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EFFECTS OF A HIP ORTHOSIS ON LUMBOPELVIC COORDINATION IN INDIVIDUALS WITH AND WITHOUT LOW BACK PAIN

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EFFECTS OF A HIP ORTHOSIS ON LUMBOPELVIC COORDINATION IN INDIVIDUALS WITH AND WITHOUT LOW BACK PAIN

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering in the College of Engineering at the University of Kentucky

By

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2020

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ABSTRACT OF THESIS

EFFECTS OF A HIP ORTHOSIS ON LUMBOPELVIC COORDINATION IN INDIVIDUALS WITH AND WITHOUT LOW BACK PAIN

Individuals with low back pain (LBP) demonstrate an abnormal lumbopelvic coordination compared to back-healthy individuals. This abnormal coordination presents itself as a reduction in lumbar contribution and an increase in pelvic contribution to trunk motion. This study investigated the ability of a hip orthosis to correct such an abnormal lumbo-pelvic coordination by restricting pelvic rotation and, as a result, increasing lumbar contribution. The effects of the hip orthosis on the magnitude and timing aspects of lumbopelvic coordination were investigated in 20 patients with LBP and 20 asymptomatic controls. The orthosis significantly increased lumbar contributions by 11%, 5.42%, 4.84%, and 4.89% during forward bending, lateral bending to the left, and axial twisting to the left and right, respectively, and increased the amount of lumbar dominant motion during forward bending and return. Orthosis-induced changes in magnitude and timing aspects of lumbo-pelvic coordination were smaller in patients with LBP; likely because our relatively young patient group had significantly smaller unrestricted pelvic rotations compared to asymptomatic individuals. However, the hip orthosis was capable of causing the expected changes in magnitude and timing aspects of lumbo-pelvic coordination in individuals with relatively large pelvic contributions to trunk motion; therefore, application of a hip orthosis may provide a method of correcting abnormal lumbopelvic coordination, particularly among patients with LBP who demonstrate large pelvic rotations, that warrants further investigation.

KEYWORDS: low back pain, lumbopelvic coordination, lumbopelvic rhythm, hip orthosis.

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4/23/2020

Date

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CHAPTER 1. INTRODUCTION

1.1 LOW BACK PAIN

Low back pain (LBP) affects up to 38% of individuals each year (Hoy et al., 2012) and total annual costs associated with LBP are estimated to exceed $100 billion (Katz, 2006). Up to 44% of acute LBP patients will experience recurrence within 1 year (Woolf and Pfleger, 2003), and 10-15% of patients will develop chronic LBP (Balague et al., 2012), which is the leading cause of disability (Maher et al., 2017). A major problem in treatment of LBP is the ability of current diagnostic methods to determine the cause of a patient's pain (Hancock et al., 2007.) At least 90% of LBP cases are categorized as non-specific LBP, meaning that no pathological cause was identified. (Woolf and Pfleger, 2003). This challenge has led researchers to search for factors that may have a role in the experience of LBP. One of these factors is lower back biomechanics, which have been suggested to play a causal role in the experience of LBP (Adams et al., 2006). Specifically, researchers have investigated differences in lower back biomechanics between individuals with and without LBP. By detecting abnormalities in lower back biomechanics in LBP patients, researchers can provide clinicians with a better understanding of the possible causes of a patient's LBP. This can lead to the development of treatment methods that target the root cause of a person's pain, allowing for more effective, individualized treatment. It may also allow clinicians to identify patients who are at risk of developing LBP, so that it may be prevented altogether.

