed prior to the start of lumbopelvic motion. *People without LBP:* There were no significant correlations between any of the variables examined.

Conclusion: People with LBP demonstrated a relationship between lumbopelvic motion during *passive* and *active* HLR; people without LBP do not demonstrate the relationship.

These findings suggest that the neural system may not compensate as well for the non-contractile elements of the musculoskeletal system or gender-specific characteristics evident during a passive movement.

Key Words: hip lateral rotation, spine, trunk, gender

INTRODUCTION

Assessments of both *passive* and *active* movements typically are included in examinations of people with musculoskeletal pain problems.[18] *Passive* movements often are included to assess structural abnormalities, tissue characteristics, end-range extensibility of a joint, pain, and radicular symptoms.[7,14] Assessment of active movements often are included to provide additional information about muscle activation, force generation, and coordination of movement, as well as, symptom behavior during active movements.[25]

Assessments of *active* and *passive* movements are part of the standardized examination for people with low back pain (LBP) based on the Movement System Impairment (MSI) model.[27,34] Trunk movement tests are included for the obvious purpose of assessing trunk movements. By contrast, the primary reason for including limb movement tests is to assess the effect of limb movement on the lumbopelvic region. In the MSI examination, the limb is moved passively before the patient performs the same movement actively. The *passive* movement is performed to (1) demonstrate to the patient what he will be asked to perform, (2) provide the clinician with information about end-range extensibility of the joint of interest, and (3) provide the clinician with information about how the passive movement affects the lumbopelvic region. Next, the patient is asked to perform the same movement actively. During the *active* movement, the examiner observes the amount and timing of limb and lumbopelvic motion. Of primary interest during assessment of a limb movement is *when* in the test movement lumbopelvic motion begins. Sahrmann has proposed that lumbopelvic motion that begins soon after the start of a movement is evidence of a relative flexibility issue.

Relative flexibility is described as the tendency of one or more segments to move more readily than other, adjacent segments during a movement.[27] Relative flexibility is proposed to occur because of variations in stiffness of adjacent segments. For example, if the lumbopelvic region were less stiff than the hip, then the lumbopelvic region would be more likely to move early during a hip movement. Relative flexibility is considered important because many daily activities occur in the early to mid ranges of motion rather than end ranges of motion. If lumbopelvic motion begins soon after the start of a limb movement, then the lumbopelvic region may move each time the limb moves across the day. The increased frequency of lumbopelvic motion may contribute to an increase in lumbopelvic region tissue stress, microtrauma, and ultimately, LBP.[23,24]

Of particular interest to the current work is the clinical observation that when a limb is moved passively, the lumbopelvic region also moves. In addition, the pattern of lumbopelvic motion observed during a *passive* limb movement appears to be similar to the pattern of lumbopelvic motion observed during the *active* limb movement. To date, however, the relationship between lumbopelvic motion demonstrated during *passive* and *active* limb movement tests has not been investigated. Furthermore, because our previous observations are based on examining people with LBP, we do not know whether the potential relationship between lumbopelvic motion during a *passive* and *active* limb movement is unique to people with LBP, or whether people without LBP also demonstrate a similar relationship.

The primary purpose of the current study was to examine the relationship between lumbopelvic motion demonstrated during a *passive* and an *active* version of a limb movement test in people with and people without LBP. The movement test examined in this study was hip lateral rotation (HLR) performed in prone because (1) HLR provokes symptoms in many people with LBP,[10,33] and (2) lumbopelvic motion demonstrated during *active* HLR is different between people with and people without LBP.[29] We hypothesized that how soon the lumbopelvic region began to move during *passive* HLR would be related to how soon the lumbopelvic region began to move during *active* HLR. A secondary purpose of the current study was to examine the relationship between how soon the lumbopelvic region began to move during *active* HLR and a number of different subject characteristics, clinical findings, and laboratory findings. Because prior data suggest gender differences in lumbopelvic motion during *active* limb movements in people with LBP,[10,28,30] we hypothesized that gender would be related to how soon the lumbopelvic region began to move during *active* HLR. Identifying factors related to how soon the lumbopelvic region begins to move during *active* HLR may provide insight regarding (1) questionnaires or clinical test items that may be important to assess in people with LBP, and (2) intervention strategies that may be important to consider when addressing lumbopelvic motion during limb movements.

METHODS

Subjects

Nineteen subjects with LBP and 20 subjects without LBP were included in the current study. All subjects were recruited from community and clinic sources. People were included in the LBP group if they reported having chronic or recurrent[37] LBP for a minimum of 6 months. People were excluded from the group without LBP if they reported having experienced LBP that limited activities of daily living for greater than 3 days or for which they sought medical attention. Potential subjects were excluded from the study if they reported having (1) a height and weight that was consistent with a body mass index (BMI) greater than 30, (2) a hip or knee injury that limited activities of daily living, (3) a history of a spinal fracture or surgery, or (4) a diagnosis by a physician of a structural deformity of the spine, systemic inflammatory condition, or other serious medical condition that could affect movement (e.g., Parkinson's disease). Prior to participation in the study, all subjects read and signed an informed consent approved by the Human Research Protection Office of Washington University School of Medicine.

Clinical Measures

All subjects completed self-report surveys and clinical tests.

Self-report questionnaires

All subjects completed 2 questionnaires: (1) a demographic and LBP history questionnaire, and (2) the Baecke Habitual Activity Questionnaire.[1] Subjects with LBP also completed a modified Oswestry Disability Index[8] and provided a current pain score using the verbal numeric pain rating scale.[19]

Clinical tests

Right and left passive HLR were measured with the subject in prone with the knee flexed to 90°. To minimize pelvic motion during HLR, the subject's pelvis was stabilized with a belt and the assistance of a second tester. An inclinometer was placed superior to the lateral malleolus to measure the position of the tibia at start and end of HLR. Hip lateral rotation range of motion was calculated as the difference between the start and end values. Right and left femoral anteversion was measured with the subject in prone, the pelvis stabilized as described above, and the knee flexed to 90°. The tested hip was rotated medially and laterally until the tester determined the position of rotation at which the greater trochanter was most prominent laterally.[26] A goniometer was then used to measure the position of the tibia relative to vertical. The stationary arm of the goniometer was aligned vertically; the moving arm was aligned with a line from the tibial tuberosity to the midpoint of the malleoli. Generalized joint hypermobility was tested using the Beighton Hypermobility Scale. The scale includes a number of tests that examine flexibility of different segments including the hands, elbows, spine, and knees.[3]

Laboratory Measures

Kinematic data

Subjects participated in *active* and *passive* HLR trials. For all trials, subjects were prone. The tested lower limb was positioned with the knee flexed to 90° and with the hip in neutral abduction/adduction and 5° of medial rotation. The non-tested lower limb was positioned in full hip and knee extension. The tester supported the tested limb in the start position prior to the start of each trial to allow the subject to relax. For *active* HLR, the subject was instructed to bring the foot in as far as possible (i.e., lateral rotation) and then return the foot to the start position (i.e., medial rotation). While giving the instructions prior to the first trial, the tester rotated the tested hip a few degrees to provide the subject with information about the desired direction of motion. Subjects were allowed to move at a self-selected speed. For *passive* HLR, the subject was asked to relax as the tester laterally rotated the hip as far as possible before returning the hip to the start position. End of motion during the *passive* trials was defined as the point in the range at which either (1) the tester was unable to rotate the hip any further, or (2) the tibia of the tested limb came in contact with the non-tested limb. The pelvis was not stabilized to prevent motion during *active* or *passive* HLR trials. *Active* HLR trials were completed prior to *passive* HLR trials so that subject's *active* HLR performance would not be affected by the fact the hip had been moved passively. Five trials of HLR were performed with the right and left hip separately for both the *active* and *passive* conditions.

Electromyographic data

Electromyographic (EMG) data were collected from select trunk and limb muscles to assess activity during the *passive* trials. Surface electrodes with an inter-electrode distance of 2.22 centimeters were used. Muscle activity was recorded bilaterally from the following muscles: latissimus dorsi,[20] lumbar erector spinae,[22] multifidus,[6] rectus abdominus,[22] internal oblique,[22] external oblique, and lateral hamstrings.[5] Subjects were instructed to remain relaxed throughout the trial, but muscle activity was not assessed until data were being processed.

Data Processing

Kinematic data

Methods for kinematic data processing have been described previously.[29] Briefly, kinematic data were collected using a 6-camera motion capture system (EVaRT, Motion Analysis Corporation, Santa Rosa, CA, USA). Data from reflective markers placed over landmarks of the trunk, pelvis, and limbs were used to calculate angular displacement and velocity of limb and lumbopelvic region movement across time. Hip lateral rotation was indexed using a lower limb vector defined by markers placed superficial to the lateral malleolus and the lateral knee joint line. Lumbopelvic rotation was indexed using a pelvic vector defined by markers placed superficial to the right and left posterior superior iliac spines (Figure 4.1). Spine length was defined as the distance from a marker superficial to the 7th cervical vertebrae to the midpoint between the markers placed superficial to the posterior superior iliac spines. Shank length was defined as the distance from a marker superficial to knee joint line to a marker superficial to the lateral malleolus.

The start of HLR was defined as the point at which angular velocity of the lower leg vector exceeded 5% of the maximal angular velocity during the trial. The start of lumbopelvic rotation was defined as the point at which angular velocity of the pelvic vector exceeded 10% of the maximal angular velocity. The end of movement for HLR and lumbopelvic rotation was defined as the point at which 99.5% of the maximal angle had been achieved. Kinematic data for hip and lumbopelvic motion were examined from the start of HLR to the end of HLR. Start of lumbopelvic motion during HLR was indexed by the amount of HLR completed prior to the start of lumbopelvic motion.

Electromyographic data

Using a Myosystem 1400A (Noraxon, Inc., Scottsdale, AZ, USA), EMG data were sampled at a rate of 1200 Hz with a 12-bit analog to digital conversion and bandpass filtered at 10-500 Hz. During data processing, EMG data were full-wave rectified. Baseline EMG activity was obtained during the first 50ms of each trial. A muscle was considered active during the *passive* HLR motion if EMG activity exceeded 3 standard deviations above the baseline EMG.[16,17] Trials were eliminated from the data set if any of the muscles were active during the *passive* movement. Four subjects with LBP were eliminated from the final data set due to muscle activity detected during all right and left *passive* trials. The final data set included 20 subjects without LBP and 15 subjects with LBP. Table 4.1 summarizes characteristics of the final sample.

