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Differences in end-range lumbar flexion during slumped sitting and forward bending between low back pain subgroups and genders

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Abstract

Patterns of lumbar posture and motion are associated with low back pain (LBP). Research suggests LBP subgroups demonstrate different patterns during common tasks. This study assessed differences in end-range lumbar flexion during two tasks between two LBP subgroups classified according to the Movement System Impairment model. Additionally, the impact of gender differences on subgroup differences was assessed. Kinematic data were collected. Subjects in the Rotation (Rot) and Rotation with Extension (RotExt) LBP subgroups were asked to sit slumped and bend forward from standing. Lumbar end-range flexion was calculated. Subjects reported symptom behavior during each test. Compared to the RotExt subgroup, the Rot subgroup demonstrated greater end-range lumbar flexion during slumped sitting and a trend towards greater end-range lumbar flexion with forward bending. Compared to females, males demonstrated greater end-range lumbar flexion during slumped sitting and forward bending. A greater proportion of people in the Rot subgroup reported symptoms with each test compared to the RotExt subgroup. Males and females were equally likely to report symptoms with each test. Gender differences were not responsible for LBP subgroup differences. Subgrouping people with LBP provides insight into differences in lumbar motion within the LBP population. Results suggesting potential consistent differences across flexion-related tasks support the presence of stereotypical movement patterns that are related to LBP.

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INTRODUCTION

Low back pain (LBP) may be related to patterns of lumbar postures and movements used to perform different tasks, but it is unclear which patterns with which tasks contribute to LBP. For example, increases in both lumbar flexion and extension have been linked to LBP. Some studies have reported increased lumbar flexion in people with LBP during activities involving flexion, such as golfing and cycling (Lindsay and Horton, 2002; Burnett et al., 2004). Other studies have reported that increased lumbar extension is associated with LBP during sitting (Vergara and Page, 2002). Inconsistent findings regarding the direction of increased lumbar movement or the presence of flexed versus extended postural alignment potentially associated with LBP may be due to the inclusion of subjects with widely varying movement patterns in a single LBP group. Several researchers have proposed that there are subgroups of people with LBP whose symptoms are associated with different direction-related postures or movement patterns (e.g., flexion- or extension-related) (Van Dillen et al., 2003; Fritz et al., 2006; Dankaerts et al., 2006B).

If multiple LBP subgroups are studied as a single population, differences between subgroups demonstrating patterns in opposite directions could average out to suggest no difference in motion between people with and without LBP. When subgrouping was not included in the study design, several studies found no differences in lumbar postural alignment and motion between people with and without LBP (Battie et al., 1990; Esola et al., 1996; Ferguson et al., 2004). Still other studies found that decreased lumbar motion is associated with LBP (Rudy et al., 1995; Porter and Wilkinson, 1997; Adams et al., 1999; Wong and Lee, 2004). Lumbar postural alignment and motion characteristics associated with LBP may be more clearly identified when people with LBP are subgrouped based on lumbar patterns associated with symptoms.

Systems of subgrouping people with LBP have allowed researchers to identify consistent differences in lumbar posture and motion between people with flexion- or extension-related LBP symptoms and people without LBP. O'Sullivan has described a system based, in part, on lumbar posture and movement patterns (O'Sullivan, 2005; Dankaerts et al., 2006B). Studies that subgrouped people with LBP using O'Sullivan's system reported that during typical sitting men with flexion-related LBP sat closer to their end-range of available lumbar flexion compared to men without LBP (O'Sullivan et al., 2006) and that people in a flexion-related subgroup sat in more lumbar flexion than people without LBP and people in an extension-related subgroup (Dankaerts et al., 2009). Additionally, during slumped sitting, investigators found that people with extension-related LBP demonstrated less end-range lumbar flexion than people with flexion-related LBP and people without LBP (Dankaerts et al., 2006a). Finally, these investigators also found that people with extension-related LBP demonstrated less end-range lumbar flexion during forward bending than people with flexion-related LBP (Dankaerts et al., 2009). Investigators using the Movement System Impairment (MSI) model for LBP (Sahrmann, 2002) found that while there were no differences in standing lumbar alignment between people with and without LBP, when subgrouped, people with LBP in an extension-related subgroup stood in more lumbar extension than people with LBP in a flexion-related subgroup and people without LBP (Norton et al., 2004). Differences in end-range lumbar flexion during flexion-related tasks between subgroups based on the MSI model have not been studied.