1.2 CHARACTERIZING LUMBOPELVIC COORDINATION

Research on lower back biomechanics in LBP patients includes studies comparing trunk motion and lumbopelvic coordination (LPC) between LBP patients and healthy controls (Mayer et al., 1984; Marras and Wongsam, 1986; Porter and Wilkinson, 1997; Thomas and France, 2008; Thomas et al, 2008). Lumbopelvic coordination, or lumbopelvic rhythm, refers to the relative contributions of the lumbar spine and pelvis to trunk motion, both from timing and magnitude aspects, and has been commonly observed in patients with LBP and compared to asymptomatic individuals. Differences in LPC may suggest differences in control and loading of the spine and may play a role in development of LBP (Vazirian et al., 2016b). Therefore, they may indicate abnormalities in lower back biomechanics that can be targeted for LBP treatment. A detailed review of methods commonly used to observe the magnitude and timing aspects of LPC can be found in Vazirian et al 2016a and Needham et al 2014, but a brief summary is provided here.

LPC is commonly assessed during a trunk forward bending and return task, where a subject starts from standing position, bends forward towards their toes, and then returns to standing position. Using a variety of measurement methods, the rotations of the pelvis and thorax in the sagittal plane are measured, and lumbar flexion is calculated by subtracting pelvic rotation from thoracic rotation. Magnitude aspect of LPC are typically characterized by the values of thoracic, lumbar, and pelvic rotation at maximum forward bending posture. The ratio of lumbar (or pelvic) rotation to thoracic rotation, representing the percent contribution of the lumbar (or pelvis) to total trunk movement, is also used to characterize the magnitude aspect of LPC (Vazirian et al., 2016a).

Timing aspects of LPC are commonly investigated with signal analysis methods including 1) cross-correlation, 2) relative phase, and 3) vector coding. Cross correlation methods determine the time delay between the lumbar and pelvic motion signals and indicates whether the movement of lumbar is behind or ahead of the movement of the pelvis (Vazirian et al., 2016a). In relative phase methods, the phase angle of the lumbar and pelvis is calculated at each point in the signal, and the difference between the phase angles of lumbar and pelvic motion at each time point is used to generate a continuous relative phase curve. Mean absolute relative phase (MARP) is calculated by taking the average of the rectified continuous relative phase over the entire motion, or any segment of the motion. The value of MARP indicates whether the movements of lumbar and pelvic are more synchronous (in-phase) or asynchronous (out of phase). Deviation phase (DP) is also calculated by taking the standard deviation of the relative phase curve. DP gives a measure of variability of the coordination pattern. (Shojaei et al., 2017b). Vector coding methods generate a plot of lumbar rotation vs pelvic rotation and calculate vectors from each point to the next. The angles of these vectors (relative to the positive x-axis), referred to as coupling angles, indicate whether each segment is moving in the positive or negative direction, if they are moving in the same direction, and whether there is a greater movement from the lumbar or pelvis. For example, a vector with an angle of 30° would indicate that both the pelvis and lumbar are moving in the positive direction, and the horizontal component of the vector being larger than the vertical component indicates larger lumbar contribution to the movement. Vector coding methods also give a measure known as coupling angle variability (CAV), which describes the amount of variability in the coordination pattern, similar to the deviation phase found in relative phase methods. (Needham et al., 2014).

1.3 ABNORMAL LUMBOPELVIC COORDINATION (LPC)

1.3.1 MAGNITUDE ASPECT

LBP patients have typically shown smaller lumbar and larger pelvic contributions to trunk movement compared to asymptomatic individuals with no history of LBP. Mayer et al. was one of the first to propose a non-invasive method for examining lumbar range of motion during a forward flexion task and found less lumbar contribution to trunk motion in patients with chronic LPB compared to back healthy individuals (Mayer et al., 1984). Marras and Wongsam reported a 25% smaller lumbar contribution during forward bending and return tasks when comparing patients with chronic LBP to back healthy controls (Marras and Wongsam, 1986). Ahern et al. also observed lumbar flexion during forward bending and found an average of 27 degrees in patients with chronic LPB compared to 52 degrees in a back healthy control. (Ahern et al., 1988). Porter and Wilkinson compared men with chronic LBP and men without LBP and reported larger pelvic rotation and less lumbar flexion in the patients with chronic LBP (Porter and Wilkinson, 1997).

