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Original article

Differences in kinematics of the lumbar spine and lower extremities between people with and without low back pain during the down phase of a pick up task, an observational study

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ABSTRACT

Background: Limited research exists on lumbar spine and lower extremity movement during functional tasks in people with and without low back pain (LBP).
Objective: To determine differences in lumbar spine and lower extremity kinematics in people with and without LBP during the down phase of a pick up task.
Design: Cross-sectional, observational study.
Method: 35 people (14 M, 21 F, 26.9 ± 10.9 years, 24.8 ± 3.2 kg/m^2); 18 with and 17 without LBP were matched based on age, gender and BMI. Kinematics of the lumbar spine and lower extremities were measured using 3D motion capture, while subjects picked up an object off the floor. People with LBP were examined and assigned to movement-based LBP subgroups. Repeated measures ANOVA tests were conducted to determine the effect of group and region on lumbar spine and lower extremity kinematics. A secondary analysis was conducted to examine the effect of LBP subgroup on lumbar spine kinematics.
Results: Compared to controls, subjects with LBP displayed greater upper and less lower lumbar flexion ($P < 0.05$), and more lumbar flexion during the first 25% of the pick up task ($P < 0.01$). There were no group differences in frontal or axial plane lumbar spine kinematics. Subjects with LBP displayed more frontal plane movement at the knee than control subjects ($P < 0.01$). There were no significant effects of movement-based LBP subgroup on kinematics ($P > 0.05$).
Conclusions: When evaluating movement during a functional task, the clinician should consider regional differences in the lumbar spine, pattern of movement, and lower extremity movement.

1. Introduction

Low back pain (LBP) is a common musculoskeletal condition that affects one third of the American population at any given point in time and up to 80% of Americans will experience LBP at some point during their lifetime (Andersson, 1999). Chronic low back pain is most common in working-age adults and is associated with a high number of comorbidities such as depression, anxiety, sleep disorders, and other musculoskeletal and neuromuscular conditions (Gore et al., 2012). Furthermore, LBP is the fifth leading cause of doctor's visits annually with 56.8% of those visits for nonspecific LBP (Freburger et al., 2009). The combination of comorbidities, high rates of prescription drug use, and frequent doctor's visits associated with LBP create a significant financial burden on the healthcare system and economy (Gore et al., 2012; Katz, 2006; Martin et al., 2008).

When evaluating a patient with LBP, physiotherapists often use a movement-based approach to determine what movements may be related to the LBP problem or improve LBP symptoms in order to guide diagnosis and treatment (Sahrmann, 2002). Examining characteristics of functional movements may be of particular importance in people with LBP since functional movements are often repeated across the day, and when impaired, could contribute to the development or persistence of pain. Also, understanding

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movement-based impairments during functional activities in people with LBP can provide a basis for modifying these activities during treatment.

Several factors need to be considered when interpreting spine kinematics during functional activities. Recent studies provide strong evidence that there are regional differences in kinematics between the upper (L1-L3) and lower lumbar spine (L4-L5) (Dankaerts et al., 2006; Mitchell et al., 2008). There is further evidence to support dividing people with LBP into subgroups when examining movement because of the variability in strategies used to accomplish a task and subgroup differences in movement pattern (Dankaerts et al., 2006; Gombatto et al., 2007; Van Dillen et al., 2007). Dankaerts et al. examined kinematics during sitting and reported that differences between LBP and control groups were only evident when the subjects were divided into LBP subgroups, and that movement-based measures can predict subgroup classification (Dankaerts et al., 2006; Dankaerts et al., 2009). Therefore, regional differences in lumbar spine kinematics (upper vs. lower) and LBP subgroups are important factors to consider when interpreting spinal kinematics.

Several investigators have examined lumbar spine and hip kinematics during functional tasks.(Lee et al., 2011; Mitchell et al., 2008; Sanchez-Zuriaga et al., 2011; Shum et al., 2005a,b; 2007). This research supports using kinematic analysis to differentiate between subjects with and without LBP during a lifting task. However, to our knowledge, no study has examined three-dimensional spine and lower extremity kinematics during a multi-planar functional task that is routinely performed during daily activities, differentiating upper and lower lumbar spine segments, between a clinical population of people with LBP and people without LBP, and among movement-based LBP subgroups.