LBP may also be related to certain tasks. Some tasks, such as prolonged sitting and frequent forward bending, increase the risk of developing LBP (Andersson, 1981; Williams et al., 1991; Lotters et al., 2003). However, the growing understanding of subgrouping suggests that the risk of LBP may be influenced not only by *what* task is performed, but *how* high-risk tasks are performed. The current study examines end-range lumbar flexion during two

common high-risk tasks: slumped sitting and standing forward bending. End-range lumbar flexion, as opposed to total lumbar flexion range of motion, was selected because we were only interested in the final position of the lumbar spine. Greater absolute amounts of lumbar flexion, regardless of an individual's starting position, may indicate greater lumbar tissue laxity and a reduced ability of the passive structures of the lumbar spine to provide stability, particularly in resisting flexion. These tissue characteristics may place people at greater risk for tissue injury and pain (McGill and Cholewicki, 2001; Adams et al., 2002). The specific tasks examined in the current study were chosen because they are both common flexion-related tasks, but differ in the static versus dynamic nature of the task. We will assess the consistency of flexion-related patterns across these tasks for two LBP subgroups classified based on the MSI model.

Differences in lumbar posture and motion between LBP subgroups could be influenced by gender differences. Previous studies of differences in lumbar flexion between LBP subgroups included more males in flexion-related groups and more females in extension-related groups (Dankaerts et al., 2006a; Dankaerts et al., 2009). One study comparing people with flexion-related LBP to people without LBP included only male subjects (O'Sullivan et al., 2006). The imbalance in gender distributions in past studies may have influenced the subgroup findings. In the back-healthy population, it has been reported that men tend to adopt sitting postures and perform movements, such as forward bending, with greater lumbar flexion than women (Dunk and Callaghan, 2005; Norton et al., 2005). Additionally, men tend to stand in more lumbar flexion and women in more lumbar extension (Norton et al., 2004). These findings suggest that, when there are uneven distributions of males and females, differences in posture and movement patterns between genders could influence differences found between LBP subgroups. The current research will assess whether subgroup differences are independent of potential gender differences by incorporating comparable distributions of males and females within each subgroup.

The purpose of this study was to examine the effects of LBP subgroup, classified based on the MSI model, on lumbar end-range flexion and symptom behavior with a flexed posture (slumped sitting) and a flexion-related movement (forward bending). The study included the two most prevalent of five LBP subgroups studied to date: Rotation (Rot) and Rotation with Extension (RotExt) (Gombatto et al., 2007; Van Dillen et al., 2007). The Rot subgroup demonstrates patterns of posture and motion and LBP symptoms during tests associated with lumbar rotation, flexion, and extension. The RotExt subgroup demonstrates patterns of posture and motion and LBP during tests associated with lumbar rotation, and extension, but not flexion. We predicted that the Rot subgroup would display greater end-range lumbar flexion with slumped sitting and forward bending compared to the RotExt subgroup, and that the Rot subgroup would be more likely to report increased symptoms with both tasks than the RotExt subgroup. A secondary purpose was to examine differences in end-range lumbar flexion between males and females and the effect of such differences on LBP subgroup results. We predicted that males would show greater end-range lumbar flexion than females, regardless of LBP subgroup, and that gender effects would not be specific to either LBP subgroup.