Abnormal LPC was also shown in patients with non-chronic (acute) LBP. Paquet at al. reported smaller lumbar movements during a forward bending task in patients with non-chronic LBP compared to healthy individuals. The patients with LBP fell into two subgroups: one with abnormal movement, and one with movement similar to the healthy controls. The patients with LBP who had abnormal movement had a significantly longer duration of pain compared to those with normal movement (39 vs 20 days). (Paquet et al., 1994). Shojaei et al. also examined patients with non-chronic LBP during forward bending and found smaller lumbar flexion and larger pelvic rotation compared to healthy individuals. Among patients with LBP, they also observed smaller lumbar angular velocity, acceleration, and deceleration. They suggest that the abnormal LPC is an adaptation to reduce demand on the lower back and avoid pain (Shojaei et al., 2017a). It has been proposed that abnormal LPC in patients with chronic LBP is a maladaptive response where the patient’s natural response to LBP becomes a mechanism that helps continue the disorder (O’Sullivan, 2005, van Dieen et al., 2017).

1.3.2 TIMING ASPECT

Timing aspects of LPC have also been observed to be different in patients with LBP. Shojaei et al. compared females with and without acute LBP during a forward bending and return task using relative phase methods. Patients with LBP had a smaller mean absolute relative phase (more in-phase, synchronous movement of lumbar and pelvis), as well as smaller deviation phase (less variable movement) (Shojaei et al., 2017b). Mokhtarinia et al. also reported more in phase coordination (smaller mean absolute relative phase) in patients with chronic LBP and less variability in movement (smaller deviation phase) during a variety of trunk flexion activities. (Mokhtarinia et al., 2016) During walking, Seay et al. and Selles et al. reported more in-phase movement and less variability in LBP patients (Seay et al., 2011a, Selles et al., 2001).

Literature concerning use of vector coding to analyze forward bending and return tasks is limited; however, it has been used to observe lumbopelvic coordination during walking. Seay et al. reported more in-phase movement (occurring in the same direction) of the pelvic and lumbar during walking in LBP patients compared to individuals with no history of LBP. They also reported these same differences when comparing people with a history of LBP (but no current symptoms) to people with no history of LBP. Furthermore, they reported less lumbar only movement in both LBP groups (Seay at el., 2011b). Pelegrinelli et al. also observed a more in-phase lumbopelvic coordination when comparing chronic LBP patients to healthy controls and observed more lumbar-dominant movement, but found that coupling angle variability was not different between groups. (Pelegrinelli et al., 2020).

1.4 PERSISTENCE OF ABNORMAL LPC AFTER SYMPTOM IMPROVEMENT

Studies have suggested that abnormal LPC in LBP patients can persist after pain subsides. (Vazirian et al,. 2016b). Esola et al. found that asymptomatic people with a history of LBP showed smaller lumbar contributions during the middle stage of forward bending, and greater lumbar contribution during the early stage of backward return, compared to those without a history of LBP. Ferguson et al. examined recovery from acute LBP by monitoring symptoms and movement during trunk flexion-extension tasks and reported that trunk movements did not return to normal for several weeks after pain had subsided. (Ferguson et al, 2016). It has been suggested that this behavior is related to fear of pain. Thomas and France examined lumbar flexion during recovery from acute LBP and found that patients who reported high fear of re-injury displayed reduced lumbar contributions for up to 12 weeks following the LBP episode. (Thomas and France, 2008). Shojaei et al. observed patients suffering from acute LBP over a six-month period. At the beginning of the study, patients with LBP exhibited larger pelvic and smaller lumbar rotations compared to healthy controls. Over the six-month period, the abnormal LPC persisted despite patients reporting a significant decrease in pain level (Shojaei et al., 2019).

