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Factors contributing to lumbar region passive tissue characteristics in people with and people without low back pain

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Abstract

Background—Previously, we demonstrated that people in the Rotation with Extension low back pain subgroup display greater asymmetry of passive tissue characteristics during trunk lateral bending than people without low back pain. The purpose of this secondary analysis is to examine factors that explain the group differences.

Methods—Twenty-two people in the Rotation with Extension subgroup, and 19 people without low back pain were examined. Torque, lumbar region kinematics, and trunk muscle activity were measured during passive and isometric resisted trunk lateral bending. The dependent variables were lumbar region passive elastic energy to each side; the independent variables included group, gender, anthropometrics, trunk muscle characteristics, and an interaction factor of group and trunk muscle characteristics. Multiple linear regression was used for the analysis.

Findings—Anthropometrics explained passive measures to the left ($P=.03$). Anthropometrics ($P<.01$), trunk muscle characteristics ($P<.01$), and the interaction of group and trunk muscle characteristics ($P=.01$) explained passive measures to the right. After accounting for gender and anthropometrics, 43.7% of the variance in passive measures to the right was uniquely accounted for by trunk muscle characteristics for the Rotation with Extension subgroup, compared to 0.5% for the group without low back pain.

Interpretation—Anthropometrics explained passive measures with trunk lateral bending to both sides, in both groups. For people in the Rotation with Extension subgroup, there was a direct relationship between trunk muscle performance and passive measures to the right. Muscle is an

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Conflict of interest statement

None of the authors on the current manuscript (Gombatto, Norton, Sahrman, Strube, and Van Dillen) have any financial or personal relationships with other people or organizations that could inappropriately influence (bias) our work.

important contributing factor to asymmetry in this subgroup and should be considered in treatment.

Keywords

Low back; Stiffness; Muscle

1. Introduction

Low back pain (LBP) is a musculoskeletal problem that often can develop into a chronic or recurrent problem (Andersson, 1999). However, the etiology of a LBP problem often is unknown and people are commonly assigned a diagnosis of non-specific LBP (Hart et al., 1995; Kelsey and White, 1980). Identifying homogeneous subgroups of people with LBP is useful for understanding the factors that contribute to different types of LBP problems and for specifying treatment strategies that address the contributing factors. Several examination-based classification systems for LBP have been developed to identify subgroups of people with LBP (Delitto et al., 1995; McKenzie, 1981; Sahrman, 2002). One classification system, the Movement System Impairment (MSI) system, was developed to identify the specific movement and alignment patterns that contribute to the LBP problem (Sahrman, 2002). Subgroups in the MSI system are named based on the directions of lumbar region movement and alignment that are associated with impairments and pain during a clinical examination. Subgroup-specific treatment then focuses on modifying the movement and alignment impairments with the goal of affecting LBP symptoms (Van Dillen and Sahrman, 2006; Van Dillen et al., 2003a, 2003b).

Using both clinical and laboratory measures, prior studies have examined differences in movement patterns between two of the more prevalent LBP subgroups from the MSI system, the Rotation and the Rotation with Extension subgroups (Gombatto et al., 2007; Van Dillen et al., 2003b, 2007). We have reported that people in the Rotation subgroup display symmetrical movement of the lumbar region during both a trunk movement and a limb movement. However, people in the Rotation with Extension subgroup, display asymmetrical lumbar region movement during the trunk and limb movements. Asymmetrical movement patterns in the Rotation with Extension subgroup may contribute to the LBP problem because asymmetrical movements have been reported to increase a person's risk for developing LBP (Marras et al., 1995).

In an effort to understand the relationship between asymmetry and LBP in the Rotation with Extension subgroup, we examined differences in passive tissue characteristics between people in the Rotation with Extension subgroup and people in a No LBP group. In a primary analysis of the data, we reported that people in the Rotation with Extension subgroup displayed greater asymmetry of passive tissue characteristics than people in the No LBP group (Gombatto et al., 2008b). Thus, asymmetry of passive tissue characteristics may be related to the LBP problem in the Rotation with Extension subgroup. This asymmetry may be either a reflection of the fact that people in the Rotation with Extension subgroup move asymmetrically or an explanation for why they move asymmetrically.