METHODS

Subjects

Subjects in this study were part of a larger clinical trial comparing the effectiveness of two physical therapy treatments for chronic, non-specific LBP. Pre-treatment data from subsets of these subjects were analyzed for this study. Average subject age, height, weight, BMI, years since onset of LBP, current pain, and modified Oswestry LBP disability score are reported in Table 1. Subjects were 18–60 years old with chronic LBP, as defined by Von

Korff (1994). During testing, subjects were experiencing typical LBP symptoms, but were not in an acute flare-up (Von Korff, 1994). Subjects were excluded if their symptoms were magnified (Waddell et al., 1980); they displayed a primary hip problem; or if they had a history of spinal deformity, disc herniation, spinal fracture or surgery, pain or parasthesia below the knee, systemic inflammatory condition, or other serious medical condition. Additionally, subjects were excluded if they needed assistance to walk, were pregnant, were involved in litigation for their LBP, were receiving disability or worker's compensation benefits, or were referred from a specialized pain clinic. Approval for the use of human subjects was granted by the university's Human Research Protection Office. All subjects provided informed consent before participation.

Subjects participated in two different tests: slumped sitting and forward bending in standing. For the slumped sitting test, data were analyzed for 40 subjects, 20 classified as the Rot subgroup (10 male, 10 female) and 20 classified as the RotExt subgroup (10 male, 10 female). For the forward bending test, data were analyzed for 43 subjects, 25 classified as the Rot subgroup (13 male, 12 female) and 18 classified as the RotExt subgroup (8 male, 10 female). There were 29 subjects that were included in both the slumped sitting and forward bending data sets.

Clinical Examination

Subjects participated in a standardized examination based on the MSI model for LBP (Van Dillen et al., 1998; Sahrmann, 2002; Van Dillen et al., 2003; Norton et al., 2004; Trudelle-Jackson et al., 2008; Harris-Hayes and Van Dillen, 2009; Henry et al., 2009), performed by one of three trained physical therapists (range 2–28 years of experience). Based on postures and directions of lumbar motion consistently observed across the examination and associated with LBP symptoms, subjects were classified into one of five LBP subgroups, of which the most prevalent subgroups are Rot and RotExt (Van Dillen et al., 1998; Van Dillen et al., 2003). These two subgroups were included in the current study. Prior to the examination, subjects completed a set of self-report questionnaires that included a demographic and medical/LBP history questionnaire (Deyo et al., 1994), a verbal numeric rating scale of current LBP symptoms (Jensen et al., 1994), and the modified Oswestry LBP disability questionnaire (Fritz and Irrgang, 2001). Subjects reported whether their LBP symptoms increased, decreased, or stayed the same relative to the initial positions during the tests of slumped sitting and forward bending. Subject responses were separated into two categories for analysis: increase in LBP symptoms or no increase in LBP symptoms.

Kinematic Data Collection

For the slumped sitting test, subjects were sitting on a bath bench, adjusted so that their thighs were parallel to the floor, hip and knee angles were $\sim 90^\circ$, feet were flat on the floor, and lumbar spine was in a neutral position. Then they were asked to sit slumped. For the forward bending test, subjects started in standing, feet hip width apart, and were asked to bend as far forward as they could without bending their knees.

Kinematic data were collected using a six-camera, 3D motion capture system (EVaRT, Motion Analysis Corporation, Santa Rosa, CA, USA). Six retro-reflective markers were taped to the skin in the following locations: 7 cm bilateral to the first lumbar vertebra (L1), fifth lumbar vertebra (L5), second sacral vertebra (S2), greater trochanters, and lateral knee joints. Sagittal end-range lumbar flexion was calculated as the angle composed of a vector connecting the L5 marker and the midpoint of the bilateral L1 markers and a vector connecting the S2 and L5 markers in the sagittal plane (Figure 1). Zero was defined as when the two vectors were collinear. Due to the possibility of hip flexibility affecting lumbar motion during forward bending, hip flexion was also assessed. Hip flexion was calculated as

