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Asymmetry of lumbopelvic movement patterns during active hip abduction is a risk factor for low back pain development during standing

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Abstract

An induced-pain paradigm has been used in back-healthy people to understand risk factors for developing low back pain (LBP) during prolonged standing. We examined asymmetry of lumbopelvic movement timing during a clinical test of active hip abduction in back-healthy people who developed LBP symptoms during standing (Pain Developers; PDs) compared to back-healthy people who did not develop LBP symptoms during standing (Non Pain Developers, NPDs). Participants completed the hip abduction test while movement was recorded with a motion capture system. Difference in time between start of hip and lumbopelvic movement was calculated (startdiff). PDs moved the lumbopelvic region earlier during left hip abduction than right hip abduction. There was no difference between sides in NPDs. In PDs, the amount of asymmetry was related to average symptom intensity during standing. Asymmetric lumbopelvic movement patterns may be a risk factor for LBP development during prolonged standing.

Keywords

Prolonged standing; low back pain; hip abduction; asymmetry

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1. INTRODUCTION

Epidemiological studies have shown that jobs requiring prolonged standing are associated with increased reports of LBP (Andersen, Haahr, & Frost, 2007; Macfarlane et al., 1997; Picavet & Schouten, 2000; Roelen, Schreuder, Koopmans, & Groothoff, 2008; Tissot, Messing, & Stock, 2009). Recent studies have used an induced-pain paradigm to understand characteristics that predispose a person to LBP development during prolonged standing (standing paradigm) (Gregory, Brown, & Callaghan, 2008; Gregory & Callaghan, 2008; Marshall, Patel, & Callaghan, 2011; Nelson-Wong, Alex, Csepe, Lancaster, & Callaghan, 2012; Nelson-Wong & Callaghan, 2010; Nelson-Wong & Callaghan, 2010; Nelson-Wong & Callaghan, 2010; Nelson-Wong & Callaghan, 2014; Nelson-Wong, Flynn, & Callaghan, 2009; Nelson-Wong, Gregory, Winter, & Callaghan, 2008; Nelson-Wong, Howarth, & Callaghan, 2010). The paradigm consists of back-healthy people (BHP) standing for 2 hours while performing simulated, light work tasks. Participants rate their LBP symptom intensity on a 100 mm visual analogue scale (VAS) at baseline and every 15 minutes throughout the 2 hours. Based on their VAS rating, participants are classified either as a pain developer (PD) or a non-pain developer (NPD). Across previous studies, 28% to 71% of participants have been classified as PDs. The standing paradigm has been shown to be reliable and valid (Nelson-Wong & Callaghan, 2010; Sorensen, Johnson, Callaghan, George, & Van Dillen, 2014).

One area of investigation in which differences between PDs and NPDs have been identified is in activation patterns of the hip and trunk muscles during standing (Nelson-Wong & Callaghan, 2010; Nelson-Wong et al., 2008). Specifically, compared to NPDs, PDs displayed a greater magnitude of co-contraction of bilateral gluteus medius muscles during the first 30 minutes and the final 30 minutes of standing (Nelson-Wong & Callaghan, 2010). In addition, PDs were more likely than NPDs to develop an episode of LBP in the 3 years following participation in the standing paradigm (Nelson-Wong & Callaghan, 2014). The authors suggested that the PDs may be a subclinical group that is different from the NPDs prior to LBP symptom development.

Given the differences between PDs and NPDs in hip muscle activation during standing, a clinical movement test was developed to challenge frontal plane trunk control during hip abduction (Nelson-Wong et al., 2009). The purpose of the test was to screen BHP for risk of developing LBP during standing. The screening test was an active hip abduction movement performed in side lying. One examiner scored the person's movement based on visual assessment. Defined criteria were used to guide the examiner's judgments. The scoring criteria the examiner used quantified how well the participant maintained alignment of the trunk and pelvis in the frontal plane during the movement. Data from the limb with the poorer performance score were used for analyses. The authors reported that, compared to NPDs, PDs displayed decreased control of the trunk during the hip abduction test. Thus, the clinical test of active hip abduction discriminated between PDs and NPDs (Nelson-Wong et al., 2009). In addition, Marshall et al. reported that PDs had decreased hip abductor endurance compared to NPDs prior to participation in the standing paradigm (Marshall et al., 2011). The differences between PDs and NPDs suggest differences (1) are present before

LBP development, and (2) may put some people at risk for LBP under specific loading conditions.