To better understand how to address an asymmetry of passive tissue characteristics with treatment, we examined the factors that may explain the identified asymmetries. The specific factors we thought would have an impact on passive properties of the lumbar region included characteristics of the individual such as age, gender, anthropometrics, and physical activity (Beach et al., 2005; Blackburn et al., 2004; Gajdosik et al., 1999; McGill et al., 1994; Parkinson et al., 2004). Anthropometrics were included because variables such as height, weight, waist circumference, and others can be used to characterize body

composition in terms of the amounts of muscle bulk and soft tissue in the lumbar and abdominal regions. Such factors would have the potential to influence measures to both sides in everyone, regardless of low back pain status. Habitual levels of physical activity were included because they may affect relative body composition and mechanical properties of structures that contribute to passive tissue characteristics. We also thought that characteristics of the trunk muscles, such as torque-generating capacity and magnitude of muscle activation, may help explain passive properties of the trunk. The purpose of this study was to conduct a secondary analysis to examine whether characteristics of the individual and of the trunk muscles are related to the measurements of passive tissue characteristics in the Rotation with Extension subgroup and in the No LBP group. We hypothesized that factors such as age, gender, anthropometrics, and activity level would explain passive properties during trunk lateral bending to both sides, and in both groups. Because of the reported asymmetry in passive measures for the Rotation with Extension subgroup, however, we hypothesized that trunk muscle characteristics would explain lumbar region passive tissue characteristics to one side only in the Rotation with Extension subgroup.

2. Methods

2.1. Participants

Participants were selected from a convenience sample of people who responded to advertisements in the community. People who responded were asked a series of questions to determine if they qualified for the study. People were included in the LBP group if they had experienced LBP that (1) limited performance of daily activities for greater than 3 days, or required medical treatment, and (2) had been ongoing for at least 6 months (Von Korff, 1994). People were included in the No LBP group if they had no history of LBP. People were excluded from participating if they had a history of a serious spinal condition (e.g. tumor or infection) or systemic disease affecting the musculoskeletal or neuromuscular system. People with LBP also were excluded from participating if they were in an acute flare-up of their LBP problem (Von Korff, 1994) or if their LBP exceeded 3/10 on an 11-point verbal numeric rating scale (0–10, 10=worst possible pain) on the day of testing (Downie et al., 1978; Jensen et al., 1994). Patients with a pain rating $>3/10$ were excluded from participating because higher levels of pain have the potential to affect a person's ability to relax during passive movements. Excluding patients with higher levels of pain should not have affected our ability to detect lumbar region impairments, because the impairments of interest should be present even if there is no acute flare-up. All participants read and signed an informed consent document that was approved by the Human Studies Committee at Washington University School of Medicine.

2.2. Self-report and clinical measures

Participants completed the following self-report measures: (1) demographic and LBP-history questionnaire (Deyo et al., 1994), (2) verbal numeric rating scale of symptoms and pain body diagram (LBP only) (Downie et al., 1978; Jensen et al., 1994), (3) a modified Oswestry Disability Index (LBP only) (Fritz and Irrgang, 2001), (4) Baecke Habitual Activity questionnaire (Baecke et al., 1982), and the SF-36 Health Status Questionnaire (McHorney et al., 1993). Several anthropometric measures were acquired on the day of testing. The examiner measured height, weight and circumferential measures both at the narrowest point of the waist and at the widest point of the hips. The average of three measures for the waist and hips and the ratio of waist to hip circumference were calculated.

All participants with LBP were examined using a standardized clinical examination and people with LBP were classified into subgroups based on the examination. At the conclusion

of the examination, the participant was assigned to one of the following 5 subgroups: (1) Extension, (2) Flexion, (3) Rotation, (4) Rotation with Extension, or (5) Rotation with Flexion. Details of the examination and classification system have been described in previous publications. Validity and reliability have been studied and found to be acceptable (Harris-Hayes and Van Dillen, 2009; Henry et al., 2009; Norton et al., 2004; Trudelle-Jackson et al., 2008; Van Dillen et al., 1998, 2003b).

Previously we reported that people in the Rotation with Extension subgroup display greater asymmetry of movement compared to other LBP subgroups (Gombatto et al., 2007; Van Dillen et al., 2007). A primary analysis of kinematic and force data on the current sample demonstrated that people in the Rotation with Extension subgroup also display greater asymmetry of passive tissue characteristics compared to people in the No LBP group during passive trunk lateral bending (Gombatto et al., 2008b). The focus of the current report is on examining the factors that explain the asymmetry. Thus, a secondary analysis was conducted on data from twenty-two people in the Rotation with Extension subgroup and nineteen people in the No LBP group.