Data Analyses

SPSS 15.0 for Windows (SPSS Inc., Chicago, IL, USA) was used to perform all statistical analyses. Chi-square goodness of fit analyses and independent samples t-tests were used to test for differences between people with and people without LBP on relevant subject characteristics, clinical findings, and laboratory findings. Correlational and hierarchical multiple regression analyses were performed separately for each group.

Correlational analyses

Because of the interest in variables that potentially might be related to lumbopelvic motion during *active* HLR, Pearson product-moment correlation coefficients were calculated. The amount of HLR completed prior to the start of lumbopelvic motion during *active* HLR was correlated with (1) the amount of HLR completed prior to the start of lumbopelvic motion during *passive* HLR, and (2) different subject characteristics, clinical findings, and laboratory findings including age, weight, height, spine length, shank length, passive HLR range of motion with the pelvis stabilized, femoral anteversion, and generalized joint hypermobility. Pearson product-moment correlation coefficients also were calculated between any variables that were significantly correlated with the amount of HLR completed prior to the start of lumbopelvic motion during *active* HLR. When appropriate, a principal components analysis was conducted to reduce the number of variables included in the hierarchical multiple regression analysis.

Multiple regression analysis

The criterion variable was the amount of HLR completed prior to the start of lumbopelvic motion during *active* HLR. Variables that were correlated significantly ($P<0.05$) with the criterion variable were included in the hierarchical multiple regression analysis. The order of variable entry was based on theoretical importance.

RESULTS

There were no differences between people with and people without LBP in gender distribution, age, weight, height, spine length, shank length, passive HLR range of motion with the pelvis stabilized, femoral anteversion, or generalized joint hypermobility (Table 4.1). The only movement variable for which there was a difference between people with and people without LBP was the laboratory measure of end range of passive HLR without the pelvis stabilized. Compared to people with LBP, people without LBP demonstrated a greater amount of passive HLR (Table 4.2).

People with LBP

Correlational analyses. There was a significant correlation between the criterion variable, the amount of HLR completed prior to the start of lumbopelvic motion during *active* HLR, and (1) amount of HLR completed prior to the start of lumbopelvic motion during *passive* HLR (Figure 4.2), (2) gender, (3) height, (4) spine length, and (5) shank length. None of the correlation coefficients between the criterion variable and any other variables were significant (Table 4.3). The amount of HLR completed prior to the start of lumbopelvic motion during passive HLR was significantly correlated with gender ($r=0.663$, $P=0.007$), but not with height, spine length, or shank length ($r<0.500$, $P>0.080$ for all correlations). Gender was correlated significantly with height, spine length, and shank length ($r>0.600$, $P<0.010$ for all correlations). Height, spine length, and shank length were all correlated significantly with each other ($r>0.600$, $P<0.001$ for all correlations). Because height, spine length, and shank length were all significantly correlated with the criterion variable and with each other, a principal components analysis was conducted. The principal components analysis resulted in one factor that represented vertical anthropometrics. The factor was included in the multiple regression analysis.

Multiple regression analysis. Variables were entered into the regression analysis in the following order: (1) amount of HLR completed prior to the start of lumbopelvic motion during *passive* HLR, (2) gender, and (3) the vertical anthropometric factor. The amount of HLR completed prior to the start of lumbopelvic motion during *passive* HLR was entered into the regression analysis first because our primary purpose was to examine the relationship between lumbopelvic motion demonstrated during *active* and *passive* HLR. The amount of HLR completed prior to the start of lumbopelvic motion during *passive* HLR explained 69.5% of the variance in the criterion variable; gender explained an additional 9.7% of the variance in the criterion variable. The vertical anthropometric factor explained an additional 1.1% of the variance, however, this increment was not significant (Table 4.4).

People without LBP

There were no significant correlations between the criterion variable, and any of the subject characteristics, clinical findings, or laboratory findings (Table 4.3). A multiple regression analysis, therefore, was not performed on the data for people without LBP. Figure 4.3 illustrates the relationship between lumbopelvic motion demonstrated during *passive* and *active* HLR in people without LBP.

DISCUSSION

Lumbopelvic motion that begins soon after the start of an *active* limb movement is thought to be important because of its potential contribution to increased frequency of lumbopelvic motion across the day, tissue stress, and potentially LBP symptoms. Clinical observation suggests that the pattern of lumbopelvic motion observed during a *passive* movement is similar to the pattern of lumbopelvic motion observed during an *active* movement. The primary purpose of the current study, therefore, was to examine the relationship between lumbopelvic motion during *passive* and *active* HLR. Consistent with our hypothesis, how soon the lumbopelvic region moved during *passive* HLR was related to how soon the lumbopelvic region moved during *active* HLR in people with LBP; if the lumbopelvic region moved soon after the start of *passive* HLR then the lumbopelvic region moved soon after the start of *active* HLR. In people without LBP, there was no relationship between lumbopelvic motion during *active* and *passive* HLR.

Many factors, including musculoskeletal and neural factors, may contribute to how a person moves actively. The current study focused on how a number of factors were related to lumbopelvic motion during *active* HLR. One factor of interest was relative flexibility observed during a passive movement. Sahrmann has described relative flexibility as the tendency of one or more segments to move more readily than other, adjacent segments during a movement.[27] Relative flexibility is proposed to occur because of variation in stiffness at adjacent segments. Relative flexibility has been examined in people with LBP,[10,29,32,34-36] but only during active movements. During an *active* movement, both musculoskeletal and neural factors may contribute to the observed movement pattern; during a passive movement, only musculoskeletal factors may contribute to the observed movement pattern. Thus, in an attempt to disentangle the impact of musculoskeletal and neural factors, we examined both *passive* and *active* versions of a limb movement test.

During a passive movement, non-contractile elements of the musculoskeletal system (e.g. tendon, connective tissue) may affect how soon the lumbopelvic region begins to move. If one segment is less stiff than an adjacent segment, then the less stiff segment may move earlier during the movement than the stiffer segment.[27] For example, if the lumbopelvic region is less stiff than the hip, then the lumbopelvic region would begin to rotate soon after the start of HLR. If the lumbopelvic region and hip were equally stiff, then the hip would move through its full rotation range of motion before the lumbopelvic region would rotate.

During an *active* movement, the effects of the neural system will interact with the non-contractile elements of the musculoskeletal system. For example, activation of trunk musculature may result in a movement pattern during *active* HLR that is different from the pattern observed during *passive* HLR. During *active* HLR, a person may compensate for a hip that is stiffer than the lumbopelvic region by activating the trunk muscles to stabilize the lumbopelvic region. A person who compensates for the stiffer hip would demonstrate no lumbopelvic rotation or lumbopelvic rotation that begins near the end of the *active* HLR motion despite demonstrating lumbopelvic rotation that began soon after the start of *passive* HLR. A person may also demonstrate lumbopelvic motion that occurs sooner during *active* HLR than during *passive* HLR. Lumbopelvic motion may occur sooner during *active* HLR if the person activates the trunk muscles that rotate the lumbopelvic region in the same direction as the rotation of the hip, rather than stabilize the lumbopelvic region as the hip rotates. It is also possible that the neural system will not affect the movement pattern observed during the passive movement. If the person does not activate the trunk muscles to rotate or stabilize the lumbopelvic region during *active* HLR, then there will be no difference in how soon the lumbopelvic region moves during the *passive* or *active* the limb movement. Therefore, assessment of lumbopelvic motion during both *passive* and *active* movement may provide important information. Assessment of *passive* movement may provide information about the contribution of non-contractile elements of the musculoskeletal system to an observed movement pattern. Assessment of *active* movement may provide information about how the neural system compensates for, or contributes to the movement pattern observed during a *passive* movement.

In the current study, people with and people without LBP demonstrated lumbopelvic motion that began soon after the start of *passive* HLR. However, only the LBP group demonstrated a relationship between lumbopelvic motion demonstrated during *active* and *passive* HLR. Such findings might suggest that, the neural system does not compensate for the non-contractile elements of the musculoskeletal system in people with LBP. In people without LBP, the contribution of the neural system appears to be more variable; some, but not all people without LBP compensate for the non-contractile elements of the musculoskeletal system. Examination of why people with LBP do not demonstrate compensatory strategies during an active movement may provide information about what factors contribute to a LBP problem.

The current study is the first to provide preliminary information about (1) how non-contractile elements of the musculoskeletal system may contribute to lumbopelvic motion observed during an *active* limb movement and (2) how this contribution may differ between people with and people without LBP. Investigators have examined passive tissue characteristics of people with LBP,[2,11,13,15,21,31] but, to our knowledge, no one has investigated whether (1) there are differences in characteristics of non-contractile elements between adjacent segments (2) whether a difference in characteristics of non-contractile elements between segments is related to *active* movement, or (3) how the neural system compensates for characteristics of non-contractile elements of the musculoskeletal system. Further examination of non-contactile elements at adjacent segments would be beneficial for understanding lumbopelvic region movement patterns during *passive,* and, in some cases, *active* limb movements. Additional information about the factors that contribute to movement patterns observed during *passive* and *active* movement could improve the design of intervention for people with LBP. For example, it may be beneficial to (1) stretch the stiffer segment, or (2) train the patient to increase activation of trunk muscles to stabilize the lumbopelvic region during an *active* movement.

The second purpose of the current study was to examine the relationship between lumbopelvic motion during *active* HLR and a number of other variables. In people with LBP, gender, height, spine length, and shank length were correlated significantly with lumbopelvic motion during *active* HLR. Gender explained an additional 9.7% of the variance in lumbopelvic motion during *active* HLR beyond the variance explained by lumbopelvic motion during *passive* HLR. When these two variables were taken into account, vertical anthropometrics did not account for a significant increase in the variance in lumbopelvic motion during *active* HLR. In people without LBP, there were no relationships between lumbopelvic motion during *active* HLR and any of the variables of interest.