The purpose of this study was to examine differences in three-dimensional lumbar spine and lower extremity kinematics in people with and without LBP during the functional task of picking up an object from the floor. Based on prior research, we hypothesized that people with LBP would demonstrate less lumbar flexion accompanied by greater lumbar rotation as has been reported in previous studies (Lee et al., 2011; Shum et al., 2005b). We expected these movement differences to be most apparent in the lower lumbar spine (Mitchell et al., 2008). Because of the close coupling of the lower extremity and lumbar spine during the pick up task and that the lower extremities were free to move during the task, we also hypothesized that people with LBP would display greater lower extremity flexion compared to controls, in order to accomplish the task. A secondary purpose was to examine kinematic differences among movement-based LBP subgroups during the task.

2. Materials and methods

A cross-sectional observational design was utilized to examine differences in kinematics between people with and without LBP. The study was approved by the Human Subjects Research Committee at Nazareth College (Rochester, NY) and subjects provided written informed consent prior to participating.

2.1. Participants

A sample of thirty-five people between the ages of 18–65 was recruited and tested in the Movement Analysis Laboratory at Nazareth College (Rochester, NY) from January 2011 through May 2013. The sample size was determined based on group differences in kinematics during functional tasks from two pilot studies (Gombatto et al., 2010, 2011). Based on a power analysis, 15 subjects were needed to detect a statistically significant effect (partial $\eta 2 = 0.338$). Eighteen subjects with LBP were recruited from two different outpatient orthopedic clinics where they were seeking treatment. Seventeen control subjects were recruited from the college campus and surrounding community, including physicians offices. Subjects with LBP were included if they reported a primary complaint of LBP for which they sought physical therapy treatment, and were tested prior to commencing treatment. Subjects without LBP were included if they had no history of LBP, and were matched to a subject in the LBP group based on age, gender, height, weight, and BMI. People were excluded from participating if they had a history of serious spinal or medical conditions, physical or mental disabilities, pregnancy, or with a BMI greater than 30 kg/m^2.

2.2. Self-report measures

Subjects with LBP completed self-report questionnaires including a demographics form, Modified Oswestry Disability Index (ODI), Fear-Avoidance Beliefs Questionnaire (FABQ), and a numeric rating scale (NRS) for symptoms of LBP. The modified ODI is a valid and reliable measure to assess perceived disability related to spine conditions (Fritz and Irrgang, 2001). Modified ODI scores range from 0% to 100% with high percentages associated with high disability (Fairbank et al., 1980; Fritz and Irrgang, 2001). The FABQ is an index of fear avoidance beliefs during physical activity and work duties with higher scores indicating increased fear avoidance beliefs due to LBP (Waddell et al., 1993). Subjects with LBP rated their current symptoms and symptoms over the last seven days using an 11-point NRS (0 = no pain, 10 = worst imaginable pain).

2.3. Motion capture measurements

A nine-camera, three-dimensional optical motion capture system (Vicon, Inc.) was used to measure kinematics of the trunk and lower extremities while each subject performed three trials of a pickup task. Retroreflective markers were placed on predetermined anatomical landmarks of the spine, pelvis, and lower extremities (Fig. 1).

The upper lumbar segment was defined by 2 markers 4 cm lateral to the spinous processes of L1 and a single marker on the spinous process of L3. The lower lumbar segment was defined by 2 markers 4 cm lateral to the spinous processes of L4 and a single marker on the spinous process of L5. The pelvis was defined by the markers placed on the posterior superior iliac spine, anterior superior iliac spine, posterior pelvis and iliac crests bilaterally. Three markers were placed on each thigh and lower leg segments bilaterally for lower extremity segments. Calibration markers were placed on the medial and lateral femoral condyles bilaterally for joint center calculations. The custom spine model used in this study was tested for validity and reliability, and demonstrated acceptable validity ($R^2 > 0.84$), high reliability (ICCs>0.97), and low standard error of the measurement for both in-plane (1.4–1.8°) and out-of-plane (0.6–2.4°) movements (Gombatto et al., 2013; Mazzone et al., 2016). The functional method was used to calculate the location of hip joint centers, and an anatomical method was used to calculate knee joint center (Schwartz and Rozumalski, 2005).