2.3. Laboratory measurements

The system that was used to measure lumbar region passive tissue characteristics and trunk muscle characteristics consisted of a custom movement device, a motion capture system (Motion Analysis Corporation), and a surface electromyography system (Noraxon USA, Inc.). The system and procedures have been described in detail in prior publications; the validity and reliability of the system have been tested and found to be acceptable (Gombatto et al., 2008a, 2008b).

Briefly, the custom movement device was designed and constructed to allow frictionless movement of the lumbar spine in the frontal plane (Fig. 1). Each participant was placed prone on the movement device; the pelvis was secured to a stationary table, and the thorax was secured to a moveable cradle. Three porous air-bearings (NewWay®, Inc., Aston, PA, USA) were secured to the under-surface of the cradle to allow for frictionless movement of the cradle on an underlying platform. Two force transducers (± 50 pound capacity, Omegadyne, Inc.) were mounted to each side of the cradle to measure the force required to (1) move the participant passively through a lateral bending motion, and (2) maintain the participant's trunk in a neutral position during isometric resisted lateral bending. A cable was attached to each force transducer to allow the examiner to apply force in line with the metal guide along a normal tangent with the distal end of the cradle. Each cable was threaded through a 1.5" diameter loop at the end of the guide to insure the line of pull was maintained by the examiner. When the examiner pulled on the cradle via the cable, the participant's lumbar region was free to move in the frontal plane (Figs. 1 and 2). Passive trials were performed before resisted trials for all participants, but the side to which trials were performed first (right or left) was randomized for each participant. For each trial, LBP symptoms during the trial were compared to symptoms in the neutral position. A participant was considered to have increased LBP if symptoms were increased during at least one of the three trials in the specified direction.

The motion capture system was used to measure lumbar region angle in the frontal plane during passive trunk lateral bending (TLB) and the moment arm length for lumbar region torque calculations. Reflective markers were placed as follows: superficial to the 1st and 4th lumbar spinous processes, a 3-marker triad superficial to the 2nd sacral vertebra (local coordinate system), and 3 collinear markers on the custom movement device. Prior to each trial, the lumbar region of the participant was placed in a neutral position. Neutral position was defined as the position at which reflective markers on L1, L4 and S2 were collinear in the frontal plane. *Lumbar region angle* (α) in the frontal plane was defined as the angle of

the lumbar region vector (S2 to L1) relative to the superior-inferior axis of the local coordinate system at S2. *Moment arm length* was defined as the perpendicular distance from the lumbar region axis of rotation at S2 and the line of action of the force defined by the 3 collinear markers in line with the guide of the custom movement device (Fig. 2).

For passive movement testing, the participant was instructed to relax completely while the examiner pulled on the cable to move the participant through a maximum range of motion at a controlled speed. The examiner controlled speed of movement of the cradle across individuals by moving the cradle a fixed distance for each beat of a metronome (at 72 beats per minute). Three practice passive trials were performed, and then measurements were taken during three test trials of passive lateral bending. Torque–angle curves were generated for each passive lateral bending movement. Passive elastic energy was defined as the area under the torque–angle curve from the start of the lateral bending movement to the point of maximum lumbar region motion. Thus, the measure of passive elastic energy was an index of passive resistance to displacement of the lumbar region throughout the trunk lateral bending movement. Measures of passive elastic energy have been tested for reliability and were found to be acceptable (ICCs .79) (Gombatto et al., 2008a). Measures of passive elastic energy were calculated for each trial and then averaged across the three trials to each side (right, left).

For isometric resisted lateral bending, while the examiner applied force to the cable, the patient was instructed to maintain the neutral position and attempt to laterally bend to maximum capacity by pulling in the direction opposite the examiner's resistance. For example, for left resisted trials, the participant provided maximal resistance to the left, while the examiner resisted by pulling toward the right. The participant was allowed 1–3 practice trials, and then measurements were taken during three test trials of resisted isometric lateral bending. Maximum torque (T_{max}) was measured for each isometric resisted trial and then averaged across the three trials to each side.