We expected a relationship between gender and how soon the lumbopelvic region began to move during *active* HLR. In prior studies, it has been reported that, compared to women, men demonstrate (1) earlier movement of the lumbopelvic region during limb movement tests,[10,28,30] and (2) greater passive and active stiffness of the lower limbs.[4,9,12] The gender differences in lumbopelvic motion and stiffness, however, were not all specific to people with LBP. Therefore, we did not expect the relationship between gender and lumbopelvic motion during *active* HLR to be significant only for people with LBP. People with LBP may not compensate during an *active* movement for gender specific characteristics that may be important to the development or persistence of a LBP problem.

One limitation of the current study is that we did not measure passive or active stiffness of the lumbopelvic region or hips. Relative flexibility is proposed to be a result of variations in stiffness of adjacent segments. Measurement of stiffness of the lumbopelvic region and adjacent segments would provide important information about the potential role of stiffness to relative flexibility. The current study suggests that further exploration of the mechanisms contributing to relative flexibility is indicated.

A second potential limitation of the current study is that we examined only one limb movement test. Thus, the results reported here may not represent a global relationship between findings during *passive* and *active* movement tests. Future studies could examine whether the relationships identified in the current study are replicated with other limb movement tests.

A third potential limitation is that we did not monitor all muscles that potentially could be active during the *passive* HLR test. Because we used surface EMG, we were unable to monitor all muscles of the hip and spine. It is possible that the relationship between *passive* and *active* HLR demonstrated by people with LBP was due to muscle activity (e.g. tensor fascia latae, iliopsoas) during the *passive* trials demonstrated by people with LBP, but not people without LBP.

CONCLUSION

The findings of the current study suggest that both the pattern of lumbopelvic motion demonstrated during *passive* HLR and gender are related to the pattern of lumbopelvic motion demonstrated during *active* HLR in people with LBP but not in people without LBP. These findings might suggest that the neural system in people with LBP does not compensate for the non-contractile elements of the musculoskeletal system evident during a *passive* movement or gender-specific characteristics. Understanding the factors that contribute to lumbopelvic motion during a limb movement may enhance intervention for people with LBP.

KEY POINTS

Findings: The pattern of lumbopelvic motion demonstrated during *passive* HLR and gender are related to the pattern of lumbopelvic motion demonstrated during *active* HLR in people with LBP, but not people without LBP.

Implications: In people with LBP, the neural system may not compensate for the non-contractile elements of the musculoskeletal system evident during a passive movement or gender-specific characteristics.

Caution: The findings of the current study are specific to one limb movement test, hip lateral rotation performed in prone.

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Table 4.1 Subject characteristics

	People with LBP (N=15)	**People without LBP** (N=20)	**Statistical Value, Degrees of Freedom, *P*-value**
Gender	M=7, F=8	M=10, F=10	X^2=0.038, df=1, *P*=0.845
Age (years)	28.1 (7.2)	26.5 (5.9)	*t*=0.730, df=33, *P*=0.471
Weight (kg)	74.1 (10.1)	72.6 (7.6)	*t*=0.481, df=33, *P*=0.634
Height (cm)	173.5(10.9)	171.4 (9.4)	*t*=0.631, df=33, *P*=0.532
Body mass index (kg/m^2)	24.8 (3.0)	24.9 (2.8)	*t*=0.049, df=33, *P*=0.962
Spine length (cm)	48.1 (3.6)	46.8 (2.8)	*t*=1.132, df=33, *P*=0.266
Shank length (cm)	38.7 (3.1)	38.1 (3.1)	*t*=0.885, df=33, *P*=0.564
Passive hip lateral rotation[*] (degrees)	45.4 (10.0)	49.1 (7.2)	*t*=1.290, df=33, *P*=0.206
Femoral anteversion (degrees)	11.3 (5.5)	11.4 (5.5)	*t*=0.047, df=33, *P*=0.963
Generalized join hypermobility[†] (0-9)	2.2 (3.2)	2.1 (2.5)	*t*=0.156, df=33, *P*=0.877
Current pain score[‡] (0-10)	2.0 (1.2)	NA	NA
Duration of LBP (years)	6.8 (3.3)	NA	NA
Modified Oswestry Disability Index[§] (0-100 %)	13.5 (9.5)	NA	NA
Number of acute flare-ups[‖] in previous 12 months	5.8 (4.3)	NA	NA

Abbreviation: LBP, low back pain
Values expressed as mean (standard deviation)
[*] Passive hip lateral rotation with pelvis stabilized, measured with inclinometer
[†] Generalized joint hypermobility measured with Beighton Hypermobility Scale[3]
[‡] Pain measured using a verbal numeric pain rating scale[19]
[§] Disability measured using Modified Oswestry Disability Index[8]
[‖] A flare-up is defined as a period (usually a week or less) when back pain is markedly more severe than usual[37]

Table 4.2 Means, standard deviations, and statistical values for variables calculated during active and passive hip lateral rotation.

Variable	**People with LBP**	**People without LBP**	**Statistical Values, Degrees of Freedom, *P*-value**
Active Condition			
Maximal HLR angle	44.4 (8.2)	48.9 (6.7)	*t*=1.782, df=33, *P*=0.084
Maximal lumbopelvic rotation angle	8.1 (3.4)	8.0 (2.8)	*t*=0.066, df=33, *P*=0.947
HLR angle at start of lumbopelvic rotation	4.7 (3.6)	6.8 (4.0)	*t*=1.585, df=33, *P*=0.122
Passive Condition			
Maximal HLR angle	52.3 (7.2)	57.1 (4.9)	*t*=2.337, df=33, ***P*=0.026**
Maximal lumbopelvic rotation angle	9.7 (2.5)	9.7 (2.5)	*t*=0.004, df=33, *P*=0.997
HLR angle at start of lumbopelvic rotation	3.7 (7.1)	4.8 (4.6)	*t*=0.600, df=33, *P*=0.552

Abbreviations: LBP, low back pain; HLR, hip lateral rotation
All values expressed in degrees, mean (standard deviation)
Significant group differences indicated in bold-face type

Table 4.3 Pearson product-moment correlations between the amount of hip lateral rotation completed prior to the start of active hip lateral rotation and subject characteristics, clinical findings, and laboratory findings.

	Angle of HLR at start of lumbopelvic motion during active HLR			
	People with LBP		**People without LBP**	
	Correlations[a]	***P*-value**	**Correlations[a]**	***P*-value**
Gender	**0.786**	**<0.001**	0.161	0.497
Age	-0.490	0.064	0.071	0.766
Weight	-0.284	0.304	-0.208	0.380
Height	**-0.662**	**0.007**	-0.209	0.376
Spine length	**-0.565**	**0.028**	-0.165	0.487
Shank length	**-0.597**	**0.019**	0.392	0.087
Passive hip lateral rotation†	-0.191	0.494	-0.126	0.597
Femoral anteversion	0.384	0.195	0.232	0.324
Generalized joint hypermobility	0.149	0.595	0.141	0.554
Angle of HLR at start of lumbopelvic rotation during passive HLR	**0.834**	**<0.001**	0.391	0.088

Abbreviations: LBP, low back pain; HLR, hip lateral rotation
Significant correlations indicated in bold-face type
* Pearson Product-Moment Correlations
† Passive hip lateral rotation with pelvis stabilized, measured with inclinometer

Table 4.4 Hierarchical multiple regression analysis results for people with low back pain.

	Criterion Variable Angle of HLR at start of lumbopelvic motion during active HLR	
Predictor Variables	**R^2 Change**	***P*-Value**
Angle of HLR at start of lumbopelvic motion during passive HLR	0.695	**<0.001**
Gender	0.097	**0.036**
Vertical anthropometric factor from principal components analysis	0.011	0.444
Total R^2	0.803	**<0.001**

Abbreviations: HLR, hip lateral rotation
Significant R^2 change indicated in bold-face type

Figure 4.1 Kinematic model with hip lateral rotation (β) and lumbopelvic rotation (θ) calculations. LM: lateral malleolus, K: knee, PSIS: posterior superior iliac spine.

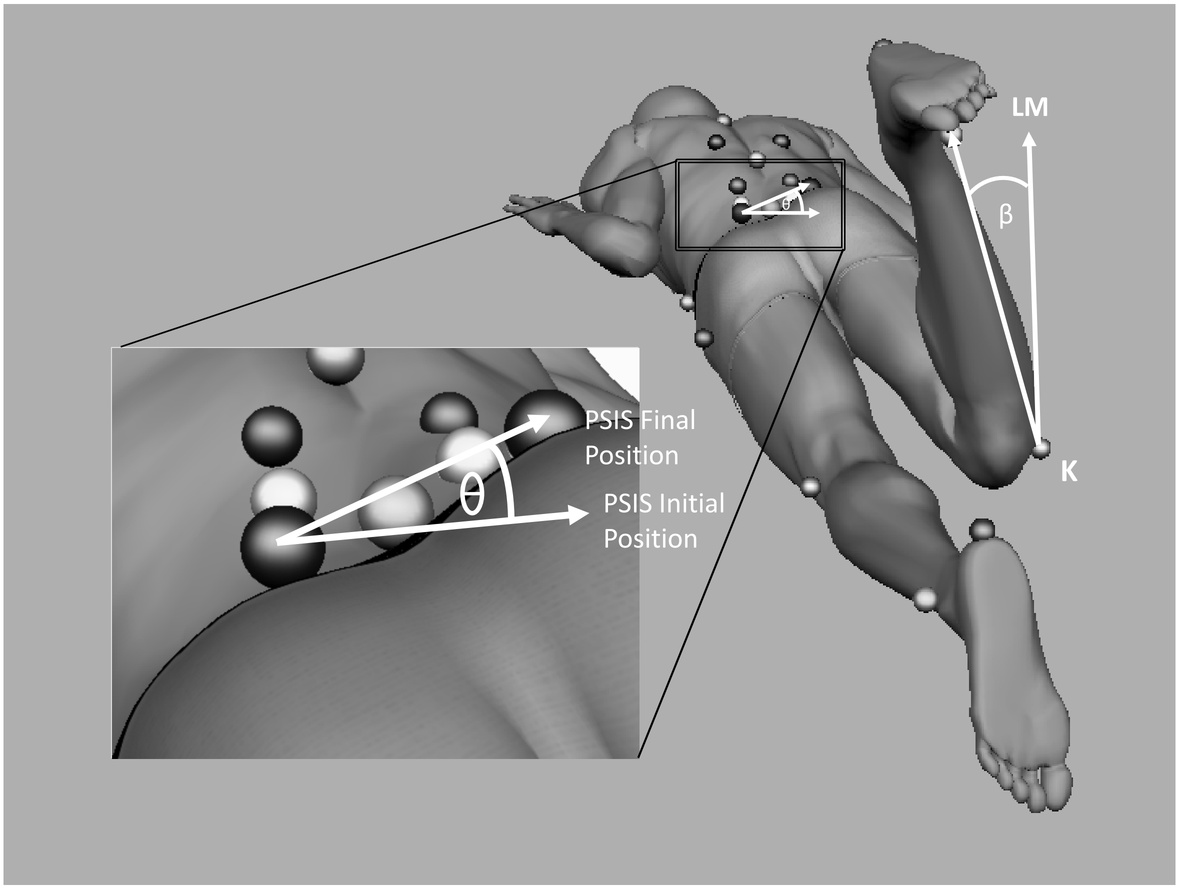


Figure 4.2 Relationship between lumbopelvic motion demonstrated during *passive* and *active* hip lateral rotation in people with low back pain.