the angle between the vector connecting the S2 and L5 markers and the vector connecting the right lateral knee and the right greater trochanter markers in the sagittal plane for forward bending (Figure 1). Zero was defined as when these vectors were parallel. Data were sampled at 60 Hz. Data were initially filtered using a fourth order, dual-pass, Butterworth filter with a cut-off frequency of 2.0 Hz to identify movement initiation and termination. Because subjects performed the test movement at self-selected speeds, a filtering frequency based on individual movement times was then used (Winter, 1990). Raw data were re-filtered at subject-specific frequencies (ranges for slumped sitting: 1.4–9.1 Hz, and forward bending: 1.8–5.2 Hz), calculated as the reciprocal of 15% of the period of movement with the following equation: $1/[0.15 * (\text{movement time})]$, based on individual lumbar segment movement times.

For slumped sitting, lumbar movement initiation was identified when the angle changed 2° and reached 10% of its maximum velocity; movement termination was identified when the lumbar angle reached 97% of its maximum angle and 15% of its maximum velocity. For forward bending, movement initiations and terminations were calculated based on the change of the combined spine and hip flexion angles. Movement initiation was identified when the combined angle changed 5° and reached 7% of its maximum velocity; movement termination was identified when the combined angle reached 99.5% of the maximum angle.

Data Analysis

Data were analyzed for the end-range lumbar flexion angles achieved at movement termination during slumped sitting and for the end-range lumbar and hip flexion angles achieved at movement termination during forward bending (Figure 1). To compare baseline subject characteristics and angles between subgroups and genders, 2×2 analysis of variance tests were performed. The 95% confidence intervals (CI) around the mean differences were calculated for each main effect. Finally, to estimate effect size, partial eta squared (η^2) values were calculated. The following guidelines were used to interpret these values: small $\eta^2=0.01$, medium $\eta^2=0.06$, large $\eta^2=0.14$ (Cohen, 1988). Logistic regression analyses were used to compare symptom behavior during the slumped sitting and forward bending tests based on subgroup and gender. Odds ratios with 95% CIs were also calculated to estimate effect size.

RESULTS

Subject Characteristics

For both samples of subjects, males were significantly taller and heavier than females ($P<0.01$). There were no differences in age, body mass index, years since pain onset, current pain or modified Oswestry LBP disability score between subgroups or genders for either slumped sitting or forward bending ($P>0.05$) (Table 1).

Slumped Sitting

As predicted, the Rot subgroup displayed greater end-range lumbar flexion ($M=7.22^\circ$, $SE=2.01^\circ$) than the RotExt subgroup ($M=0.72^\circ$, $SE=2.06^\circ$) during slumped sitting ($P=0.02$; $CI=[0.92 \text{ to } 12.08]$; $\eta^2=0.13$). The effect of gender did not appear to be specific to either subgroup as there was no interaction between subgroup and gender for end-range lumbar flexion ($P=0.26$). For both subgroups, males displayed greater end-range lumbar flexion than females (males: $M=6.83^\circ$, $SE=1.89^\circ$; females: $M=1.10^\circ$, $SE=2.23^\circ$; $P=0.04$; $CI=[0.15 \text{ to } 11.31]$; $\eta^2=0.11$) (Figure 2).