Electromyographic (EMG) activity of external oblique and lumbar erector spinae muscles was monitored bilaterally during passive and resisted testing using a Myosystem 1400A (Noraxon USA, Inc.) and bipolar surface electrodes. Electrode placement and procedures for EMG data acquisition and processing, and maximum voluntary isometric contraction (MVIC) testing have been described in detail in previous publications (Gombatto et al., 2008b). External oblique and lumbar erector spinae muscle activity was monitored during passive and isometric resisted testing and was expressed as a percentage of the participant's MVIC. For passive movement testing, a movement was considered passive if the activity of muscles opposing the movement direction did not exceed 2% of the participant's MVIC for a period of 0.3 seconds during the trial (Scannell and McGill, 2003). For isometric resisted testing, normalized EMG curves were examined for each muscle from the start of muscle activity to the point at which maximum torque was achieved during the trial. The area under the normalized EMG curve from start to maximum torque was calculated and then was normalized to time for each muscle. To index trunk muscle characteristics on each side, the sum of the area under the normalized EMG curves for external oblique and lumbar erector spinae muscles was calculated ($rightEMG = right\ external\ oblique + right\ erector\ spinae$; $leftEMG = left\ external\ oblique + left\ erector\ spinae$). EMG measures were averaged across the three resisted trials to each side (right, left).

3. Analyses

In the primary analysis of these data, asymmetry of lumbar region passive elastic energy was greater in the Rotation with Extension LBP subgroup than in the No LBP group (Gombatto

et al., 2008b). For this secondary analysis, passive elastic energy was the dependent variable and we conducted separate analyses for measures to the right and left.

Independent variables were selected for inclusion in the secondary analysis if they had the potential to explain lumbar region passive elastic energy. Based on prior research, gender (Beach et al., 2005; Blackburn et al., 2004; McGill et al., 1994), age (Gajdosik et al., 1999), activity level (Beach et al., 2005; Parkinson et al., 2004), anthropometrics, and trunk muscle characteristics may explain lumbar region passive measures. In particular, we hypothesized that trunk muscle characteristics may explain the side-to-side differences in passive measures for the Rotation with Extension subgroup.

Pearson product-moment correlation coefficients were calculated to examine bivariate relationships between the independent variables and passive elastic energy to each side. A *t*-test was conducted to examine gender differences in passive elastic energy. Because we hypothesized that the relationship between independent variables and passive measures may be different between the Rotation with Extension subgroup and the No LBP group, the bivariate relationships were examined separately for each group. Relationships between variables with *P*-values <0.15 for either group, to either side, were considered important and were included in subsequent analyses (Flynn et al., 2002).

For independent variables that were related to passive elastic energy ($P < 0.15$) and represented the same construct (e.g. anthropometrics), principal component analyses (PCA) were conducted. Principal component analysis provides a *z*-score that represents the linear combination of the component variables that accounts for the most variance of the component variables. Based on commonly accepted criteria, a principal component is considered acceptable and representative of the construct if it meets both of the following criteria: 1) an eigen value greater than 1, and 2) the eigen value for the principal component is above a clear break in the scree plot (Portney, 2009). An anthropometric principal component was derived from the variables of height, weight, BMI, circumferential waist measures, and the ratio of waist/hip circumferential measures. Component loadings for variables on the first derived anthropometric principal component ranged from 0.81 to 0.97, and the anthropometric principal component explained 77.7% of the cumulative variance in anthropometric variables. A muscle component was derived from the variables of EMG and torque (e.g., rightEMG and right *T*_{max} for right muscle component). A muscle that displays greater EMG activity and can generate more torque during the resisted test is assumed to be more resistant to passive stretch than a muscle that generates less torque and relatively less EMG activity during the resisted test (Chleboun et al., 1997; Magnusson et al., 1997). Electromyography and maximum torque during resisted *right* TLB were used to quantify performance of muscles on the right side of the trunk. The trunk muscles on the right side then would be lengthened and constrain passive movement to the *left*. Electromyography and maximum torque during *left* resisted trials tested trunk muscles on the left side and should affect passive measures when the subject is moved to the *right* during the TLB movement. Component loadings for the first derived muscle component were 0.84 for both EMG and torque variables on the left and 0.80 for both EMG and torque variables on the right. The muscle components explained 69.8% and 64.5% of the cumulative variance in the muscle variables for the left and right side, respectively. The *z*-scores for the derived anthropometric and muscle components were included as independent variables in subsequent analyses.