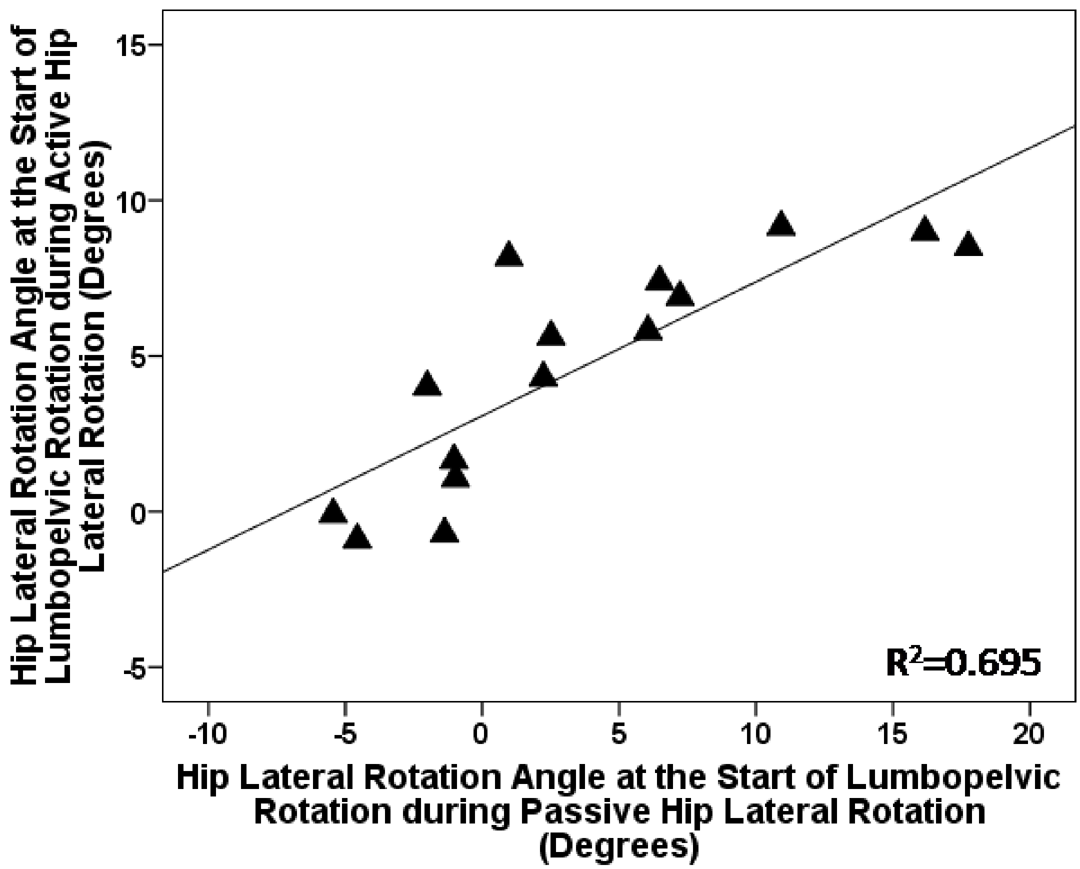
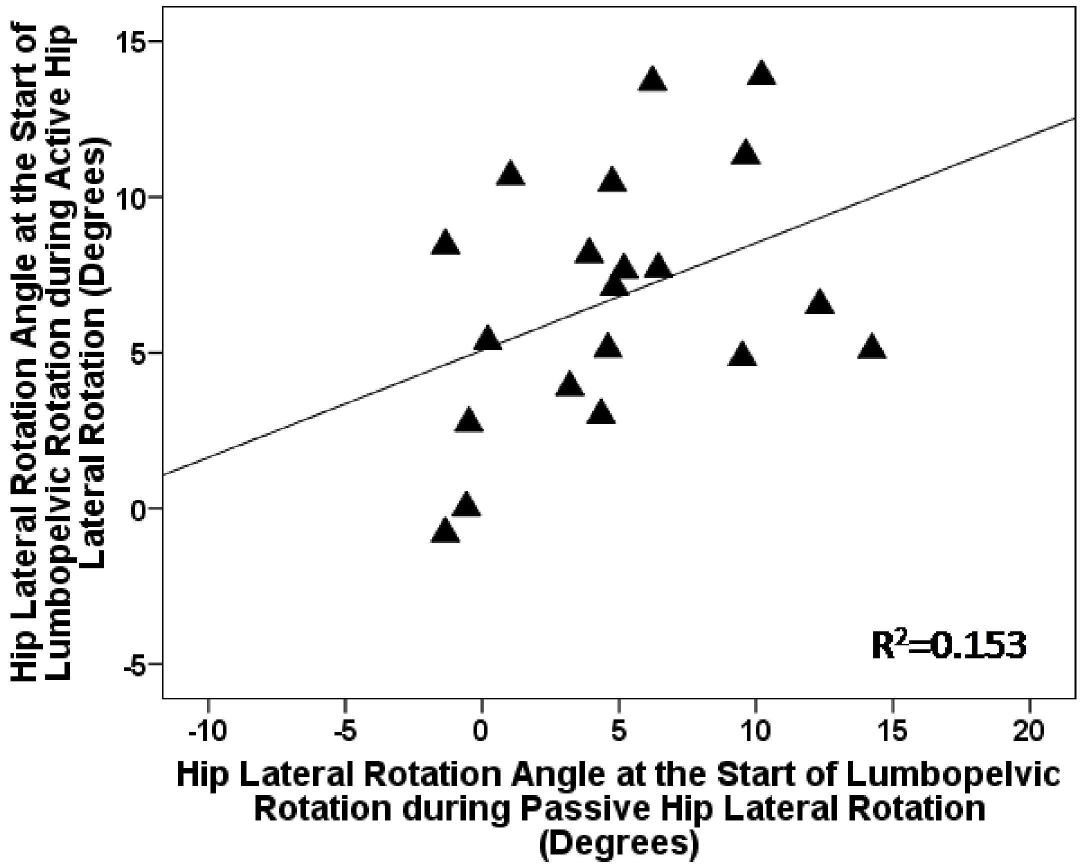


Figure 4.3 Relationship between lumbopelvic motion demonstrated during *passive* and *active* hip lateral rotation in people with low back pain.



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Chapter 5

The effect of within-session instruction on lumbopelvic motion during hip lateral rotation in people with and people without low back pain

In Review: Scholtes SA, Norton BJ, Lang CE, Van Dillen LR. The effect of within-session instruction on lumbopelvic motion during a lower limb movement in people with and people without low back pain. *Man Ther*.

ABSTRACT

The purpose of the current study was to examine how effectively people with and people without low back pain (LBP) modify lumbopelvic motion during a limb movement test. Nineteen subjects with chronic or recurrent LBP and 20 subjects without LBP participated. Kinematic data were collected while subjects performed active hip lateral rotation (HLR) in prone. Subjects completed trials (1) using their natural method (Natural condition) of performing HLR, and (2) following standardized instructions to decrease lumbopelvic motion (Modified condition). Variables of interest included (1) the amount of HLR completed prior to the start of lumbopelvic motion, and (2) the maximum amount of lumbopelvic motion demonstrated during HLR. Compared to the Natural Condition, all subjects improved their performance during the Modified condition by (1) completing a greater amount of HLR prior to the start of lumbopelvic motion, and (2) demonstrating less lumbopelvic motion ($P<0.01$ for all comparisons). People without LBP demonstrated a greater difference between the Natural and Modified conditions in both variables ($P<0.06$ for both comparisons). In conclusion, people are able to modify lumbopelvic motion following instruction, but people with LBP do not modify as well as people without LBP.

Keywords: spine, limb, hip lateral rotation, instruction, lumbopelvic motion

INTRODUCTION

Low back pain (LBP) is a musculoskeletal condition that affects up to 80% of the population at some point in their lifetime.[17] Although as many as 90% of individuals who initially seek medical treatment for an acute episode of LBP stop seeking medical treatment within 3 months of the initial consultation, as many as 75% of these individuals state they are not fully recovered one year later.[7] The economic and social impact of the persistent and recurrent course of LBP has led to the development and study of many diverse treatment options.

In spite of the numerous studies conducted, no treatment has been found to be consistently effective for alleviating the persistent symptoms and functional limitations associated with LBP. One proposal for the inconsistent findings is that previous treatments have not adequately addressed the importance of movements performed frequently across the day.[23] If movements are performed repeatedly across the day, then these movements could contribute to the often persistent and recurrent course of LBP.