Forward Bending

End-range lumbar flexion between subgroups was not statistically significantly different. However, in line with our prediction, there was a trend towards greater end-range lumbar flexion for the Rot subgroup ($M=11.02^\circ$, $SE=1.17^\circ$) compared to the RotExt subgroup ($M=6.92^\circ$, $SE=1.85^\circ$) during standing forward bending ($P=0.07$; $CI=[-0.31 \text{ to } 7.59]$; $\eta^2=0.08$). Hip angles were not different between the two LBP subgroups (Rot: $M=88.05^\circ$, $SE=2.48^\circ$; RotExt: $M=89.41^\circ$, $SE=3.58^\circ$; $P=0.90$; $CI=[-8.25 \text{ to } 7.31]$; $\eta^2<0.001$). The effect of gender did not appear to be specific to either subgroup as there were no interactions between subgroup and gender for end-range lumbar ($P=0.53$) or hip ($P=0.82$) flexion angles. For both subgroups, males displayed greater end-range lumbar flexion (males: $M=12.21^\circ$, $SE=1.52^\circ$; females: $M=6.53^\circ$, $SE=1.25^\circ$; $P=0.01$; $CI=[3.58 \text{ to } 9.04]$; $\eta^2=0.18$) (Figure 3) and less end-range hip flexion (males: $M=82.28^\circ$, $SE=2.71^\circ$; females: $M=94.66^\circ$, $SE=2.51^\circ$; $P<0.01$; $CI=[4.41 \text{ to } 19.98]$; $\eta^2=0.21$) (Figure 4) than females.

Symptoms

As predicted, a greater proportion of subjects in the Rot subgroup compared to the RotExt subgroup reported an increase in symptoms with both slumped sitting ($P=0.01^a$; $OR=7.00$; $CI=[1.74 \text{ to } 28.17]^b$) and forward bending ($P=0.03^a$; $OR=4.25$; $CI=[1.17 \text{ to } 15.45]^b$). The effect of gender did not appear to be specific to either subgroup as there was no interaction between subgroup and gender for symptom behavior with slumped sitting ($P=0.26$) or forward bending ($P=0.55$). Equal proportions of men and women reported an increase in symptoms with slumped sitting ($P=0.29^a$; $OR=0.55$; $CI=[0.16 \text{ to } 1.91]^b$) and forward bending ($P=0.74^a$; $OR=1.09$; $CI=[0.33 \text{ to } 3.62]^b$) (Table 2).

DISCUSSION

In this study, two LBP subgroups, classified according to the MSI model, demonstrated predictable differences in end-range lumbar flexion across two flexion-related tasks. Subjects in the Rot subgroup displayed significantly greater end-range lumbar flexion during slumped sitting and a trend towards greater end-range lumbar flexion during forward bending than subjects in the RotExt subgroup. Despite no differences between subgroups in current pain on the day of testing (Table 1), the Rot subgroup was also more likely to report increased symptoms with both tasks than the RotExt subgroup. During both slumped sitting and forward bending, males displayed greater end-range lumbar flexion than females; however, the subgroup differences identified were not the result of gender differences in end-range lumbar flexion. Comparable distributions of males and females in each subgroup were used and no interactions between subgroup and gender on end-range lumbar flexion were present. These findings support recommendations of subgrouping people with LBP by demonstrating that subgroups of people with LBP differ in amounts of end-range lumbar flexion during tests of posture and potentially during movement (Van Dillen et al., 2003).

The findings of the current study are consistent with previous research on slumped sitting and typical sitting. A prior study demonstrated that during slumped sitting, subjects in a flexion-related LBP subgroup sat in more end-range lumbar flexion compared to an extension-related LBP subgroup (Dankaerts et al., 2006a). Prior studies also demonstrated that during typical sitting, subjects in a flexion-related LBP subgroup sat in more lumbar flexion compared to an extension-related LBP subgroup (Dankaerts et al., 2006a; Dankaerts et al., 2009). The results of the current study are also consistent with others' observations of end-range lumbar flexion during forward bending in people with LBP. Dankaerts et al

^a*P* value associated with logistic regression analysis.

^b95% confidence interval for the odds ratio.

(2009) found that subjects in a flexion-related LBP subgroup had greater end-range lumbar flexion with forward bending compared to subjects in an extension-related LBP subgroup.