1.5 ABNORMAL LPC AND LBP RECCURENCE

Research suggests that abnormal LPC can have severe biomechanical consequences for the lower back. Tafazzol et al. used a biomechanical modeling study to demonstrate that a reduction in lumbopelvic ratio (a decrease in lumbar contribution) during a forward bending task indicates a decrease in passive lumbar contribution to spine equilibrium, increasing compression and shear forces at the L5-S1 vertebrae (Tafazzol et al., 2014). In a study examining age-related differences in LPC, Vazirian et al. stated that less lumbar flexion indicates less stretch from spinal supporting tissues, and therefore less passive contribution from the tissues to offset the external demand of the task. This would result in an increase in active contributions from muscles, leading to higher forces on the spine. (Vazirian et al., 2017a). Shojaei et al. found that patients with LBP exhibiting smaller amounts of lumbar flexion experienced significantly higher shearing demands on the lower back when bending forward to lower a small load (4.5 kg), compared to healthy controls (Shojaei et al., 2018).

Silva et al. reported that LBP recurrence rate is as high as 33% with 1 year, and that previous LBP was the only significant predictor of LBP recurrence. (Silva et al., 2017). As stated before, patients with both acute and chronic LBP exhibit abnormal LPC that persists even after pain has subsided. Given the detrimental effects that abnormal LPC has on spinal loading and the fact that abnormal LPC persists after an episode of LBP, it is worth investigating the role that abnormal LPC might have in LBP recurrence and development of chronic LBP, and whether or not abnormal LPC can be corrected in order to reduce recurrence of LBP and development of chronic LPB.

1.6 CORRECTION OF ABNORMAL LPC

Exercise or physical therapy programs that include coordination and stabilization of the lumbar spine have been effective in reducing LBP (Searle et al., 2015). Sharvapour et al. observed lumbopelvic rhythm (LPR) of patients with LBP during forward bending before and after an 8-week lumbar stabilization exercise program. Patients reported a decrease in pain; however, there was no significant change in LPR, and patients continued to display smaller lumbar and larger pelvic range of motion compared to healthy controls. Sharvapour et al. suggested that patients had learned to stiffen the lumbar spine during the program and had retained the movement pattern after pain had subsided. (Sharvapour et al., 2017). Mayer et al. observed the effects of a functional restoration program on lumbar and pelvic range of motion in LPB patients. Out of 49 participants, 32 exhibited normal lumbar range of motion after the treatment, compared to only 13 before the treatment. The patients who achieved normal lumbar range of motion reported significantly lower pain ratings, compared to the patients who did not achieve normal range of motion. This study shows a relationship between correction of abnormal LPC and a reduction in LBP symptoms; however, the functional restoration program was unable to achieve normal LPC in 17 of the patients. (Mayer et al., 2009).

In some cases, lumbar orthosis belts have been used to limit lumbar movement and alleviate LBP symptoms. Lariviere et al. studied the effects of different lumbar orthosis belts on lumbopelvic coordination in healthy individuals, in order to evaluate their efficacy in treating LBP (Lariviere et al., 2014). The lumbar belts caused a significant decrease in lumbar rotation, and thus total range of motion. It was suggested that this may be beneficial in preventing and treating injury associated with soft-tissue creep during repetitive motions. However, they also reported that the belts reduced variability of coordination patterns and noted that this may be a negative effect, due to the hypothesis that variability in motor patterns is beneficial in protecting against tissue fatigue and overuse. They recommended that more research be done to determine which patients may benefit from the belts. Although lumbar belts might be helpful for individuals with lumbar injuries, it may lead to abnormal LPC by limiting lumbar range of motion. As previously described, reduced lumbar range of motion can have negative effects on the lumbar spine; therefore, caution should be used when using these lumbar belts for extended periods of time, in order to avoid encouraging abnormal LPC in patients.

1.7 CORRECTION OF LPC USING A HIP ORTHOSIS

In a previous study done by our lab, we studied the effects of a hip orthosis on lumbopelvic coordination in healthy individuals (Ballard 2019). The hypothesis was that by limiting pelvic range of motion via the orthosis, we could increase lumbar contribution to trunk motion. Healthy participants completed lateral bending, axial twisting, and forward bending and return tasks with and without a hip orthosis. It was found that total thoracic range of motion was not affected by the orthosis, and that lumbar-thoracic ratio was significantly increased when wearing the orthosis. These results indicated that lumbar contribution to trunk motion could be increased by limiting pelvic rotation, without affecting total trunk range of motion.