Many of the activities frequently performed throughout the day involve limb movements. Limb movements are important in the examination of people with LBP because limb movements produce forces on the lumbopelvic region and, therefore, could induce movement of the lumbopelvic region. Repetitive lumbopelvic motion with limb movements could contribute to accumulation of lumbopelvic region tissue stress, microtrauma, and, eventually, LBP.[19] Investigators have examined the effect of limb movements on the lumbopelvic region in people with and people without LBP. During active movements that involved the limbs, people with LBP demonstrated decreased trunk control[21] and different lumbopelvic movement patterns[26] compared to people without LBP.

Of interest to our work is lumbopelvic motion that begins soon after the start of a limb movement. Lumbopelvic motion that begins soon after the start of a limb movement is of interest because many daily activities are performed in the early to mid ranges of limb movements. If lumbopelvic motion begins soon after the start of a limb movement, and the limb movement is performed frequently across the day, then there could be an increase in frequency of lumbopelvic motion across the day.[23] We have reported that (1) people with LBP demonstrate earlier lumbopelvic motion during active limb movements than people without LBP,[24] and (2) people with LBP report a decrease in symptoms when the lumbopelvic region is manually restricted during a limb movement.[27,29]

Although modifying lumbopelvic motion during a limb movement has been found to be beneficial, the procedures previously used to modify the motion are limited. During the clinical examination, modification of lumbopelvic motion occurs through verbal instruction provided to the patient, coupled with manual stabilization provided by the clinician. This method eliminates lumbopelvic motion and decreases symptoms. Thus, prescribing an activity that reduces lumbopelvic motion during a limb movement as part of a home program may be beneficial. Successful performance of a limb movement as part of a home program however, would require the patient to be able to control movement of the lumbopelvic region independently, without manual assistance.

The purpose of the current study, therefore, was to examine how effectively people with and people without LBP independently modify lumbopelvic motion during an active limb movement test following standardized, within-session instruction. Hip lateral rotation (HLR) was examined in the current study because (1) it provokes symptoms in people with LBP,[9,28] and (2) lumbopelvic motion during HLR is different between people with and people without LBP.[24] We hypothesized that, following instruction, all people would (1) complete a greater amount of HLR prior to the start of lumbopelvic motion, and (2) demonstrate less lumbopelvic motion during HLR. We also hypothesized that people without LBP would demonstrate greater improvements in both variables than people with LBP. The current study is important because it provides information about how quickly and how effectively people independently modify a movement pattern. This information may help guide a clinician to provide the most appropriate home program for a person with LBP or a different musculoskeletal pain condition.

METHODS

Subjects

Nineteen subjects with LBP and 20 subjects without LBP participated in the study. Table 5.1 includes subject and LBP-related characteristics of the sample. Subjects were excluded from the study if they verbally reported having (1) a height and weight consistent with a body mass index (BMI) greater than 30, (2) a hip or knee injury that limited activities of daily living, (3) a history of a spinal fracture or surgery, or (4) a diagnosis by a physician of a spinal deformity, systemic inflammatory condition, or other serious medical condition that could affect the ability to move (e.g., Parkinson's disease). Subjects were included in the LBP group if they reported chronic or recurrent LBP of more than 6 months.[31] Subjects were excluded from the group without LBP if they reported any prior LBP episode that affected activities of daily living for more than 3 days or for which they sought medical or allied health intervention. Prior to participation in the study, all subjects provided informed consent approved by the Human Research Protection Office of Washington University School of Medicine.

Clinical Measures

All subjects completed self-report questionnaires including a demographic and LBP history questionnaire and a Baecke Habitual Activity Questionnaire.[2] Subjects with LBP also completed (1) a verbal numeric pain rating scale,[16] (2) a modified Oswestry Disability Index,[8] and (3) a Fear Avoidance Beliefs Questionnaire (FABQ).[32]

Laboratory Measures

Subjects performed the test of active HLR in prone.[23] At the start of each trial, the tester manually supported the tested limb in a position of neutral femoral abduction/adduction, 5° of hip medial rotation, and 90° of knee flexion. The non-tested limb was positioned in full hip and knee extension. Prior to each trial, the subject was instructed to bring the foot in as far as possible (i.e., lateral rotation) and then return the foot to the start position. Prior to the first trial, the tester assisted the subject in understanding the desired direction of motion by manually rotating the hip a few degrees. Subjects performed 5 trials using their natural movement pattern (Natural condition) and 10 trials following standardized instructions (Modified condition). All trials were performed on the right and left limbs separately. Ten Modified trials were completed to assess whether greater improvement occurred with repetition. Prior to each Modified trial, the tester provided verbal and tactile information intended to assist the subject in modifying lumbopelvic motion during HLR. The subjects were instructed verbally to contract the abdominal muscles and not allow the pelvis to rotate during HLR. While giving verbal instructions, the tester also provided tactile information to the abdominal muscles and posterior pelvis.

Kinematic data were collected using a 6-camera motion capture system (EVaRT, Motion Analysis Corporation, Santa Rosa, CA, USA). Reflective markers were placed on landmarks of the trunk, pelvis, and limbs to capture limb and lumbopelvic rotation during testing. Data were collected at a sampling rate of 60 Hz. The static resolution of the motion capture system was 1mm per cubic meter.

Data Processing

Angular displacement and velocity of movement for the lower leg and lumbopelvic region were calculated across time. Hip lateral rotation was indexed using the lower leg segment; the segment was defined by a vector from a marker superficial to the lateral malleolus to a marker superficial to the lateral knee joint line. Hip lateral rotation was calculated as a change in the angle of the lower leg segment relative to the initial position.[9] Lumbopelvic rotation was indexed using a pelvic segment; the segment was defined by a vector between markers placed superficial to the posterior superior iliac spines. Lumbopelvic rotation was calculated as a change in angle of the pelvic segment relative to the initial position (Figure 5.1).

Motion capture data was filtered using a 4th order, dual pass, butterworth filter with an initial cut-off frequency of 2.5 Hz. After filtering, the start and end points of HLR and lumbopelvic rotation were determined and movement time was calculated. Because subjects were allowed to move at a self-selected speed, data were filtered at a subject-specific cut-off frequency (fc_{ss}).[34] The frequency was calculated by taking the reciprocal of 15% of the period, fc_{ss}=1/.15*(2*movement time).

The start of HLR was defined as the point at which angular velocity exceeded 5% of the maximal angular velocity of the lower leg segment. The start of lumbopelvic rotation was defined as the point at which angular velocity exceeded 10% of the maximal angular velocity of the pelvic segment. The end of movement for each segment was defined as the point at which 99.5% of the maximal angle had been achieved.

Dependent Variables

Limb and lumbopelvic kinematics were examined from the start of HLR to the end of HLR. Two dependent variables were used to evaluate performance during both conditions. First, how soon the lumbopelvic region moved during HLR was indexed by the amount of HLR completed prior to the start of lumbopelvic motion. Completion of a greater amount of HLR prior to the start of lumbopelvic motion would indicate better performance. Second, maximal lumbopelvic rotation was defined as the maximal angle of lumbopelvic rotation achieved between the start and end of HLR. A smaller angle would indicate better performance.

Data Analyses

SPSS 15.0 for Windows (SPSS Inc., Chicago, IL, USA) was used to perform all statistical analyses. Chi-square goodness of fit analyses or two-tailed, independent samples t-tests were used to test for differences between groups on relevant subject characteristics. Because there was no change in performance with greater repetition of movement, the averages of the 5 Natural trials and the 10 Modified trials were examined for each dependent variable. Trials from the right and left limbs were averaged for both conditions. Two-tailed, paired t-tests were used to test for differences between the Natural and Modified conditions on each dependent variable. Because *a priori* hypotheses were directional in nature, 1-tailed, independent samples t-tests were used to test for differences between groups (1) on each dependent variable for each condition, and (2) in the change between conditions for each dependent variable.[11] The effect size for each comparison was indexed using Cohen's d statistic. Statistical significance for all analyses was set at P-value<0.05.

RESULTS

There were no differences between people with and people without LBP in sex distribution, age, or BMI (Table 5.1). Means, standard deviations, mean differences, and statistical test results for all variables for each condition are provided in Table 5.2.

Overall

Following instructions in the modified condition, subjects in both groups improved their performance as demonstrated by (1) achieving more HLR prior to the start of lumbopelvic rotation (HLR at start of lumbopelvic rotation; LBP: t=4.390, P<0.001; NoLBP: t=4.242, P<0.001; Figure 5.2) and (2) moving the lumbopelvic region less (maximal lumbopelvic rotation angle; LBP: t=5.121, P<0.001; NoLBP: t=8.596, P<0.001; Figure 5.3).

Group comparisons

Following instruction, people without LBP demonstrated a greater change in performance than people with LBP. People without LBP demonstrated (1) a greater decrease in lumbopelvic rotation (mean difference between conditions; LBP: 2.8, NoLBP: 4.2; t=1.863, P=0.035, d=0.596) and (2) a tendency towards a greater increase in the amount of hip rotation achieved prior to lumbopelvic rotation (mean difference between conditions; LBP: 6.4, NoLBP 11.4; t=1.652, P=0.055, d=0.526)

DISCUSSION

The purpose of the current study was to examine how effectively people modify lumbopelvic motion during HLR following standardized, within-session instruction. Consistent with our first hypothesis, all people could improve their HLR performance following instruction. People in both groups (1) completed a greater amount of HLR prior to the start of lumbopelvic rotation, and (2) demonstrated less lumbopelvic rotation during HLR. Consistent with our second hypothesis, people without LBP were better at modifying their performance than people with LBP as demonstrated by (1) a greater decrease in maximal lumbopelvic rotation during HLR, and (2) a tendency toward a greater increase in the amount of HLR completed prior to the start of lumbopelvic rotation.

Our prior work suggests that modifying lumbopelvic motion during a limb movement by manually stabilizing the lumbopelvic region improves a person's LBP symptoms immediately.[27,29] Learning to modify lumbopelvic motion during limb movements, therefore, may be beneficial for people with LBP. The current study demonstrates that people with LBP are able to modify lumbopelvic motion independently within one testing session. Thus, it is reasonable to expect people with LBP would be able to perform an activity to improve lumbopelvic motion during a limb movement as part of a home program.