The trunk movement differences between PDs and NPDs during the hip abduction test are particularly interesting because some of the clinical movement tests used to classify people with LBP into subgroups are intended to identify deficits in lumbopelvic control (Van Dillen et al., 1998; Van Dillen et al., 2003; Van Dillen et al., 2003; Van Dillen, Maluf, & Sahrman, 2009). The LBP subgroups identified are named for the consistency of responses (symptoms and signs) with clinical tests associated with one or more types of spinal loading (e.g. rotation, extension, flexion). Interestingly, one clinical LBP subgroup, the rotation with extension subgroup (RotExt), reports an increase in LBP symptoms earlier during standing than other LBP subgroups (unpublished data). People are diagnosed in the RotExt subgroup based upon reports of increased symptoms with movements and postures during clinical tests that result in extension or rotation loading on the lumbar spine (Maluf, Sahrman, & Van Dillen, 2000; Van Dillen et al., 2003) and reports of decreased symptoms when the extension or rotation loading is modified (Van Dillen et al., 2003; Van Dillen et al., 2003; Van Dillen et al., 2009). The RotExt subgroup also displays asymmetric lumbopelvic movement patterns during clinical tests of trunk and hip movements (Gombatto, Collins, Engsborg, Sahrman, & Van Dillen, 2007; Van Dillen, Gombatto, Collins, Engsborg, & Sahrman, 2007). The asymmetric movement patterns are associated with an increase in the person's LBP symptoms (Gombatto et al., 2007; Van Dillen et al., 2003; Van Dillen et al., 2007; Van Dillen et al., 2009). Given the findings related to the RotExt clinical LBP subgroup we reasoned that BHP that develop LBP symptoms during standing may have similar characteristics to people in the RotExt subgroup. In support of this logic we have reported that compared to NPDs, PDs displayed increased lumbar lordosis in standing (Sorensen, Norton, Callaghan, Hwang, & Van Dillen, 2015). Prior studies have documented that people in the RotExt subgroup display increased lumbar lordosis in standing compared to people in another LBP subgroup and BHP (Norton, Sahrman, & Van Dillen, 2004). It currently is not known, however, if the PDs would display asymmetric timing of lumbopelvic movement during the hip abduction test as the RotExt subgroup does during clinical movement tests. In addition, it is not known if the asymmetry would be related to a PD's LBP symptom intensity.

The purposes of this study were to examine the (1) asymmetry of timing of lumbopelvic movement during the active hip abduction test in PDs compared to NPDs, and (2) association between the magnitude of asymmetry and the LBP symptom intensity reported during standing by the PDs. We hypothesized that PDs would display larger right to left asymmetry in timing of lumbopelvic movement during the active hip abduction test than NPDs, and the amount of asymmetry would be related to LBP intensity reported by PDs. The findings from this study potentially could provide evidence that BHP that develop LBP symptoms during standing have lumbopelvic movement patterns that are similar to a subgroup of people who already have clinical LBP and complain of symptoms during standing (RotExt subgroup). Similar asymmetric movement patterns between the PDs and the RotExt subgroup would suggest that the movement pattern is present prior to a person developing clinical LBP, and is a potential risk factor for initial LBP development if the person is exposed to a specific type of loading, i.e., prolonged standing.