1.8 OBJECTIVE

This thesis aimed to continue this line of research by performing the same experiment with patients with LBP. In addition to observing effects of the orthosis on magnitude aspects of LPC, timing aspects were also observed during the forward bending and return task using a vector coding technique. The orthosis was only shown to be effective in altering LPC in individuals with no history of LBP. Thus, it was uncertain if the orthosis would still be effective in altering LPC in patients with LBP. As stated previously, abnormal LPC among patients with LBP is believed to be a defensive mechanism to avoid triggering pain. Therefore, it was possible that individuals currently suffering from LBP may be resistant to LPC correction. However, we expected that the orthosis would continue to have the desired effect on magnitude aspects of LPC (smaller pelvic contribution and greater lumbar contribution) as observed in Ballard 2019. Furthermore, we expected that the magnitude of these changes would be greater for patients with LBP because they would have larger pelvic rotations than the healthy individuals. We also expected to see greater amounts of lumbar dominant motion due to the orthosis restricting hip movement, and we expected to see a decrease in coupling angle variability, indicating a more stable movement pattern. If these hypotheses were supported by our results, this would provide justification for future research in using the hip orthosis to treat LBP through correction of abnormal LPC.

CHAPTER 2. METHODS

2.1 STUDY DESIGN AND PARTICIPANTS

A repeated measures design was used to evaluate the effects of the orthosis on LPC across three tasks. These tasks were 1) trunk forward bending and backward return (flexion extension), 2) left and right lateral bending (side to side bending), and 3) left and right axial twisting. The participants were twenty individuals (10 M, 10F, Table 2.1) age 18-28 with a recent history of LBP or current LBP. Each participant completed all three tasks with and without a hip orthosis. Task and condition (with or without orthosis) orders were randomized. In order to eliminate factors other than LBP and the orthosis that may affect LPC, presence of musculoskeletal or neuromuscular disorders other than LBP, current musculoskeletal injuries, and a history of spinal surgery were considered as exclusion criteria. Before any data was collected, each participant underwent an informed consent and screening process that was approved by the University of Kentucky Institutional Review Board. Data from these 20 subjects was combined with data from 20 back healthy (no LBP) individuals (11M, 9 F, Table 2.1) from another study (Ballard 2019) who underwent the same experiment, in order to observe how presence of LBP interacts with the effects of the orthosis.

Table 2.1: Mean (SD) of mass (Kg), stature (cm), age (year), and pain level (out of 10) for participants with and without low back pain (LBP). Anthropometric data for each group compared using an independent samples t-test; p-value < 0.05 indicates significance

Subject Demographics (SD)			
	Healthy	**LBP**	**p-value**
Weight(kg)	78.04 (17.51)	81.86 (19.95)	0.524
Stature (cm)	172.33 (7.74)	171.33 (8.6)	0.701
Age	22.7 (3.37)	21.05 (2.89)	0.105
Pain Level	N/A	4.4 (1.27)	N/A

2.2 DATA COLLECTION

At the start of the experiment, participants were fitted with Velcro straps to place wireless inertial measurement units ((IMUs; Xsens Technologies, Enschede, Netherlands) on their back over the T10 and S1 vertebrae. The T10 and the S1 IMUs measured the rotations of the thorax and pelvis respectively, and the difference between the two rotations was assumed to be the rotation of the lumbar spine. Once the IMUs were placed, the subject stood on a force plate (Advanced Mechanical Technology Inc, AMTI, Watertown, MA, USA). To determine the starting position of the accelerometers, a baseline set of data was collected from the IMUs and force plate while the participant was stationary at standing posture. After this, the subject did not leave the force plate and the IMUs were not disturbed for the rest of the experiment.