The results of the current study, however, also suggest that people with LBP do not modify lumbopelvic motion during HLR as effectively as people without LBP. People without LBP (1) tended to increase the amount of HLR completed prior to the onset of lumbopelvic rotation and (2) decreased the total amount of lumbopelvic rotation to a greater extent than people with LBP. There are a number of reasons why people with LBP may not modify a movement pattern as effectively as people without LBP. Possible reasons include muscle strength and motor control deficits, pain, and fear of pain. Each of these reasons is discussed in the following paragraphs.

The first possible reason for differences in performance between people with and people without LBP is differences in trunk muscle strength. During activities in which people are asked to perform a maximal voluntary contraction, people with LBP have less trunk muscle strength than people without LBP.[3,4,18,20] Depending on the demands of the activity, however, maximal voluntary muscle strength may not be needed for optimal performance. In the current study, people performed a stabilization activity that necessitated only a small fraction of their maximal voluntary strength. Because the HLR movement test is more of a precision task (i.e. requiring precise timing and magnitude of muscle activity) than a gross, effortful task (i.e. requiring high magnitude activation of many muscles at the same time), it is unlikely that a difference in maximal voluntary muscle strength played a role in why people with LBP were less able to modify their performance.

A second possible reason for why people with LBP do not modify a movement pattern as well as people without LBP is motor control deficits.[22] People with LBP demonstrate delayed trunk muscle recruitment during rapid limb movements.[12,13,15] Anticipatory trunk muscle activity contributes to spinal stability during an active limb movement.[1] Because people with LBP demonstrate deficits in anticipatory trunk muscle activity, they also may be less able to modify a movement that requires stabilization of the lumbopelvic region than people without LBP.

A third possible reason is pain. Experimentally-induced pain is associated with altered trunk muscle recruitment during a limb movement.[14,35] The alterations are similar to the alterations in trunk muscle recruitment demonstrated by people with LBP.[14,35] The alterations also remain, to varying degrees, after pain resolution.[14] The average pain level reported on the day of testing by subjects in the current study (VAS: 1.8/10) was less than the average pain level reported during the experimentally induced pain studies (VAS: >4/10), but the worst pain reported in the past seven days by subjects in the current study was similar (VAS: 4.3/10) to the experimentally induced levels. Therefore, if pain, whether current or recent, alters trunk muscle recruitment, then pain may have affected how well people with LBP recruited trunk muscles during the Modified condition.

Lastly, fear of pain may be a possible reason why people with LBP did not modify their performance as well as people without LBP. Fear of pain may lead to the avoidance of movements believed to cause pain[30] and could have caused our subjects with LBP not to modify their movements as well as the subjects without LBP. There are 2 reasons, however, why it is unlikely that fear of pain contributed to the current findings. We measured fear of pain with the FABQ[5,33] and none of the subjects had high levels of fear (Table 5.1). In addition, people who demonstrate a fear of pain would be likely to avoid a movement that evokes pain. Lumbopelvic motion during HLR often is associated with an increase in LBP.[28] In the current study, if people with LBP were avoiding pain, they would have demonstrated less, not more, lumbopelvic motion during HLR than people without LBP.

One potential limitation of the current study is that the findings are specific to changes in performance within one session following simple instructions with no external feedback.

We did not address whether people were able to retain the ability to modify a movement pattern or whether different instructions would provide better results. The results of the current study, however, are encouraging. With a simple instruction set and no external feedback, people in both groups were able to improve their performance independently in a relatively short period of time. These findings suggest that, with instruction, people with LBP may be able to repeat the activity effectively as part of a home program. Furthermore, there is evidence to suggest that external feedback, particularly biofeedback, is beneficial in improving motor performance and learning in people with LBP.[10] Thus further study to identify (1) the ability of people with LBP to modify a movement pattern during a second session, (2) the most effect instruction set, and (3) the types of external feedback that would be most beneficial for improving performance, as well as learning, may result in better outcomes in performance for people with LBP.

A second potential limitation of the current study is that there was no statistical difference in the change in pain reported by people with LBP between the Natural and Modified conditions. Some subjects reported improvement in pain during the Modified condition whereas other subjects reported a worsening of pain during the Modified condition. There are a couple of reasons why we think there was not an overall improvement in pain in the current study. First, in prior studies in which people with LBP reported a decrease in pain following modification included manual stabilization of the lumbopelvic region as part of the modification; the result was elimination of lumbopelvic motion.[27,29] In the current study, although subjects with LBP demonstrated a decrease in lumbopelvic motion, lumbopelvic motion was not completely eliminated. It is possible that subjects in the current study did not achieve enough of a decrease in lumbopelvic motion to result in a decrease in pain. Second, it is possible that subjects who reported an increase in pain during the Modified condition may have activated their back extensor muscles during HLR. An increase in back extensor muscle activity may have resulted in contraction of muscles that were the source of the person's symptoms. An increase in back extensor activity would also potentially have contributed to co-contraction of the trunk muscles because subjects were instructed to contract their abdominal muscles as part of the procedures for modifying their lumbopelvic region. Co-contraction could have resulted in compression of tissues of the lumbar region and an increase in pain.

A third potential limitation of the current study is that there was no difference between people with and people without LBP in the maximal lumbopelvic rotation angle demonstrated during HLR in the Natural condition. We have previously reported that people with LBP demonstrate a greater amount of lumbopelvic rotation during HLR than people without LBP.[24] However, in the previous report, the groups were different with regard to the type of activity they participated in regularly; people with LBP participated in a rotation-related sport a minimum of two times per week whereas people without LBP did not participate in a rotation related sport.[24] In the current study, subjects did not participate in any specific activity on a regular basis. In the prior study, it is possible that the difference in activity participation between the two groups contributed to the different in lumbopelvic rotation reported between people with and people without LBP. However, lumbopelvic motion during a limb movement is symptom provoking in people with LBP[25,28] and symptoms are reduced when the lumbopelvic motion is restricted manually[27,29] suggesting that lumbopelvic motion demonstrated during a limb movement would still be important in the current sample of people with LBP. It may be that how soon the lumbopelvic region moves during the limb movement is more important than the total amount of lumbopelvic motion.

It is also possible that a larger sample size would have resulted in greater differences between groups for both dependent variables of interest. The sample size in the current study (N=39) was small relative to our previous study (N=91). Despite the small sample size, however, the effect size, as calculated with Cohen's d, was medium (d=0.5)[6] for some variables of interest, particularly for the amount of HLR completed prior to the start of lumbopelvic rotation (Table 5.3). A medium effect size would suggest that, despite a small sample size, the results of this study might be important. The authors recognize, however, that collection of a larger sample would further strengthen the reported results.

CONCLUSION

The findings of the current study suggest that people with and people without LBP are effective at modifying lumbopelvic motion during the test of active HLR in prone following standardized, within-session instruction. Both groups are able to (1) delay the onset of lumbopelvic rotation during HLR and (2) decrease the maximal amount of lumbopelvic rotation demonstrated during HLR. However, compared to people with LBP, people without LBP appear to be more effective at modifying lumbopelvic motion during HLR. This suggests that people with LBP may require more or different instruction as well as external feedback to improve lumbopelvic motion during HLR.

People with LBP, however, were able to improve lumbopelvic control during a limb movement suggesting it is reasonable to expect people with LBP would independently be able to perform an exercise to improve lumbopelvic motion as part of a home program. Further study is necessary to better identify the most optimal instruction and feedback to maximize how well people with LBP independently modify lumbopelvic motion during a limb movement.

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Table 5.1 Subject characteristics.

	People with LBP (N=19)	**People without LBP** (N=20)	**95% Confidence Intervals of the Mean Difference**	**Statistical Value, Degrees of Freedom, *P*-value**
Sex	M=10, F=9	M=10, F=10	NA	X^2=0.027, df=1, *P*=0.869
Age (years)	27.3 (6.6)	26.5 (5.9)	-3.3 – 4.9	*t*=0.405, df=37, *P*=0.688
Body mass index (kg/m^2)	24.5 (2.9)	24.9 (2.8)	-1.5 – 2.2	*t*=0.380, df=37, *P*=0.706
Current pain score[a] (0-10)	1.8 (1.0)	NA	NA	NA
Duration of LBP (years)	8.5 (4.2)	NA	NA	NA
Number of acute flare-ups[b] in previous 12 months	6.2 (4.4)	NA	NA	NA
Modified Oswestry Disability Index[c] (0-100 %)	13.9 (9.2)	NA	NA	NA
Fear Avoidance Beliefs Questionnaire[d]				
Work subscale (0-42)	10.1(6.8)	NA	NA	NA
Physical activity subscale (0-24)	11.1(3.6)	NA	NA	NA

Abbreviation: LBP, low back pain
Values expressed as mean (standard deviation).
[a] Pain measured using a verbal numeric pain rating scale.[16]
[b] A flare-up is defined as a period (usually a week or less) when back pain is markedly more severe than usual.[31]
[c] Disability measured using Modified Oswestry Disability Index.[8]
[d] Fear avoidance measured using Fear Avoidance Beliefs Questionnaire.[32]

Table 5.2 Means, standard deviations, mean differences, and statistical values for hip lateral rotation variables for people with and people without low back pain.

Variable	People with LBP (N=19)	People without LBP (N=20)	Mean Difference	Statistical Values, *P*-value[a], Effect Size[b]
Natural Condition[c]				
Maximal HLR angle	44.4 (8.5)	48.9 (6.7)	4.53	*t*=1.852, ***P*=0.036**; d=0.592
HLR angle at the start of lumbopelvic rotation	4.5 (3.6)	6.8 (4.0)	2.25	*t*=1.839, ***P*=0.037**; d=0.590
Maximal lumbopelvic rotation angle	8.1 (3.4)	8.0 (2.8)	0.05	*t*=0.048, *P*=0.481; d=0.016
Modified Condition[d]				
Maximal HLR angle	40.7 (9.4)	45.0 (10.5)	4.29	*t*=1.342, *P*=0.094; d=0.430
HLR angle at the start of lumbopelvic rotation	10.9 (7.8)	18.2 (12.3)	7.30	*t*=2.198, ***P*=0.017**; d=0.709
Maximal lumbopelvic rotation angle	5.3 (3.3)	3.8 (2.7)	1.42	*t*=1.467, *P*=0.076; d=0.470

Abbreviations: LBP, low back pain; HLR, hip lateral rotation
Values expressed as mean (standard deviation).
Degrees of freedom equals 37 for all comparisons.
Significant group differences indicated in bold-face type.
[a] P-values are for 1-tailed t-test.
[b] Effect size determined using Cohen's d, calculated as the difference in the group means divided by the pooled standard deviation; 0.2=small, 0.5=medium, 0.8=large.[6]
[c] In the Natural condition, subjects performed hip lateral rotation using their preferred method.
[d] In the Modified condition, subjects performed hip lateral rotation following instruction to modify lumbopelvic motion during hip lateral rotation

Figure 5.1 Kinematic model with hip lateral rotation (β) and lumbopelvic rotation (θ) calculations. LM: lateral malleolus, K: knee, PSIS: posterior superior iliac spine.