2.4. Procedure

A small object of negligible weight (digital metronome) was placed on the floor six inches in front of each subject. The subject was instructed to pick up the object as they normally would, at a self-selected speed and using a self-selected hand. Subjects were then asked to use the same hand to pick up the object across all three trials of the pickup task. Twenty-nine subjects used their right hand, five subjects used their left hand, and one subject used

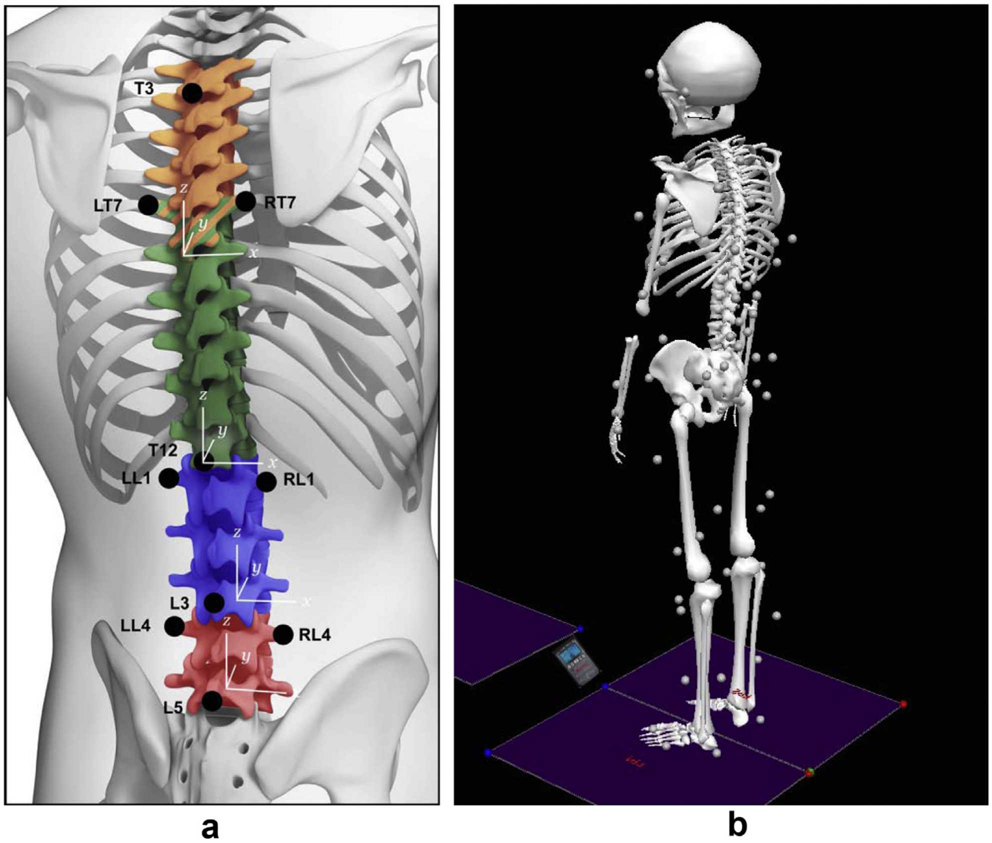

Fig. 1. a Multi-segmental lumbar spine model, reproduced with permission from Elsevier (Gombatto et al., 2015), **b** full body kinematic model.

both hands to pick up the object. To control for hand selection during the task, pick up hand was used as a covariate for all data analyses. During each trial, each subject with LBP was queried to determine whether LBP symptoms increased, decreased, or remained the same as a result of the pick up task. Subjects were considered to have increased symptoms with the task if they reported increased LBP with any one of the three trials.

2.5. Clinical examination

After motion capture testing, a clinical examination was conducted for all subjects with LBP, by a licensed physical therapist with advanced training in the Movement System Impairment (MSI) classification system (first author). Subjects were placed into movement-based subgroups (Rotation, Extension with Rotation, Flexion with Rotation) based on the direction of movement impairments and associated LBP symptoms. The MSI system has been tested and found to be reliable and valid when classifying subjects with LBP into movement-based subgroups (Harris-Hayes and Van Dillen, 2009; Van Dillen et al., 1998).