2. METHODS

2.1. Participants

Fifty-seven BHP (28 female, 29 male) participated in the study. The sample includes the same participants from previous reports comparing lumbar curvature in PDs and NPDs (Sorensen et al., 2015) and the relationship of LBP symptom development to psychological factors in PDs (Sorensen, George, Callaghan, & Van Dillen, 2016). Participants were recruited from the St. Louis metropolitan area. Inclusion criteria included no lifetime history of an episode of LBP that resulted in (1) seeking some type of health intervention (e.g., medical, physical therapy, chiropractic), (2) three or more consecutive days of missed work or school, or (3) three or more days of altered activities of daily living. Exclusion criteria included employment in a job that involved standing in one place for more than 1 hour per day during the last 12 months, inability to stand for > 4 hours, a body mass index > 30, or report of LBP symptoms at the beginning of the standing task. If a participant reported any symptoms (any value above 0 mm on the VAS) at the start of standing, he or she was excluded from the study. All participants read and signed an informed consent form that was approved by the Human Research Protection Office at Washington University School of Medicine.

2.2. Self-Report Measures

After signing the informed consent document, all participants remained seated to report their current LBP symptom intensity level on a VAS. The VAS is a 100 mm horizontal line with the anchors of “no pain” and “worst pain imaginable.” Participants placed an ‘X’ through the line at the point that best represented their perception of their current LBP symptom intensity. Intensity was quantified by measuring the distance of the ‘X’ from the left end of the scale with a ruler. Greater distances indicated higher symptom intensities. Participants then completed the Baecke Questionnaire of Habitual Physical Activity (Baecke, Burema, & Frijters, 1982). Information also was collected on which leg the participant would use to kick a ball in order to determine leg dominance. The dominant leg was defined as the stance leg during kicking.

2.3. Laboratory Measures

At baseline, prior to the 2 hour standing period, retro-reflective markers were placed on predetermined landmarks of the trunk, pelvis and lower extremities. The specific marker placements are provided in Table 1. A calibration trial was captured and then markers on the lateral portion of the body were removed. Positioning and instructions provided during the testing were the same as those used by Nelson-Wong et al (Nelson-Wong et al., 2009) (Figure 1). Briefly, participants were positioned in side lying in the middle of the capture volume. The participant was positioned such that his or her lumbar spine was in a neutral alignment with regard to flexion and extension and rotation, the hips were in a neutral alignment with regard to flexion and extension, and the knees were extended. The examiner checked to assure that the participant’s shoulders, hips, knees, and ankles were in a straight line. The bottom arm was resting on the floor perpendicular to the body. The top arm was resting on the trunk with the hand positioned on the participant’s abdomen to ensure that he or she did not use the arm for balance during the hip movement. Participants were instructed

to raise their top leg towards the ceiling as far as they could and then return it to the starting position. They were told to keep their knee straight and keep the leg in line with their body, trying not to let their trunk or pelvis move. The side to be tested first was randomized. Three separate trials were performed with each leg. Marker positions were captured using an 8 camera, 3-dimensional Vicon T-Series motion capture system (Vicon Motion Systems, Denver, CO). The sampling rate of the system was 120 Hz. Participants moved at a self-selected speed and were given 10 seconds to complete each trial. All participants were able to perform the trials within the allotted time.

2.4. Standing Paradigm Protocol

Following performance of the hip abduction trials, participants were positioned in front of a work table in a 0.61 m × 1.22 m confined workspace. The table was adjusted to 5 cm below the participant's wrist while his or her elbows were flexed to 90° (Kromer & Grandjean, 1997). Participants then stood for 2 hours performing simulated light work tasks. Participants were allowed to shift their weight as often as desired but were told to keep both feet on the ground the majority of the time. The participants were not allowed to rest their feet on the legs of the table or arms on the surface of the table.

The tasks used included shuffling cards, sorting poker chips, and a simple assembly task. There also was a quiet standing condition. The work tasks and quiet standing were completed in 15 minute blocks of time with the order of tasks randomized prior to the start of standing. Randomization of the tasks was performed using random.org/lists. Each task and the period of quiet standing were completed twice during the two hours, with the added constraint that the same task could not be performed consecutively. At baseline and every 15 minutes during the standing test, participants reported the intensity of their LBP symptoms on the VAS. For each participant, the maximum VAS (Max VAS) score that was reported during the 2 hours of standing was identified. The average VAS score throughout the 2 hours of standing also was calculated for each participant.