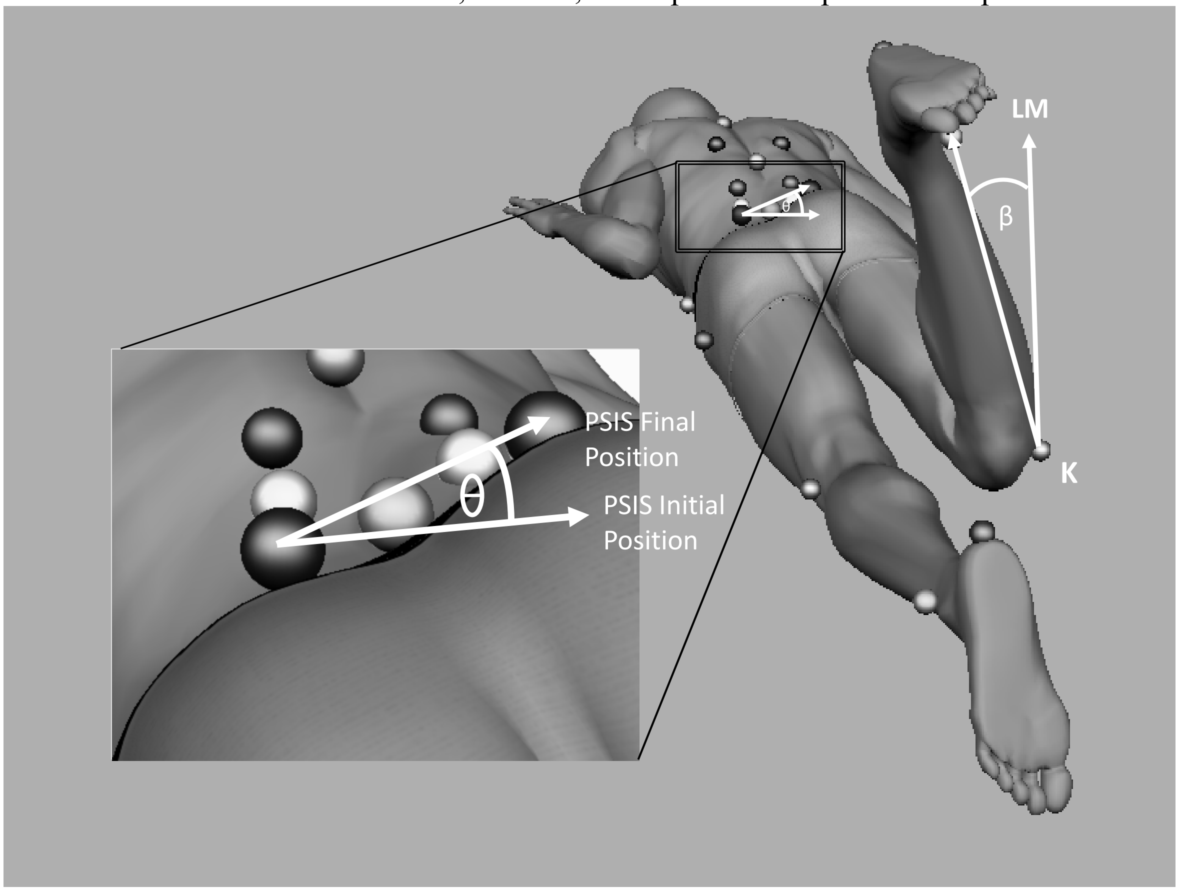


Figure 5.2 Mean (95% confidence interval) amount of hip lateral rotation completed prior to the start of lumbopelvic rotation during the Natural and Modified conditions for people with and people without low back pain (LBP). In the Natural condition, subjects performed hip lateral rotation using their preferred method. In the Modified condition, subjects performed hip lateral rotation following instruction to modify lumbopelvic motion during hip lateral rotation

a. People without LBP

b. People with LBP

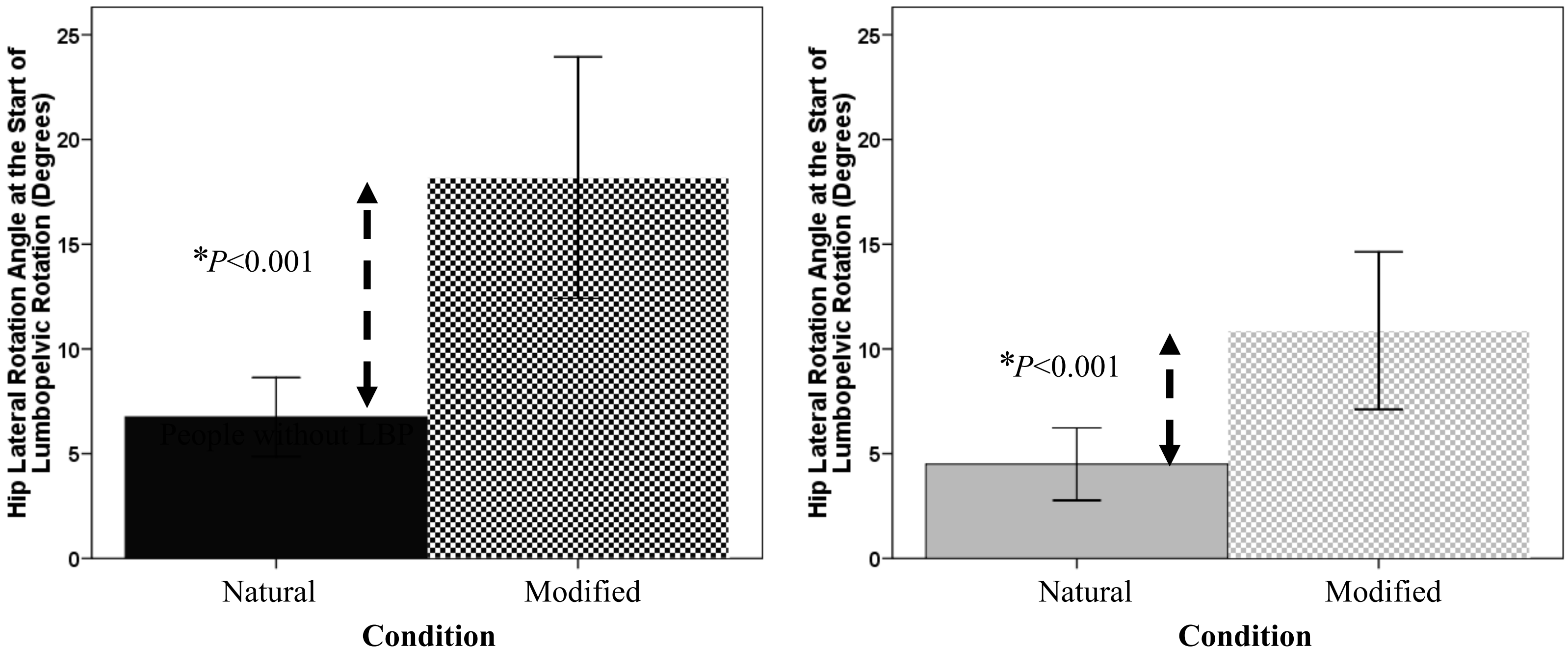
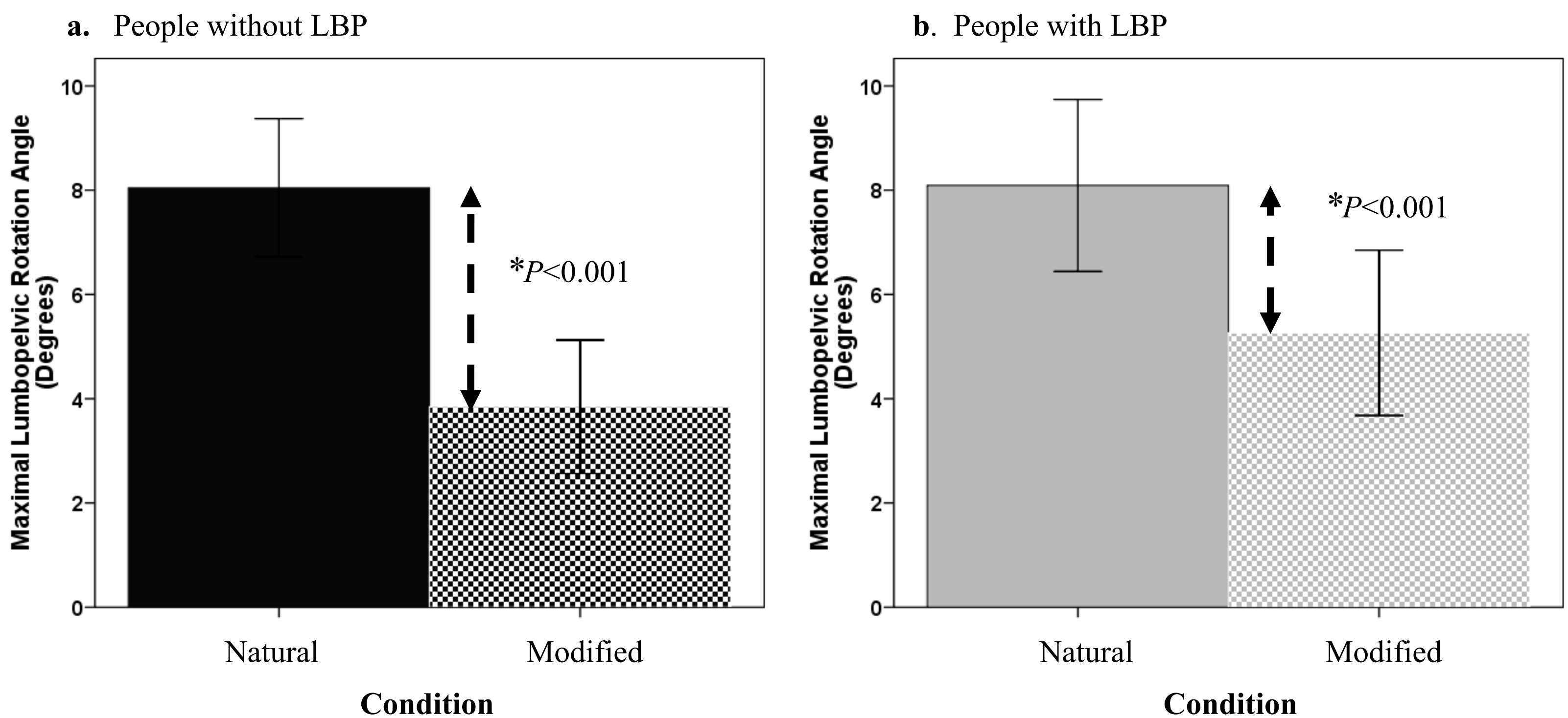