The current study also indicates that gender is a factor in end-range lumbar flexion during flexion-related tasks. The findings are consistent with research on back-healthy subjects showing males adopt greater lumbar flexion than females during prolonged sitting and that males have greater lumbar flexion and less hip flexion compared to females during forward bending and a reaching task involving forward bending (Thomas et al., 1998; Dunk and Callaghan, 2005; Norton et al., 2005). In the current study, a similar relationship between lumbar flexion exhibited by men and women during slumped sitting and forward bending was also evident in people with LBP.

One possible reason for differences in end-range lumbar flexion between genders and subgroups could be differences in hip movement. During forward bending, reduced hip flexion might contribute to greater end-range lumbar flexion. This could explain differences between males and females observed in this study, where greater lumbar flexion corresponded to reduced hip flexion for males compared to females. It is logical that decreased hamstring flexibility could limit hip flexion motion during forward bending, thereby encouraging greater lumbar flexion to compensate. Studies of healthy individuals have demonstrated that males have reduced hamstring flexibility compared to females (Blackburn et al., 2004; Davis et al., 2008). Although there is some evidence to suggest a relationship between reduced hamstring flexibility and decreased pelvic or hip flexion during forward bending in healthy individuals (Gajdosik et al., 1992; Gajdosik et al., 1994) and in people with LBP (Esola et al., 1996), the evidence regarding the relationship between hamstring flexibility and lumbar flexion is equivocal and the studies are limited methodologically (Gajdosik et al., 1992; Gajdosik et al., 1994; Esola et al., 1996; Thomas et al., 1998). On the other hand, the amount of hip flexion may not influence differences in end-range lumbar flexion between subgroups. There were differences in end-range lumbar flexion between subgroups, but not in end-range hip flexion during forward bending. This may suggest that hip flexibility affecting lumbar motion is not the main issue differentiating subgroups, but rather the issue may be related to the consistent demonstration of lumbar flexion *across* tasks.

The finding of differences in end-range lumbar flexion between genders and subgroups across two different flexion-related tasks provides some support to the proposal that people adopt directional, stereotypic patterns of posture and movement. The frequent use of a limited repertoire of stereotypic posture and movement patterns used across many daily activities could lead to microtrauma to lumbar region tissues (Sahrmann, 2002). It has been proposed that a cycle of spinal ligament subfailure leading to changes in neuromuscular control and subsequent tissue injury plays a role in LBP (Panjabi, 2006). Repeated use of end-range flexion across many tasks could potentially result in tissue changes that reduce spinal stability and put people at risk for tissue damage, injury, and pain (McGill and Cholewicki, 2001; Adams et al., 2002; Sbriccoli et al., 2004). For flexion-related LBP subgroups, during postures maintained for long periods of time (e.g., slumped sitting), passive structures could lose their ability to support the spine. During movements that take the lumbar spine into a great amount of lumbar flexion (e.g., forward bending), the combination of stereotypic movement patterns involving exaggerated end-range flexion and tissue laxity from prior exposure to flexion postures could promote greater repeated use of certain tissues and further injury to the lumbar spine.

The current study lends support to the proposal that repeated adoption of end-range lumbar flexion during many tasks may put people at greater risk for pain during flexion. The Rot subgroup, which showed a pattern of greater lumbar flexion during slumped sitting and

forward bending than the RotExt subgroup, were more likely to report symptoms during both tests. However, males, who showed greater lumbar flexion during slumped sitting and forward bending than females, were not more likely to report symptoms during either test. Differences in symptoms during both slumped sitting and forward bending found between subgroups, but not between genders, suggest that increased end-range flexion values alone do not directly correspond to an increased likelihood of LBP symptoms. We would propose that the interaction of increased end-range motion, paired with decreased movement variability across activities and an increased likelihood of performing repeated end-range motions, is what sets a person up to develop pain. For the Rot subgroup, avoiding lumbar flexion, particularly end-range lumbar flexion, may be an important component of treatment.