2.5. Data Processing

To calculate hip joint angles and pelvis segment angles over time, kinematic data were processed in Visual 3D software version 5.0 (C-Motion, Inc., Germantown, MD). First, a model was built to represent the local coordinate system of the pelvis segment, left thigh segment, and right thigh segment for the movement trials. The proximal end of the pelvis segment was defined using the right and left iliac crest markers. The distal end of the pelvis was defined using the right and left greater trochanter markers. The segment was tracked using the right and left anterior superior iliac spine (ASIS) and right and left posterior superior iliac spine (PSIS) markers. The proximal end of the thigh segments was defined by a virtual marker created at 25% of the distance between the right and left greater trochanter markers. The distal end of the thigh was defined using the medial and lateral knee joint line markers. The segment was tracked using the 2 markers on the anterior thigh and 2 markers on the posterior thigh. Marker coordinate data were low pass filtered with a cutoff of 3 Hz using a 4th order dual pass Butterworth filter.

Three-dimensional Cardan hip joint angles then were calculated as the thigh segment relative to the pelvis segment with an abduction/adduction, internal/external rotation, flexion/extension rotation sequence. Three-dimensional Cardan pelvis segment angles were calculated as the pelvis segment relative to the lab coordinate system with a lateral pelvic tilt, pelvic transverse rotation, anterior/posterior pelvic tilt rotation sequence. Frontal plane angular data for the hip joint and the pelvis segment were further processed using custom written programs in MATLAB version 2013b software (MathWorks Inc., Natick, MA) to identify starts and ends of movement. Frontal plane angles were analyzed as they are used in the clinical diagnosis of individuals to the RotExt subgroup (Sahrmann, 2002).

Hip abduction range of motion was calculated as the degrees of hip abduction from the start of movement to maximum hip abduction. The determination of the start and end of movement was based on the process reported by Van Dillen et al., 2007 (Van Dillen et al., 2007). Briefly, the hip abduction and lumbopelvic angles were plotted over time. The angle-time plots were then visually examined to determine threshold criteria for the start and end of movement. An algorithm was established in order to identify the start and end of movement for all trials. Start and end points of movement based on the threshold were then plotted and visually inspected for accuracy. An accurate start of movement was defined as a consistent increase in the slope of the angle-time plot. An accurate end point was defined as the point in which the angle-time plot appeared to reach a maximum. The threshold values for the angular displacement that resulted in the most accurate start and end points for the majority of participants and trials were chosen. For both hip abduction and pelvic tilt the threshold for start of movement was defined as a 1° increase from baseline and the end of movement was defined as 98% of the maximum angle. We then calculated a specific variable to index the timing of lumbopelvic movement typically seen during lower extremity movements in people in the RotExt subgroup. The lumbopelvic movement pattern typical of the RotExt subgroup involves moving the lumbopelvic region earlier and more asymmetrically during a hip movement compared to other subgroups of people with LBP (Gombatto et al., 2007; Van Dillen et al., 2003; Van Dillen et al., 2007; Van Dillen et al., 2009). The variable was the difference in time between the start of the hip abduction movement and the start of the pelvis movement (startdiff; Figure 2). The startdiff variable was calculated to index the relative timing of lumbopelvic movement onset during hip abduction. We have used the startdiff variable previously to index the relative timing of the onset of lumbopelvic movement during hip lateral and hip medial rotation (Scholtes, Gombatto, & Van Dillen, 2009; Van Dillen et al., 2007). Because each individual moved at a self-selected speed, the startdiff value was normalized to total hip abduction movement time for each trial (startdiff/hip abduction movement time) (Van Dillen et al., 2007). Right to left asymmetry of the startdiff variable was calculated as the difference between the startdiff value on the right and left side. A value of zero indicated no asymmetry between the right and left sides; larger values indicated more asymmetry.