To examine the relationship between the independent variables and passive elastic energy, a two-step linear regression analysis was conducted for each movement direction (GLM procedure in SPSS, Version 19). One analysis was conducted for right passive trunk lateral bending and another analysis for left passive trunk lateral bending. The dependent variables

were right and left passive elastic energy. Based on the established criteria for inclusion (bivariate relationship, $P < 0.15$), independent variables included in the first step of the linear regression analysis (main effects testing) were the following: group (Rotation with Extension subgroup, No LBP group), gender, anthropometric component, and trunk muscle component (Table 1). In the second step of the analysis, we added the interaction factor of group $\times$ trunk muscle component because we hypothesized that trunk muscle characteristics would contribute the most to differences in symmetry of passive tissue measures between the two groups. Then, we calculated the percent variance in passive elastic energy that was explained by the variables included in each step of the analysis. The difference in percent variance explained between the first and second step was calculated to determine the amount of unique variance accounted for by the interaction effect (ΔR^2). Post-hoc regression analyses were conducted for significant interaction effects. One subject in the Rotation with Extension subgroup was unable to perform resisted testing because of reports of increased symptoms across the testing session. This subject was excluded from the final analysis, resulting in 21 subjects in the Rotation with Extension subgroup.

4. Results

The participant characteristics for both groups are summarized in Table 2. Low back pain history and symptom characteristics for people in the Rotation with Extension subgroup are included in Table 3.

4.1. Linear regression analyses

The anthropometric component was the only significant variable related to passive elastic energy for *left* TLB ($P = .03$). There was a direct relationship between anthropometric measures and passive elastic energy of the lumbar region during left TLB for both the Rotation with Extension subgroup and the No LBP group. Thirty-one percent of the variance in *left* passive elastic energy was explained by the main effects of group, gender, anthropometrics and the trunk muscle component. No additional variance was explained by the interaction effect of group and trunk muscle component (Table 4). The anthropometric component ($P < 0.01$), the trunk muscle component ($P < 0.01$), and the interaction of group $\times$ trunk muscle component ($P = 0.01$) were significant factors related to passive elastic energy during *right* TLB. There was a direct relationship between anthropometric measures and passive elastic energy of the lumbar region during *right* TLB for both the Rotation with Extension subgroup and the group without LBP. However, the trunk muscle component had a differential effect on passive elastic energy during *right* TLB for the Rotation with Extension subgroup compared to the No LBP group. Because there was a significant interaction effect of group $\times$ trunk muscle component, we did not interpret the main effect of the trunk muscle component on passive elastic energy during *right* TLB (Portney, 2009). The main effects of group, gender, anthropometrics and the trunk muscle component explained 43% of the variance in *right* passive elastic energy. When the interaction effect of group $\times$ trunk muscle component was added in step 2 of the regression analysis, 53% of the variance in *right* passive elastic energy was explained. Therefore, 10% of the variance was uniquely explained by the interaction effect (Table 4). Unstandardized regression coefficients (B), P -values for parameter estimates, and R -squared values from the linear regression analyses are presented in Table 4.

4.2. Post-hoc analyses

To explore the interaction effect of group $\times$ trunk muscle component on passive elastic energy during *right* TLB, post-hoc regression analyses were conducted separately for each group. The post-hoc analysis for each group also included two-steps. In the first step, we examined the effects of gender and anthropometrics on passive elastic energy to the *right*. In

the second step, we added the trunk muscle component. Unstandardized regression coefficients (B), *P*-values for parameter estimates, and *R*-squared values were calculated for each step of the analysis, for each group. For the Rotation with Extension subgroup, 22.8% of the variance in passive elastic energy during *right* TLB was accounted for by gender and anthropometrics, compared to 39.5% for the No LBP group. For the second step of the post-hoc analysis, the trunk muscle component was added to determine the percent variance explained by all three variables. For the Rotation with Extension LBP subgroup, 66.5% of the variance in passive elastic energy during *right* TLB was accounted for by gender, anthropometrics and the trunk muscle component, compared to 40.0% for the No LBP group. We calculated the difference in explained variance between the second step of the post-hoc analysis with all variables included, and the first step of the analysis with only gender and anthropometrics included, to determine the amount of unique variance accounted for by the trunk muscle component (ΔR^2). For the Rotation with Extension subgroup, 43.7% of the variance in passive elastic energy during *right* TLB was uniquely accounted for by the trunk muscle component (66.5%–22.8%), compared to 0.5% for the No LBP group (40.0%–39.5%). For the Rotation with Extension subgroup, B-weights for the gender, anthropometrics, and muscle components from the second step of the post-hoc analysis were 36.0 (*P* = .10), 33.0 (*P* = 0.01) and 35.3 (*P* < 0.001) respectively. For the No LBP group, B-weights for the gender, anthropometrics and muscle components were –18.9 (*P* = 0.58), 20.6 (*P* = 0.22) and –3.6 (*P* = 0.75) respectively.