The results of this study add further evidence suggesting a link between LBP and lumbar posture and movement patterns. However, we recognize that there are limitations to the current study. First, there is no back-healthy control group. The primary purpose of this study was to compare end-range lumbar flexion between two subgroups of people with LBP. Gender differences in end-range lumbar flexion were analyzed to understand the potential effect of gender on LBP subgroup differences. Therefore, while including a back-healthy control group would provide even more information, the study objectives were able to be completed and we believe the results still lend valuable insight into potential mechanisms underlying LBP. Second, the difference in end-range lumbar flexion between LBP subgroups during forward bending did not reach statistical significance. Considering that the confidence interval around the mean difference barely included 0, and was relatively wide, the sample size likely was too small to detect this difference (Fletcher et al., 1996). However, we believe that the trend towards statistical significance during forward bending combined with the statistically significant difference in end-range lumbar flexion between subgroups during slumped sitting reveals a pattern toward greater end-range lumbar flexion for the Rot subgroup across activities. Third, it is unclear to what extent the differences in end-range lumbar flexion noted in the current study are clinically significant. To our knowledge, no studies have reported a particular value for which a difference in end-range lumbar flexion is considered clinically significant. However, given the effect sizes for the differences noted in the current study, we believe they are important. Finally, the limitation in the accuracy of using surface markers to measure kinematics should be noted.

A greater understanding of the mechanisms that contribute to LBP development, persistence, and recurrence can provide information to guide preventative and rehabilitative treatments for LBP. Subgrouping people with LBP may allow for treatments that target the posture and movement patterns most related to symptoms. Treatments emphasizing modifying lumbar movement patterns based on LBP subgrouping are showing promise (Hoffman et al., 2011; Ravenna et al., 2012). Additional research on LBP subgroups can provide further insight into the posture and movement patterns that contribute to LBP and how this information can be used to improve the care of people with LBP.

CONCLUSION

People in the Rot subgroup displayed more end-range lumbar flexion during slumped sitting and forward bending than people in the RotExt subgroup. Men displayed greater end-range lumbar flexion than women during both slumped sitting and forward bending. Differences found between subgroups, however, were not related to gender differences. These results support the proposal that people with LBP display stereotypic patterns of posture and movement. They also support the need for subgrouping people with LBP based upon patterns of posture and movement and symptoms consistently displayed across tasks. An increased understanding of differences between subgroups of people with LBP is necessary

to understand what contributes to LBP problems and to guide preventative and rehabilitative treatment strategies.

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Figure 1.

Left: posterior view of kinematic marker locations: 7 cm left (L1-L) and right (L1-R) of the first lumbar vertebra, at the fifth lumbar vertebra (L5), at the second sacral vertebra (S2), on right greater trochanter (GT), and on the right lateral knee line (LK). **Middle:** sagittal view of lumbar angle calculated from a line between the mid-point of the L1 markers (L1-M) and L5 relative to a line between L5 and S2 kinematic markers and hip angle calculated from a line between L5 and S2 relative to a line between the GT and LK kinematic markers during forward bending. **Right:** sagittal view of lumbar angle calculated from a line between the mid-point of the L1 markers and L5 relative to a line between L5 and S2 kinematic markers during slumped sitting.

Figure 2. Lumbar end-range flexion angle means and standard errors during slumped sitting for males and females, and within the rotation (Rot) and rotation with extension (RotExt) subgroups. Main effects with $P < 0.05$ are indicated by an asterisk (*).

Figure 3. Lumbar end-range flexion angle means and standard errors during forward bending for males and females and within the rotation (Rot) and rotation with extension (RotExt) subgroups. Main effects with $P < 0.05$ are indicated by an asterisk (*) and with $P < 0.07$ by *'.

Figure 4. Hip end-range flexion angle means and standard errors during forward bending for males and females and within the rotation (Rot) and rotation with extension (RotExt) subgroups. Main effects with $P < 0.05$ are indicated by an asterisk (*).