2.6. Statistical Analyses

BHP were separated into PDs and NPDs. PDs were participants that reported any symptoms after baseline and maintained the symptoms throughout the standing test. NPDs were people who reported 0 on the VAS throughout the standing task. A Chi-square analysis was

conducted to test for differences in the distribution of sex in PDs and NPDs. A Fisher's Exact test was used to test for differences in distribution of leg dominance in PDs and NPDs. Independent groups t-tests were conducted to test for differences in age, height, weight, body mass index (BMI), and activity level between the PDs and NPDs. Separate 2×2 analysis of variance tests were conducted for hip abduction range of motion and the startdiff variable. We tested for main and interaction effects of group (PDs and NPDs) and side (right vs. left). In the case of a significant interaction, post-hoc analyses were conducted to evaluate the nature of the interaction. Partial eta squared (η^2) values were calculated to estimate effect size, and were interpreted as follows: small $\eta^2 = 0.01$, medium $\eta^2 = 0.06$, and large $\eta^2 = 0.14$. (Cohen, 1988) In PDs, a Pearson correlation coefficient was calculated for the amount of right to left asymmetry of the startdiff variable and average VAS scores during standing. Statistical analyses were performed in SPSS version 21.0 (IBM, Armonk, NY). Statistical significance for all tests was set at $p = .05$.

3. RESULTS

Of the 57 participants, 24 (42%) were classified as PDs (Table 2). There were no significant differences between groups for sex, leg dominance, age, height, mass, BMI, or activity level (Table 2).

3.1. Hip Abduction Range of Motion

There was a significant main effect of side (Right = 47.43° (10.14°); Left = 45.17° (11.22°); $F(1, 55) = 5.88$; $p = 0.02$; $\eta^2 = 0.10$), with less hip abduction range of motion during trials on the left side compared to the right side (Table 1). The main effect of group was not significant (NPDs = 45.37° (10.08°); PDs = 47.59° (10.31°); $F(1, 55) = 0.66$; $p = 0.42$; $\eta^2 = 0.01$). The side by group interaction was not significant ($F(1, 1) = 0.07$; $p = 0.79$; $\eta^2 = 0.001$), indicating that the difference in hip abduction range of motion between right and left sides was the same for PDs and NPDs.

3.2. Hip Abduction Movement Time

There was a significant main effect of side (Right = 2.01 s (0.85 s); Left = 1.82 s (0.80 s); $F(1, 55) = 10.12$; $p = 0.02$; $\eta^2 = 0.16$), with less hip abduction movement time during trials on the left side compared to the right side (Table 1). The main effect of group was not significant (NPDs = 1.91 s (0.86s); PDs = 1.92 s (0.72s); $F(1, 55) = 0.002$; $p = 0.97$; $\eta^2 < 0.001$). The side by group interaction was not significant ($F(1, 1) = 0.06$; $p = 0.80$; $\eta^2 = 0.001$), indicating that the difference in hip abduction movement time between right and left sides was the same for PDs and NPDs.

3.3. Hip Abduction Startdiff Variable

There was a significant main effect of side (Right = 0.19 (0.09); Left = 0.15 (0.09); $F(1, 55) = 12.29$; $p = 0.001$; $\eta^2 = 0.18$), with lumbopelvic movement beginning earlier during hip abduction trials on the left side compared to the right side (Figure 3). The main effect of group was not significant (NPDs = 0.18 (0.08); PDs = 0.15 (0.07); $F(1, 55) = 3.20$; $p = 0.12$; $\eta^2 = 0.04$). The side by group interaction was significant ($F(1, 1) = 4.32$; $p = 0.04$; $\eta^2 = 0.07$), indicating that the difference in the start of lumbopelvic movement during hip

abduction between sides (right vs. left) was different for PDs and NPDs. Post-hoc analyses revealed that PDs moved the lumbopelvic region earlier during left hip abduction than during right hip abduction (Difference = 0.07 (0.09), 95% CI = 0.03 to 0.11; $t = 3.4$; $p = 0.002$, Cohen's $d = 0.81$). For the NPDs, on the other hand, there was no difference between sides in when the lumbopelvic region moved during hip abduction (Difference = 0.02 (0.09), 95% CI = -0.13 to 0.48; $t = 1.2$; $p = 0.25$, Cohen's $d = 0.19$). Thus, the PDs displayed more right to left asymmetry in the timing of onset of lumbopelvic movement with hip abduction compared to the NPDs (Figure 2).