5. Discussion

Findings from the current study lead us to conclude that anthropometrics are related to in vivo passive tissue characteristics of the lumbar region in both a subgroup of people with LBP and a group of people without LBP. For the Rotation with Extension LBP subgroup, the relationship of height, weight, and waist circumference measurements to passive elastic energy of the lumbar region was fair to good (*r*-values: 0.33–0.55); the same was true for the No LBP group (*r*-values: 0.38–0.68) (Table 1) (Portney, 2009). Therefore, greater height, weight, and waist circumference measurements were associated with greater resistance to passive movement of the lumbar region, irrespective of LBP status. These anthropometric measures may be important to consider as modifiable or non-modifiable factors when developing a treatment plan directed at affecting passive tissue characteristics of the lumbar region.

Trunk muscle performance also was related to passive tissue characteristics of the lumbar region, but only to one side, and only for people in the Rotation with Extension LBP subgroup. Trunk muscle performance was characterized by the amount of EMG activity and torque generated during an isometric resisted trunk lateral bending task. For the Rotation with Extension subgroup, the relationships between passive measures during trunk lateral bending and both EMG and maximum torque during isometric resisted trunk lateral bending, were moderate to good for bending to the right (*r*-values: 0.54–0.71), but poor to fair for bending to the left (*r*-value: 0.06–0.35) (Table 1) (Portney, 2009). For the No LBP group, the relationship between maximum torque and passive measures was fair to good for bending toward both right and left (*r*-values: 0.37–0.57) but the relationship between EMG and passive measures was not significant (*P*-values: 0.37–0.74). Thus, people in the Rotation with Extension subgroup who produced relatively high rather than low levels of EMG and torque when they actively tried to bend toward the left were more difficult to move passively to the right. These data suggest that measures of muscle performance should be considered along with anthropometrics when developing a treatment plan directed at affecting passive tissue characteristics of the trunk for people in the Rotation with Extension subgroup.

One potential explanation for the relationships noted between measurements from the resisted and passive tasks is that some people with LBP may have insufficient passive stability in the lumbar region as the result of either inherent laxity or an injury. Insufficient passive stability would require the trunk muscles to compensate by increasing their activity to better stabilize the spine. In the Rotation with Extension subgroup, the loss of passive stability may be asymmetric. In a prior kinematic study, people in the Rotation with Extension subgroup moved more readily during the early ranges of a trunk lateral bending movement to the left compared to the right (Gombatto et al., 2007). For this LBP subgroup, muscles on the left side of the trunk may be more developed and thus constrain passive movements to the right.

The specific direction of these effects may be related to the handedness of people in the Rotation with Extension subgroup (95.5% right-handed). For example, if right-handed people are more likely to carry objects and perform tasks with their right hand, then muscle activity on the left side of the body would be needed to offset the load or perturbation associated with movement of the right upper extremity. Even though all of the participants in the No LBP group also were right-handed, none had developed the degree of asymmetry observed in the Rotation with Extension LBP subgroup (Gombatto et al., 2007, 2008b). The potential contributions to the magnitude and direction of asymmetries, as well as the relationship between the asymmetries and spine injury and loading, require further study. In the interim, the available evidence regarding the asymmetries in the Rotation with Extension subgroup can be applied to clinical practice. Physical therapy treatment for people in this LBP subgroup could focus on reducing the asymmetry by balancing active and passive forces across the trunk through resisted exercise and stretching. To enhance long-term effects, treatment also could be focused on educating patients to modify the movement and alignment factors that may have contributed to the development and persistence of the asymmetry.