Figure 5.3 Mean (95% confidence interval) maximal lumbopelvic rotation angle during the Natural and Modified conditions for people with and people without low back pain (LBP). In the Natural condition, subjects performed hip lateral rotation using their preferred method. In the Modified condition, subjects performed hip lateral rotation following instruction to modify lumbopelvic motion during hip lateral rotation



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Chapter 6

Conclusion

Summary of Findings

The purpose of this dissertation work was to examine additional aspects of the Movement System Impairment (MSI) model, focusing specifically on lumbopelvic motion during active limb movements. In the (MSI) model, lumbopelvic motion that begins soon after the start of an active movement is thought to be important because of its potential contribution to increased frequency of lumbopelvic motion across the day, tissue stress, and potentially a low back pain (LBP) problem. With this dissertation work, we have described (1) differences between men and women with low back pain in the prevalence of early lumbopelvic region movement impairments across a number of different clinical tests that involved movement of the limb, (2) differences between people with and people without LBP in lumbopelvic motion demonstrated during active limb movement tests, (3) the relationship between passive and active lumbopelvic motion during a limb movement in people with and people without LBP, and (4) how effectively people with and people without LBP modify lumbopelvic motion during an active limb movement following standardized within-session instructions.

Gender-Related Difference in Lumbopelvic Motion

The purpose of Chapter 2 was to examine whether men and women with LBP differed in the prevalence of impairments associated with early lumbopelvic region movement during active movement tests included in a standardized examination for people with LBP. Included in the analyses for Chapter 2 were findings from three different categories of tests: active limb movements, active trunk movements potentially affected by limb tissue stiffness, and active trunk movements presumed not to be influenced by limb tissue stiffness. Compared to women, a larger percentage of men demonstrated early lumbopelvic motion with limb movement tests and trunk movement tests potentially affected by limb tissue stiffness. Men and women with LBP did not differ in the prevalence of early lumbopelvic region movement impairments during trunk movement tests presumed not to be influenced by limb tissue stiffness. Similar results were obtained when the data from the subset of people who reported an increase in symptoms during individual movement tests was examined.

Gender differences in lumbopelvic motion during clinical tests are important because they suggest possible differences in the factors contributing to LBP between men and women. A better understanding of the factors contributing to LBP for men and women may help to improve examination and intervention strategies, potentially contributing to improved outcomes. For men, it may be beneficial to address lumbopelvic motion that occurs early during the range of an active limb movement. For women, it may be more beneficial to address lumbopelvic motion that occurs later in the range of an active limb movement.

Group Differences in Lumbopelvic Motion

The purpose of Chapter 3 was to examine whether people with and people without LBP demonstrate different lumbopelvic region movement patterns during two active lower limb movement tests. Chapter 3 examined magnitude and timing of lumbopelvic motion during two active lower limb movement tests performed in prone: knee flexion (KF) and hip lateral rotation (HLR). During KF, lumbopelvic motion in the transverse (lumbopelvic rotation) and sagittal (anterior pelvic tilt) planes was examined. During HLR, lumbopelvic motion in the transverse (lumbopelvic rotation) plane was examined. Compared to people without LBP, people with LBP demonstrated a greater maximal angle of lumbopelvic rotation and earlier lumbopelvic rotation during both KF and HLR. There was no difference between groups in magnitude or timing of anterior pelvic tilt during KF.

A difference in timing of lumbopelvic motion during an active limb movement between people with and people without LBP is important because it provides support for the proposal that lumbopelvic motion that begins soon after the start of an active limb movement may be relevant to the LBP problem. Differences in timing and magnitude of lumbopelvic motion during both limb movement tests also suggest that people with LBP may have more lumbopelvic region mobility than people without LBP. Therefore, the early and increased lumbopelvic motion demonstrated by people with LBP may be important to the development, persistence, and recurrence of LBP.

Relationship between Passive and Active Hip Lateral Rotation

The purpose of Chapter 4 was to examine the relationship between how soon the lumbopelvic region begins to move during an active limb movement test and how soon the lumbopelvic region moves during a passive limb movement test in people with and people without LBP. We also examined the relationship between how soon the lumbopelvic region begins to move during an active limb movement and a number of subject characteristics, clinical findings, and laboratory findings. We examined these relationships with the test of HLR. In people with LBP, there was a relationship between how soon the lumbopelvic region began to move during active HLR and (1) how soon the lumbopelvic region began to move during passive HLR, (2) gender, and (3) a number of vertical anthropometric values. In people without LBP, how soon the lumbopelvic region began to move during active HLR was not correlated significantly with any of the variables measured.

Examination of the relationship between lumbopelvic motion during a passive limb movement and an active limb movement may provide insight into the musculoskeletal and neural factors that contribute to lumbopelvic motion observed during an active movement test. Assessment of a passive movement may provide information about the contribution of passive characteristics to an observed movement pattern. Assessment of an active movement may provide information about how the neural system compensates for, or contributes to the movement pattern observed during the passive movement. Data from Chapter 4 suggest people with LBP do not compensate for passive characteristics as well as people without LBP.

Effect of Within-Session Instruction on Lumbopelvic Motion

The purpose of Chapter 5 was to examine how effectively people with and people without LBP were able to modify lumbopelvic motion during the test of active HLR in prone. Subjects performed HLR using their natural movement pattern and following instruction intended to modify lumbopelvic motion during HLR. People with and people without LBP completed a greater amount of HLR prior to the start of lumbopelvic motion and demonstrated less lumbopelvic rotation during active HLR following instruction. People with LBP, however, tended not to be as effective at modifying lumbopelvic motion during HLR as people without LBP. People without LBP demonstrated a greater difference in maximal lumbopelvic rotation between how they moved naturally and how they moved following instruction, when compared to people with LBP. People without LBP also tended to demonstrate a greater increase in the amount of HLR completed prior to the start of lumbopelvic rotation during HLR between the two conditions when compared to people without LBP.

The results of Chapter 5 suggest that people with LBP are able to (1) improve their performance during the HLR test without manual assistance and (2) make improvements within one session. Thus, it is reasonable to prescribe an exercise to improve lumbopelvic motion during a limb movement test as part of a home program for a person with LBP. People with LBP, however, did not modify as well as people without LBP. People with LBP may benefit from different verbal or tactile cues, training of specific muscles to help stabilize the lumbopelvic region, or feedback to improve how effectively they modify lumbopelvic motion during an active limb movement.

Future Studies

There are a number of future studies that would be beneficial. First, based on the findings from Chapter 2, if men and women move differently during active movements, then it may be necessary to provide different intervention for men and women to optimize outcomes. Future studies could examine whether providing intervention addressing the specific movement impairments demonstrated by men and women results in better outcomes than a non-specific intervention.

Second, Chapter 3 describes differences in lumbopelvic motion during limb movements between people with LBP who participate in rotation-related sports and people without LBP who do not participate in rotation related sports. Future work could examine whether lumbopelvic motion that occurs soon after the start of a limb movement is specific to people with LBP who participate in rotation-related sports or whether lumbopelvic motion demonstrated early during a limb movement is present in all people with LBP. Chapter 5 of this dissertation does examine differences in lumbopelvic motion between people with and people without LBP who do not participate in a particular activity, but further examination of the presence of early lumbopelvic motion in a larger sample is warranted. Future work could also examine whether the early lumbopelvic motion demonstrated during two active limb movement tests is observed with a variety of other clinical tests and functional activities.

Third, Chapter 4 provides information about the relationship between lumbopelvic motion demonstrated during an active and a passive limb movement test in people with LBP. What factors contribute to why the lumbopelvic region begins to move soon after the start of an active or a passive limb movement, however, is unknown. Future studies could examine what factors contribute to lumbopelvic motion during passive movement (e.g. stiffness of adjacent regions), whether the factors that contribute to lumbopelvic motion during passive movement are modifiable with treatment, and if modifiable, whether the changes result in improved movement patterns during active limb movement tests.

Finally, Chapter 5 suggests that people with LBP are able to modify lumbopelvic motion during an active limb movement test, but people with LBP do not modify the movement as well as people without LBP. Future studies could examine what information results in better modification of lumbopelvic motion during an active limb movement. A number of components could be studied including (1) the most effective type of instruction (e.g. audio, visual, tactile) and (2) the effect of feedback on performance to modify lumbopelvic motion. In addition, the findings from Chapter 5 are specific to one testing session. Future studies could examine whether people are able to repeat the activity during a second testing session. Examining whether people are able to repeat the activity during a second testing session would provide information about how well people retain the information. Information about retention would provide information about how well people with LBP are able to perform the activity as part of a home program.