3.4. Relationship between Asymmetry and VAS

In PDs there was a significant positive relationship between the amount of asymmetry of the startdiff variable and average VAS scores ($r = 0.46$; $p = 0.02$; Figure 4). In PDs, the more asymmetry there was in the timing of lumbopelvic movement during hip abduction, the greater the average report of LBP symptoms (Figure 4).

4. DISCUSSION

4.1. Summary of Main Findings

The purposes of this study were to examine the (1) asymmetry of timing of lumbopelvic movement during a clinical test of active hip abduction in PDs and NPDs, and (2) relationship between right to left asymmetry and LBP symptom intensity in PDs. Our hypotheses were that (1) compared to NPDs, PDs would display more right to left asymmetry in relative timing of onset of lumbopelvic movement during hip abduction, and (2) LBP symptom intensity would be related to the amount of asymmetry in PDs. As hypothesized, compared to NPDs, PDs displayed significantly more asymmetry in the relative timing of onset of lumbopelvic movement during hip abduction. Specifically, PDs moved the lumbopelvic region earlier during hip abduction on the left leg compared to the right. The NPDs displayed no lumbopelvic movement timing differences between the right and left sides during hip abduction. The results demonstrate that lumbopelvic movement differences between people who develop LBP during prolonged standing compared with those who do not. In addition, the amount of asymmetry was related to LBP symptom intensity during standing in PDs. The findings suggest that motor control differences, such as asymmetric timing of lumbopelvic movement during a hip movement, could be a potential risk factor for initial LBP development in BHP when exposed to a prolonged standing.

Investigators previously reported that compared to NPDs, PDs displayed less control of the trunk and pelvis during an active hip abduction test (Nelson-Wong et al., 2009). In the previous study, trunk and pelvis control were assessed visually by an examiner, and scored for how well a participant maintained alignment of the trunk and pelvis in the frontal plane during the hip movement (Nelson-Wong et al., 2009). The difference between PDs and NPDs identified in the prior study was based only on an analysis of data from the hip with the poorer score. Thus, it is not known if PDs were more asymmetric in their performance than NPDs. In the current study, we used laboratory measures to quantify a specific aspect of lumbopelvic control known to characterize a subgroup of people with clinical LBP, the

RotExt LBP subgroup. People in the RotExt subgroup also tend to report standing as more symptom-provoking than people in other LBP subgroups (unpublished data). In previous studies of people with LBP, we have found that people in the RotExt subgroup tend to move the lumbopelvic region earlier and more asymmetrically during hip lateral rotation compared to the Rot LBP subgroup (Gombatto et al., 2007; Van Dillen et al., 2007). Similar to earlier reports of lumbopelvic movement patterns in the RotExt subgroup, the PDs in the current study displayed asymmetric timing of lumbopelvic movement during a hip movement. Thus, BHP who are susceptible to LBP symptoms in standing display a similar lumbopelvic movement pattern as a subgroup of people with clinical LBP who report standing as problematic.

Our prior studies show that asymmetry in the timing of movement of the lumbopelvic and lumbar region is characteristic of the RotExt subgroup (Gombatto et al., 2007; Van Dillen et al., 2003; Van Dillen et al., 2007; Van Dillen et al., 2009). The current data demonstrates a similar finding of asymmetry in the timing of lumbopelvic movement during a clinical test of hip abduction that challenges the trunk in the frontal plane, but the finding is in people who do not have clinical LBP. Asymmetric movement of the lumbopelvic region potentially can lead to a greater concentration of stress in tissue on one side of the spine compared to the other. If the movement pattern is repeated across activities throughout the day, tissue stress could accumulate rapidly on the side that is repeatedly loaded. The accumulation of tissue stress in the spine could contribute to a decrease in the load tolerance of the tissue (McGill, 1997). It is possible that when the spinal tissue whose load tolerance is diminished is placed in a sustained loading situation, such as prolonged standing, transient symptoms may be produced. Future studies should investigate if PDs and NPDs display differences in properties of the spinal tissue that suggest asymmetric loading.