Findings from the current study provide a unique contribution to the literature on biomechanical factors underlying LBP problems. Prior investigators have studied the mechanical properties of the spine and/or spinal tissues in vitro (Brown et al., 2002; Gay et al., 2006; Laborde et al., 1981). Mechanical properties of the lumbar region have been examined in vivo during active or passive movements using methods similar to those used in the current study, but with a healthy population (Beach et al., 2005; McGill et al., 1994; Parkinson et al., 2004). Other investigators have examined the stiffening effect of active muscle contraction on the trunk in people with LBP during a perturbation task (Hodges et al., 2009), and in healthy controls during sagittal and frontal plane movements (Brown and McGill, 2008). However, to our knowledge, no investigators have examined the relationship between muscle performance and passive measures in the lumbar region. Investigators who have examined the relationship between muscle activation and passive measures in other body regions have suggested that passive measures can vary based on the specific tissue tested, gender, anthropometrics, activity level, and muscle activation (Chleboun et al., 1997; Gajdosik et al., 1999).

Data from the current study support the notion that there is a relationship in the lumbar region between anthropometrics and passive measures, but that the relationship between muscle activation and passive measures varies based on LBP status.

6. Conclusion

Anthropometric characteristics explained lumbar region passive measures to both sides, in both the Rotation with Extension subgroup and the No LBP group. However, aspects of trunk muscle performance predicted lumbar region passive measures only for movement to

the right side and only in the Rotation with Extension subgroup. For people in this LBP subgroup there was a direct relationship between trunk muscle performance during resisted left TLB, and passive elastic energy with passive TLB to the right. Thus, it appears that trunk muscle performance, in part, explains the previously reported asymmetries in passive measures in the Rotation with Extension LBP subgroup. Trunk muscle performance is a modifiable factor that clinicians have the ability to influence with treatment. Further, based on these data, treatment directed at trunk muscle performance may need to differentially target each side of the trunk to address the underlying asymmetries in the Rotation with Extension subgroup.

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Fig. 1. The passive movement device including the table, platform, moveable cradle, guide and force transducers (Gombatto et al., 2008b).

Fig. 2.
Locations of reflective markers used for kinematic measurements (Gombatto et al., 2008b).

Table 1

Bivariate relationships (Pearson correlation coefficient or *t*-statistic) between predictor variables and passive elastic energy (PEE) during passive trunk lateral bending (TLB) for people in the rotation with extension low back pain (LBP) subgroup and people without LBP).

Predictor variables	Rotation with extension LBP subgroup (N=22)		People without LBP (N=19)	
	Pearson correlation coefficient or <i>t</i>-statistic value (<i>P</i>-value)		Pearson correlation coefficient or <i>t</i>-statistic value (<i>P</i>-value)	
	PEE Left TLB	PEE Right TLB	PEE Left TLB	PEE Right TLB
<i>Clinical variables</i>				
Gender	<i>t</i> =−0.93 (<i>P</i> =0.37)	<i>t</i> =−0.71 (<i>P</i> =0.48)	<i>t</i> =4.16(<i>P</i> <0.01) *	<i>t</i> =2.91 (<i>P</i> =0.01) *
Age (years)	0.25 (<i>P</i> =0.26)	−0.10 (<i>P</i> =0.67)	0.10 (<i>P</i> =0.68)	0.28 (<i>P</i> =0.24)
Height (cm)	0.38 (<i>P</i> =0.09) *	0.33 (<i>P</i> =0.13) *	0.69 (<i>P</i> <0.01) *	0.62 (<i>P</i> =0.00) *
Weight (kg)	0.45 (<i>P</i> =0.04) *	0.55 (<i>P</i> =0.01) *	0.57 (<i>P</i> =0.01) *	0.67 (<i>P</i> =0.00) *
BMI (kg/m ²)	0.27 (<i>P</i> =0.23)	0.50 (<i>P</i> =0.02) *	0.38 (<i>P</i> =0.11) *	0.54 (<i>P</i> =0.02) *
Waist circumference (cm)	0.42 (<i>P</i> =0.05) *	0.41 (<i>P</i> =0.06) *	0.51 (<i>P</i> =0.03) *	0.47 (<i>P</i> =0.04) *
Ratio of waist/hip circumference (cm)	0.36 (<i>P</i> =0.11) *	0.01 (<i>P</i> =0.98)	0.66 (<i>P</i> <0.01) *	0.55 (<i>P</i> =0.01) *
Baecke activity score (3–15)	−0.31 (<i>P</i> =0.16)	−0.03 (<i>P</i> =0.89)	0.07 (<i>P</i> =0.78)	−0.32 (<i>P</i> =0.18)
<i>Laboratory measures</i>				
Muscle activity during <i>Resisted Left</i> TLB	0.20 (<i>P</i> =0.39)	0.60 (<i>P</i> <0.01) *	−0.22 (<i>P</i> =0.37)	−0.16 (<i>P</i> =0.52)
Muscle activity during <i>Resisted Right</i> TLB	0.06 (<i>P</i> =0.79)	0.54 (<i>P</i> =0.01) *	−0.08 (<i>P</i> =0.74)	−0.19 (<i>P</i> =0.44)
Maximum Torque during <i>Resisted Left</i> TLB (inch#)	0.35 (<i>P</i> =0.12) *	0.71 (<i>P</i> <0.01) *	0.55 (<i>P</i> =0.01) *	0.47 (<i>P</i> =0.04) *
Maximum Torque during <i>Resisted Right</i> TLB (inch#)	0.35 (<i>P</i> =0.12) *	0.66 (<i>P</i> <0.01) *	0.57 (<i>P</i> =0.01) *	0.37 (<i>P</i> =0.12) *