Table 1

Subject characteristic means and standard deviations for males, females, and combined genders (Total columns) within the Rotation (Rot) and Rotation with Extension (RotExt) subgroups and combined subgroups (Total rows) for tests of slumped sitting and forward bending.

	Slumped Sitting ^a			Forward Bending ^b		
	Male	Female	Total	Male	Female	Total
Age (yrs)						
Rot	42 (11)	45 (10)	44 (10)	40 (10)	46 (11)	42 (11)
RotExt	48 (7)	42 (14)	45 (11)	48 (8)	41 (13)	44 (11)
Total	45 (9)	43 (12)	44 (11)	43 (10)	44 (12)	43 (11)
Height (cm) ^c						
Rot	174 (11)	162 (5)	168 (10)	178 (10)	160 (4)	169 (12)
RotExt	178 (7)	163 (5)	171 (10)	177 (6)	163 (9)	170 (10)
Total	176 (9)	163 (5)	170 (10)	178 (8)	162 (7)	169 (11)
Weight (kg) ^c						
Rot	79 (11)	67 (4)	73 (11)	81 (11)	65 (8)	73 (13)
RotExt	84 (13)	68 (9)	76 (13)	86 (12)	67 (10)	76 (14)
Total	81 (12)	68 (7)	75 (12)	83 (12)	66 (9)	74 (13)
Body Mass Index (kg/m ²)						
Rot	26 (3)	25 (2)	26 (2)	26 (3)	25 (3)	25 (3)
RotExt	26 (3)	26 (3)	26 (3)	27 (4)	25 (3)	26 (3)
Total	26 (3)	26 (3)	26 (3)	26 (3)	25 (3)	26 (3)
Pain Onset (yrs)						
Rot	11 (8)	16 (10)	13 (9)	12 (7)	12 (9)	12 (8)
RotExt	13 (11)	10 (8)	12 (9)	7 (5)	8 (8)	8 (6)
Total	12 (9)	13 (9)	12 (9)	10 (7)	10 (9)	10 (8)
Current Pain (0–10) ^d						
Rot	3.6 (1.8)	3.5 (2.0)	3.5 (1.9)	3.4 (1.9)	3.0 (1.6)	3.2 (1.7)
RotExt	3.6 (2.1)	2.0 (1.8)	2.8 (2.1)	3.0 (2.1)	1.6 (1.2)	2.2 (1.8)
Total	3.6 (1.9)	2.7 (2.0)	3.1 (2.0)	3.2 (1.9)	2.4 (1.6)	2.8 (1.8)
Modified Oswestry (%) ^e						
Rot	21 (11)	16 (10)	23 (11)	21 (9)	24 (11)	23 (10)
RotExt	19 (9)	17 (7)	18 (8)	18 (7)	18 (6)	18 (6)
Total	20 (10)	21 (9)	20 (9)	20 (8)	21 (10)	21 (9)

^a Slumped sitting male, female, Rot, and RotExt: n=20

^b Forward Bending male: n=21, female: n=22, Rot: n=25, RotExt: n=18

^c Main effect of gender for both tests ($P<0.05$)

^d Patient report of current pain on verbal numeric pain rating scale between 0 (no pain) and 10 (pain as bad as can be)

^e Modified Oswestry score between 0% (no LBP-related disability) and 100% (maximal LBP-related disability)

Table 2

Percentage of males, females, and combined genders (Total columns) within the Rotation (Rot) and Rotation with Extension (RotExt) subgroups and combined subgroups (Total row) reporting increased symptoms during slumped sitting and forward bend tests.

	Slumped Sitting ^a			Forward Bending ^a		
	Male (n=20)	Female (n=20)	Total (n=40)	Male (n=21)	Female (n=22)	Total (n=43)
Rot (n=20)	90%	60%	75%	69%	67%	68%
RotExt (n=20)	30%	30%	30%	25%	40%	33%
Total (n=40)	60%	45%	53%	47%	54%	50%

^aMain effect of subgroup ($P<0.05$).