4.2. Limitations

A limitation to our study was that participants were between 18-30 years of age so the results may not be generalizable to people in other age ranges. The young age of our population and the lack of regular exposure to an activity where the trunk was exposed to a sustained load, however, could be the reason that people with asymmetric movement patterns had not yet reported LBP symptoms. For example, accumulation of stress on specific spinal tissues as a result of asymmetric loading may not result in tissue damage. When the individual is placed in a condition of sustained loading on the same spinal tissues, however, transient symptoms could be experienced (Adams, 2004).

5. Conclusions

PDs displayed more asymmetry of onset of lumbopelvic movement than NPDs during the clinical test of active hip abduction. The asymmetric movement pattern during a limb movement test is similar to lumbopelvic movement patterns identified during clinical tests in a subgroup of people with clinical LBP, the RotExt subgroup. The RotExt subgroup also report standing as more symptom-provoking than people in other LBP subgroups. These data suggest that asymmetric lumbopelvic movement patterns may be a potential risk factor for initial low back pain development during prolonged standing. Future studies should

investigate whether BHP who have asymmetric lumbopelvic movement patterns and develop LBP symptoms during standing are at increased risk for developing future episodes of LBP.

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Highlights

- We investigate a risk factor for LBP symptom development during prolonged standing
- We examine asymmetry of pelvic motion during hip abduction between PDs and NPDs
- People who develop pain during standing display increased asymmetry
- Asymmetry is correlated with pain in people who develop LBP during standing

Figure 1.

a) Anterior view of the starting position for the side lying hip abduction test. b) End of hip abduction movement.

Figure 2.

Angle-time plots for hip abduction angle and lumbopelvic angle during a trial of the side lying hip abduction test. Vertical dashed lines represent the time point for the start of hip abduction motion (Hip Start), the start of lumbopelvic motion (Pelvis Start), and the end of hip abduction motion (Hip End). To index the timing of lumbopelvic motion, the time difference between Hip Start and Pelvis Start was calculated (startdiff). The startdiff variable was then normalized to Total Hip Abduction Movement Time (startdiff/hip abduction movement time).

Figure 3.

Means and standard errors for the difference in time between the start of the hip abduction movement and the start of the pelvis movement normalized to hip movement time (Startdiff; range: 0-1) for right and left leg in Non-Pain Developers (NPDs) and Pain Developers (PDs). There was a significant side by group interaction ($F = 4.32$ (1, 1); $p = 0.04$; $\eta^2 = 0.07$) indicating that the difference in the start of pelvic movement during hip abduction between sides (right vs. left) was greater for the PDs than for the NPDs.

Figure 4.

Scatterplot for the amount of asymmetry in the difference in time between the start of the hip abduction movement and the start of the pelvis movement normalized to hip movement time (Startdiff; range: 0-1) and average visual analogue scale sore (Average VAS; mm) in Pain Developers (PDs). There was a significant relationship between the amount of asymmetry of the startdiff variable and average VAS ($r = 0.46$; $p = 0.02$) indicating more asymmetry was related to greater average report of LBP symptoms during standing.

Table 1

Predetermined landmarks for marker placement.