* *P*<0.15, variables that met the criteria are listed in boldface.

Table 2

Characteristics of people in the rotation with extension low back pain (LBP) subgroup ($N=22$) and people without LBP ($N=19$).

Characteristic or measure	Rotation with extension LBP subgroup ($N=22$)	People without LBP ($N=19$)	Statistical value, degrees of freedom (df), P -value
Mean age (sd), years	31.2 (9.4)	30.3 (8.5)	$t=0.3$, $df=39$, $P=0.7$
Mean height (sd), cm	169.2 (9.1)	169.2 (9.6)	$t=0.0$, $df=39$, $P=1.0$
Mean weight (sd), kg	68.7 (11.7)	70.2 (15.1)	$t=-0.4$, $df=39$, $P=0.7$
Mean BMI (sd), kg/m^2	24.0 (2.9)	24.2 (3.0)	$t=-0.3$, $df=39$, $P=0.8$
Mean waist circumference (sd), cm	80.5 (8.4)	79.9 (10.1)	$t=0.2$, $df=39$, $P=0.8$
Mean ratio of waist/hip circumference (sd), cm	0.8 (0.1)	0.8 (0.1)	$t=-0.3$, $df=39$, $P=0.7$
Sex	14 female, 8 male	9 female, 10 male	$\chi^2=1.1$, $df=1$, $P=0.3$
Mean Baecke score (sd), 3–15	8.5 (2.5)	8.9 (1.0)	$t=-0.6$, $df=39$, $P=0.5$

Table 3

Low back pain (LBP) characteristics for people in the rotation with extension LBP subgroup ($N=22$).

Measure	Mean value (sd)
Low back pain on the day of testing using a numeric rating scale (0–10)	1.3 (0.9)
Number of years of LBP	6.9 (4.6)
Number of episodes of LBP in the last 12 months	3.0 (2.3)
Modified Oswestry Disability Index Score (0–100%)	13.6 (8.4)

Table 4

Findings from a two-step multiple regression analysis predicting passive elastic energy for people in the rotation with extension low back pain (LBP) subgroup ($N=21$) and people without LBP ($N=19$).

Predictors	Left passive elastic energy			Right passive elastic energy		
	Step 1		Step 2		Step 2	
	B	P-value	B-Weight	P-value	B-Weight	P-value
Group (rotation with extension LBP subgroup)	11.92	0.40	11.91	0.41	-1.06	0.31
Gender (female)	-7.53	0.72	-7.52	0.72	16.55	16.96
Anthropometrics component	23.26	0.03	23.27	0.04	28.26	31.13
Trunk muscle component	7.15	0.32	7.29	0.52	21.12	-1.02
Group×trunk muscle component	not included	not included	-0.24	0.99	not included	34.57
Intercept	102.21	<0.01	102.19	<0.01	104.7	105.56
R^2	0.31		0.31		0.43	0.53
ΔR^2			0.00			0.10

* P -values in the table refer to significance values for parameter estimates.