2.6. Data analysis

Data from the optical motion capture system was post-processed in Nexus (Vicon, Inc) and then exported to Visual-3D (C-motion, Inc.) to quantify 3D kinematics of the upper and lower lumbar spine, hip, and knee. Segment angles were examined and movement time was defined from the start to the end of the down phase of each movement trial. The difference between maximum and minimum angle was calculated, between the start and end of motion, to derive total excursion of each segment in each plane. Measuring angular excursion provides an index of the range of movement, in a particular plane of motion, that the subject was required to control during the task. Excursion measures were used because each person was able to self-select a movement strategy for the task. Because movement strategies and pickup hand varied across individuals, to normalize across all subjects, excursion was calculated to characterize the total amount of sagittal plane (extension to flexion), frontal plane (lateral bending from left to right), and axial plane (rotation from right to left) movement during the task. To characterize pattern of lumbar region movement during the task, movement time was divided into quartiles (0–25%, 25–50%, 50–75%, 75–100%) and change in segment angle within each quartile was calculated for each plane of motion. All kinematic measurements were averaged across the three movement trials.

Independent samples t-tests were used to test for differences between the LBP and control groups for age, gender, height, weight, BMI, and pick up movement time (Table 1). Mixed model ANOVA tests were used to examine the effect of group (LBP, control) and lumbar region (upper, lower) on spine segment excursion and pattern of motion (movement quartiles) in each plane during the pickup task. Mixed model ANOVA tests were used to examine the effect of group and segment (hip, knee) on lower extremity excursion in each plane.

To examine the effect of movement-based subgroup on kinematics during the pickup task, a subgroup analysis was conducted for only the LBP group ($N = 17$). One subject in the LBP group was not included in the subgroup analysis. The subject was unable to complete the clinical examination component of the testing due to time constraints. A repeated measures ANOVA test was used to determine the effect of MSI subgroup (Rotation, Rotation with Extension, Rotation with Flexion) on lumbar spine excursion. All

Table 1
Subject characteristics.

	Low back pain (N = 18)	Control (N = 17)	Statistic, *p*-value
Gender	M = 7, F = 11	M = 7, F = 10	$X^2 = 0.02$, $P = 0.89$
Age (years)	28.1 ± 13.1	25.6 ± 8.7	t = 0.64, $P = 0.53$
Height (cm)	169.9 ± 11.5	167.7 ± 12.9	t = 0.55, $P = 0.58$
Weight (kg)	71.2 ± 15.3	71.1 ± 14.4	t = 0.02, $P = 0.99$
BMI (kg/m^2)	24.4 ± 2.9	25.2 ± 3.5	t = 0.78, $P = 0.44$
Pickup movement time (secs)	1.8 ± 0.4	1.6 ± 0.3	t = 1.74, $P = 0.09$

data analysis was performed using SPSS software (Version 22.0) and significance levels were set at $P < 0.05$. Post-hoc tests were conducted for significant interaction effects.

3. Results

There were no significant differences between groups in age, gender, height, weight, BMI, or pickup movement time (Table 1). Low back pain symptom characteristics are reported in Table 2. Based on subjective report, 70% of subjects reported having a LBP problem >6 months duration, while 30% of subjects reported having a LBP problem of <6 months duration. Three subjects with LBP reported increased LBP with the pick up task.

3.1. Lumbar spine excursion

In the *sagittal* plane, there was a significant group by lumbar region interaction effect ($P < 0.05$). Subjects in the LBP group displayed greater movement in the upper lumbar region (4°) and less in the lower lumbar region (6°) than control subjects (Fig. 2). Separate post hoc t-tests for group differences within each region were not statistically significant ($P > 0.05$). Both groups displayed more lower than upper lumbar region movement in the sagittal plane ($P < 0.05$). There were no significant effects of group or region on *frontal* or *transverse* plane lumbar spine excursion (Ps > 0.05).