Marker Locations	Location Details
Right Iliac Crest *	Most superior aspect of right iliac crest
Left Iliac Crest *	Most superior aspect of left iliac crest
Right PSIS	Most superior aspect of right PSIS
Left PSIS	Most superior aspect of left PSIS
Right ASIS	Most superior aspect of right ASIS
Left ASIS	Most superior aspect of left ASIS
Sacrum	Spinous process
Right Greater Trochanter *	Most superior aspect of right greater trochanter
Left Greater Trochanter *	Most superior aspect of left greater trochanter
Right Posterior Proximal Thigh	2/3 distance from hip to knee along longitudinal axis of the femur
Right Posterior Distal Thigh	3/4 distance from hip to knee along longitudinal axis of the femur
Right Anterior Proximal Thigh	2/3 distance from hip to knee along longitudinal axis of the femur
Right Anterior Distal Thigh	3/4 distance from hip to knee along longitudinal axis of the femur
Left Posterior Proximal Thigh	2/3 distance from hip to knee along longitudinal axis of the femur
Left Posterior Distal Thigh	3/4 distance from hip to knee along longitudinal axis of the femur
Left Anterior Proximal Thigh	2/3 distance from hip to knee along longitudinal axis of the femur
Left Anterior Distal Thigh	3/4 distance from hip to knee along longitudinal axis of the femur
Right Lateral Knee	Lateral aspect of right knee joint line
Right Medial Knee *	Medial aspect of right knee joint line
Left Lateral Knee	Lateral aspect of left knee joint line
Left Medial Knee *	Medial aspect of left knee joint line

PSIS, posterior superior iliac spine

ASIS, anterior superior iliac spine

* Calibration only

Table 2

Participant characteristics in Non Pain Developers (NPDs) and Pain Developers (PDs).

Characteristic	Group		Statistical Value	p-value
	NPDs (n = 33)	PDs (n = 24)		
Sex (% female)*	39.4%	62.5%	$\chi^2 = 3.0$	0.09
Dominant Leg (% Left)*	87.8%	87.5%	NA [†]	1.00
Age (years)	23.9 (3.5)	24.7 (3.3)	t = -0.9	0.37
Height (cm)	171.4 (8.7)	171.8 (7.1)	t = -0.2	0.84
Mass (kg)	67.1 (9.1)	69.2 (12.8)	t = -0.7	0.48
BMI (kg/m ²)	22.8 (2.3)	23.3 (2.8)	t = -0.7	0.50
Baecke Questionnaire of Habitual Physical Activity (3-15) [‡]	8.2 (1.2)	8.1 (1.3)	t = 0.2	0.91
Startdiff Right Leg (0-1)	0.19 (0.10)	0.18 (0.08)	t = 0.3	0.77
Startdiff Left Leg (0-1)	0.17 (0.08)	0.11 (0.09)	t = 2.5	0.02 [§]
Hip Abduction Motion Time Left Leg (Seconds)	1.8 (0.9)	1.8 (0.7)	t = 0.3	0.98
Hip Abduction Motion Time Right Leg (Seconds)	2.0 (1.0)	2.0 (0.8)	t = 0.1	0.92
Hip Abduction Range of Motion Left Leg (°)	44.1 (10.3)	46.6 (12.4)	t = 0.7	0.42
Hip Abduction Range of Motion Right Leg (°)	46.6 (10.6)	48.6 (9.6)	t = 0.7	0.47
Lumbopelvic Range of Motion During Hip Abduction with Left Leg (°)	8.7 (3.6)	9.0 (3.7)	t = 0.3	0.74
Lumbopelvic Range of Motion During Hip Abduction with Right Leg (°)	7.8 (3.8)	8.8 (4.4)	t = 0.9	0.37
Maximum VAS Score (mm)	0.0 (0.0)	13.8 (9.1)	t = 8.7	0.00*
Average VAS Score (mm)	0.0 (0.0)	5.7 (5.0)	t = 6.5	0.00*

BMI, Body Mass Index

Startdiff, difference in time (seconds) between the start of the hip abduction movement and the start of the pelvis movement normalized to total hip abduction movement time

VAS, Visual Analog Scale

* Sex is the percentage of females in each group; Leg dominance is percentage of groups that are left leg dominant; all other values are the mean (standard deviation)

[†] NA; Not applicable because a Fisher's Exact Test was used to test for dominant leg[‡] Baecke et al, 1982[§] Represents a significant difference between PDs and NPDs ($p < 0.05$)