3.2. Lumbar spine movement pattern

In the *sagittal* plane, there was a significant group by pattern interaction effect for the upper lumbar region ($P < 0.01$). Specifically, post-hoc t-tests revealed that subjects in the LBP group displayed more upper lumbar flexion during the first 25% of the task than control subjects ($P < 0.01$, Fig. 3). Upper lumbar region movement patterns were not different between groups in the *frontal* or *transverse* planes (Ps > 0.05). Lower lumbar region movement patterns were not different between groups in any plane (Ps > 0.05).

Table 2
Characteristics of the low back pain group.

Low back pain group (N = 18)	Median, Range*
Years of LBP	2.0, 30
Episodes of LBP (last 12 months)	1.5, 15
Pain on VAS (0–100 mm)	29.0, 60
	Mean ± SD*
NRS for average pain last 7 days (0–10)	3.7 ± 2.4
NRS for current pain (0–10)	2.1 ± 1.9
Modified ODI (0–100%)	18.0 ± 12.7
FABQ-PA (0–24)	13.4 ± 4.5
FABQ-W (0–42)	11.5 ± 8.6

* Median and range are provided for characteristics that were not normally distributed; Mean ± standard deviation (SD) is provided for characteristics that are normally distributed.

3.3. Lower extremity kinematics

In the *frontal* plane, there was a significant main effect of group, and a group by region interaction effect (Ps < 0.01, Fig. 4). Subjects in the LBP group displayed more frontal plane movement than control subjects. Specifically, post-hoc t-tests revealed that people with LBP displayed more knee movement in the frontal plane than control subjects ($P < 0.01$). There were no significant effects of group or region on lower extremity kinematics in the *sagittal* or *axial* planes (Ps > 0.05).

3.4. Subgroup analyses

There were no significant main or interaction effects of movement-based LBP subgroup on lumbar spine kinematics in any plane (Ps > 0.05, Fig. 5), but the region by LBP subgroup interaction approached significance ($P = 0.09$, $\eta^2 = 0.33$, observed power = 0.47). Subjects in the Rotation with Flexion subgroup displayed more upper lumbar flexion and lateral bending compared to other subgroups, and people in the Rotation subgroup displayed more lower lumbar lateral bending than other subgroups.

4. Discussion

Several investigators have reported that people with LBP display less flexion movement and greater lumbar spine rotation and lateral bending than people without LBP during a variety of functional tasks (Lee et al., 2011; Mitchell et al., 2008; Shum et al., 2005b, 2007). Specifically with a pick up task, Mitchell et al. reported that all subjects displayed more lower lumbar than upper lumbar spine movement in the sagittal plane, but that history of LBP did not impact movement (Mitchell et al., 2008). Similar to the prior research, we determined that subjects in both groups displayed more lower than upper lumbar spine movement in the sagittal plane during the pickup task. However, we determined that there were group differences in sagittal plane lumbar spine movement that varied based on region. Subjects with LBP displayed less lower but more upper lumbar flexion than control subjects in the sagittal plane. Further, we found no significant differences in lumbar spine rotation and lateral bending between groups during the task.

Findings from the current study may be different from previous studies, because the severity of LBP for subjects in the symptomatic group varies across studies. Mitchell et al. examined young nursing students with a history of LBP, but subjects were not seeking treatment for LBP (Mitchell et al., 2008). The sample examined in the current study, however, is relevant to a clinical population because all subjects with LBP were seeking physical therapy treatment. Another potential explanation for differences across studies is that the current study evaluated a pick up task from a standing position, while Shum et al. evaluated tasks from the sitting position, with a relatively fixed pelvis (Shum et al., 2005b, 2007).

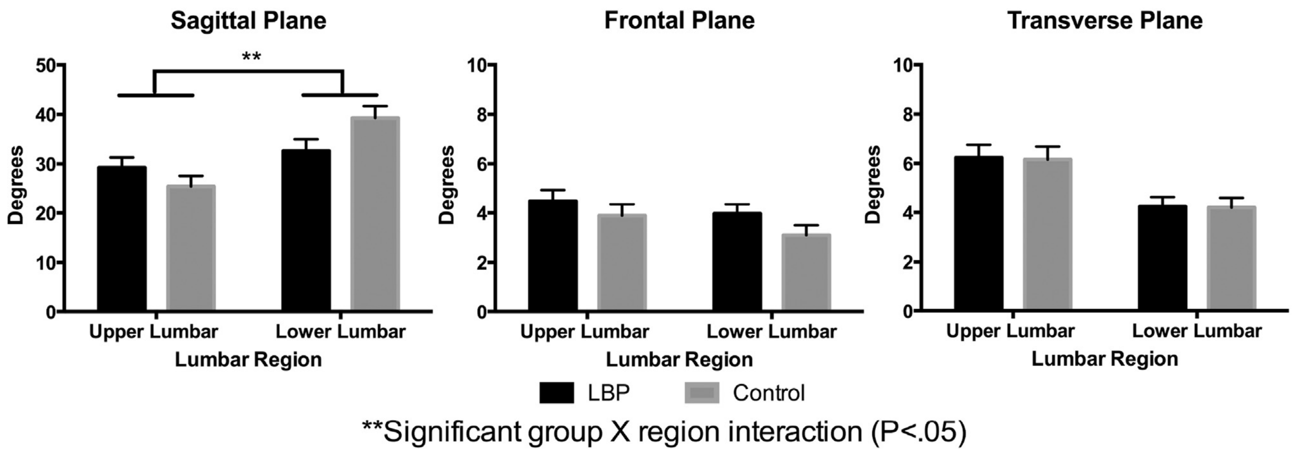

Fig. 2. Mean (±standard error) lumbar spine excursion for people with low back pain (LBP) and without low back pain (Control).

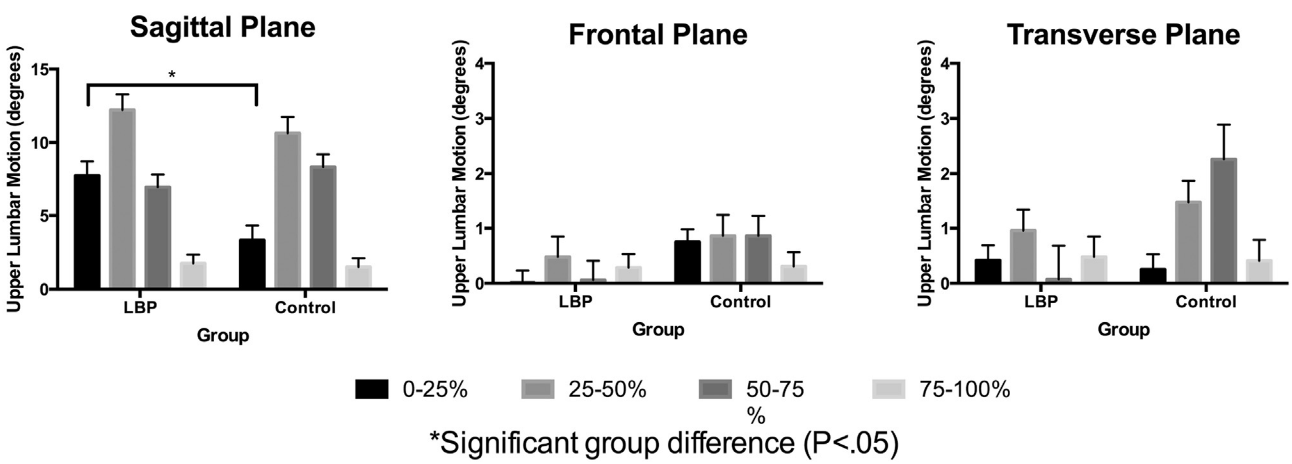

Fig. 3. Mean (±standard error) upper lumbar region movement pattern for people with low back pain (LBP) and without low back pain (Control).

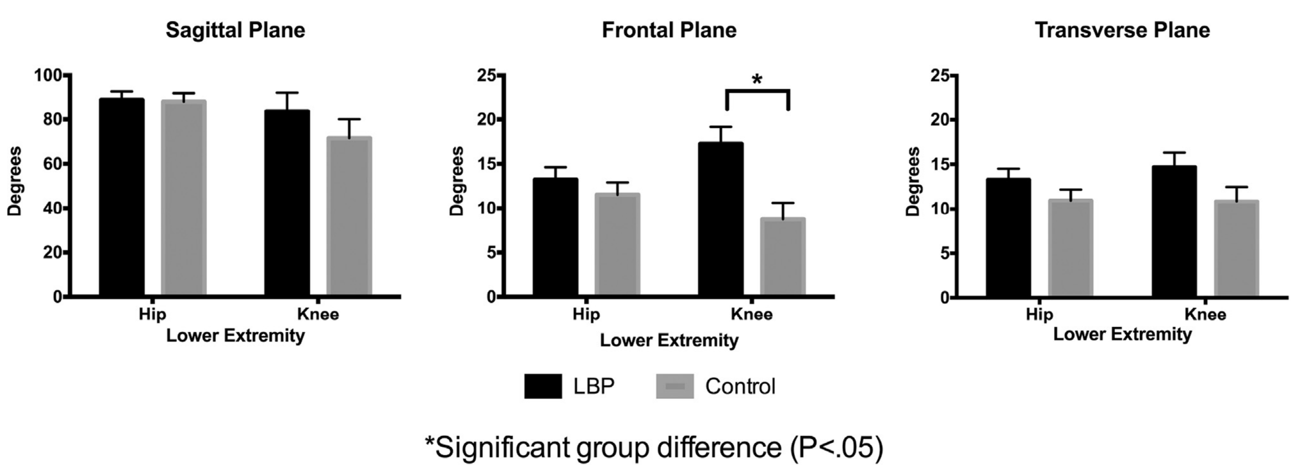

Fig. 4. Mean (±standard error) lower extremity excursion for people with low back pain (LBP) and without low back pain (Control).

Several investigators have examined pattern of lumbar spine motion during a forward bending test movement (Esola et al., 1996; Gatton and Pearcy, 1999; Kanayama et al., 1996; Lee and Wong, 2002). In the current study, when examining pattern of lumbar spine motion during a functional task involving forward bending, groups displayed differences in sagittal plane movement pattern in the upper lumbar region (Fig. 3). Subjects in the LBP group displayed significantly more upper lumbar flexion in the first 25% of the motion than control subjects. These findings are consistent with those of Esola et al., who reported that people with LBP displayed greater early lumbar flexion than people without LBP during a forward bending clinical test movement (Esola et al., 1996). The

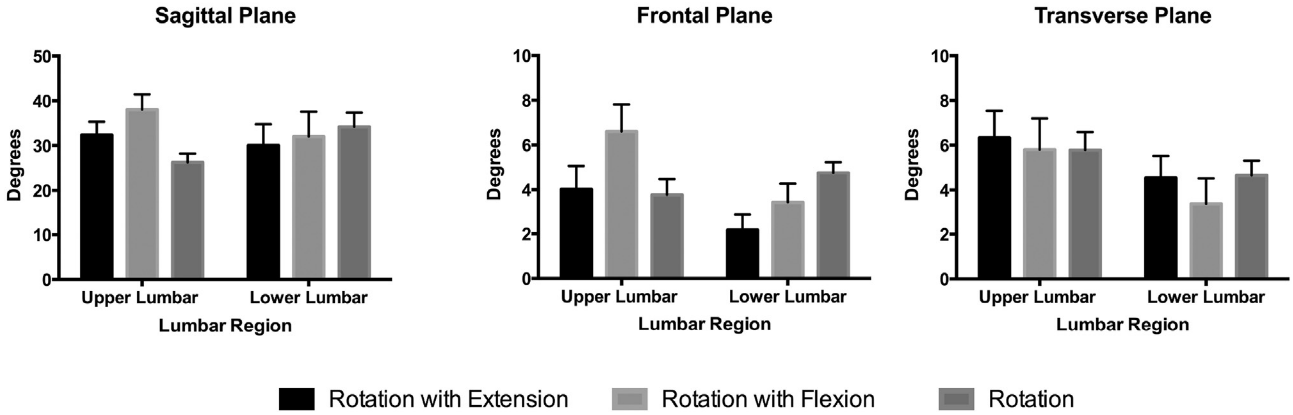

Fig. 5. Mean (±standard error) lumbar spine excursion for low back pain movement-based subgroups.

similarity in findings between the studies may suggest that people with LBP display similar movement patterns during a clinical test of forward bending and related functional activity (pick up task). These data support the need to examine lumbar spine movement throughout the functional task and not only at end-range.

Different from the prior literature, three-dimensional kinematics of the hip and knee were examined in the current study (Mitchell et al., 2008; Shum et al., 2005b, 2007). Subjects with LBP display significantly more frontal plane movement at the knee than control subjects. Greater frontal plane knee movement during functional activities that are repeated across the day, may increase stresses at these lower extremity joints, and be a potential explanation for increased risk of lower extremity injury in people with LBP (Leung et al., 2015; Zazulak et al., 2007).

There are several potential explanations for differences in lumbar spine and lower extremity movement between subjects with and without LBP. Because of the longstanding nature of the LBP problem (median of 2.0 years; Table 2), subjects in the LBP group may limit their motion in the lower lumbar region and alter their movement pattern to consciously or subconsciously avoid pain. Second, over time, subjects with LBP may have alterations in tissue mechanics, limiting lower lumbar region movement and redistributing this motion to the upper lumbar spine and lower extremities (Chan et al., 2012; Freddolini et al., 2014; Gombatto et al., 2008; Ross et al., 2015). Last, movement patterns may differ for subjects with LBP who have received previous therapy, during which they have been encouraged to increase lower extremity and decrease lumbar spine movement when picking up an object off the floor.

Dankaert et al. previously reported differences in lumbar spine kinematics between subgroups of people with LBP and people without LBP during clinical test movements (Dankaerts et al., 2006; Dankaerts et al., 2009). Other investigators have reported differences in lumbopelvic movement characteristics among LBP subgroups (Gombatto et al., 2007; Van Dillen et al., 2007). Although we did not have adequate power to detect subgroup differences, subjects in movement-based subgroups appeared to move in predictable ways during the pick up task. These movement-based subgroup differences are important to consider when evaluating a functional task and modifying movement during intervention.

One limitation of the current study is that a single functional task may not be impaired or provoke pain in all subjects with LBP. Any subject who was seeking care at one of the participating clinics was offered the opportunity to participate. Therefore, the sample was heterogeneous with regard to low back pain severity and chronicity. This heterogeneity may have affected our results, because people with acute LBP may display differences in movement characteristics when compared to people with chronic LBP. However, this sample was very pragmatic of the population of patients seeking care in physical therapy. In the current sample, only three people with LBP reported increased pain during the pickup task. These three individuals reported higher levels of current pain on the NRS (3.3 ± 0.6 compared to 1.8 ± 2.0 for the remainder of the LBP group), but had a shorter history of LBP and fewer episodes of pain in the past 12 months. It is possible that the higher baseline of pain contributed to the pain experienced and lumbar spine and lower extremity kinematics during the task. A second limitation is that the power to detect movement-based subgroup differences was limited by sample size. However the current data supports that future research is needed with larger sample sizes to investigate kinematic differences among LBP subgroups during functional activities. Last, common to surface marker measurement approaches, there is the potential for skin motion artifact that may impacts kinematic measures. However, it is unlikely that skin motion artifact would be systematically different between the groups and explain the findings reported on in the current study. Further, because of the magnitude of measurement error (~2°) relative to the degree of movement in the frontal and axial planes (~4–6°), it is possible that there was a group difference in these planes of movement during the task that could not be detected with the motion capture measures.

5. Conclusions

Difference in sagittal plane movement of the lumbar spine between subjects with LBP and controls was dependent on lumbar spine region (upper vs. lower) during the down phase of a pickup task. Although there were no significant group differences in total excursion within each lumbar spine region, subjects with LBP displayed significantly more upper lumbar region flexion than control subjects during the early phases of the task. Last, subjects with LBP display more frontal plane knee movement than controls during the pick up task. Clinicians need to consider lumbar spine regional differences, pattern of movement, and lower extremity motion when evaluating movement during functional tasks in people with LBP and modifying movement during intervention. More studies are needed to examine kinematic differences among movement-based LBP subgroups.

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Conflicts of interest

None.

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