Figure 2.1: IMU placement over T10 and S1 vertebrae while standing and during forward bending task

The subject then completed each of the three tasks with and without the orthosis. Each task was described by the study personnel and the subjects were given the opportunity to practice. For all tasks, the subjects were told to cross their arms over their chest and keep their knees straight and their feet stationary. Vocal cues for the movements were given by the study personnel. For the forward bending and backward return tasks, the subject started from the upright standing posture, and the study personnel counted out loud to 5 and said “down.” Upon hearing this, the subject would bend forward to his/her maximum comfortable trunk flexion posture and would hold this position. The study personnel would then count to 5 again and say “up,” and the subject would return to the standing position. This was done 8 times for each condition. For the lateral bending tasks, the study personnel counted to 5 and said “left,’ and the subject would bend to the left as far as comfortably possible and hold the position. Next the researcher counted to 5 and said “return”, and the subject would return to the neutral standing position. This was done again, with the subject being told to bend to the right. The procedure for the axial twisting tasks was the same as the lateral bending tasks, except that the subject twisted their trunk instead of bending side to side. Both these tasks were repeated 8 times (4 to each side) for each condition. The orthosis used was a compression wrap (BodyMate, CA, USA) that was fastened with Velcro around the subject's waist and thighs. (Figure 2.1). The same orthosis was used for all participants.

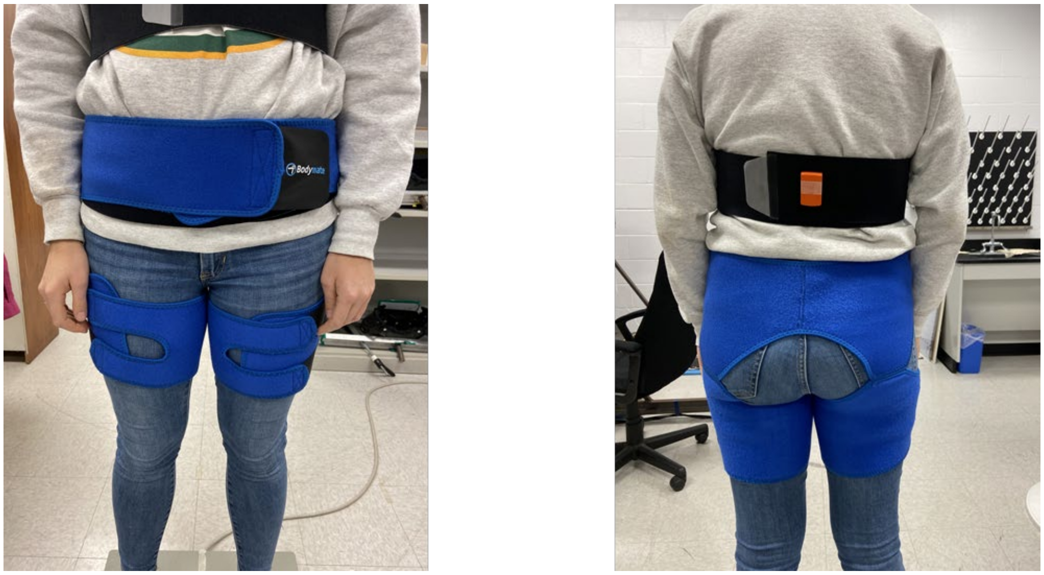

Figure 2.2: Hip Orthosis (BodyMate, CA, USA)

2.3 DATA ANALYSIS

2.3.1 MAGNITUDE ASPECT.

Orientation data was collected by the IMUs at a rate of 60 Hz using the MT Manager software (Xsens Technologies, Enschede, Netherlands). Using scripts written in MATLAB (MathWorks, MA, USA), the rotation matrices of the IMUs were used to find the rotations of the pelvis and thorax, relative to the standing position, in the primary plane of motion for each task: sagittal plane for forward bending and backward return, the transverse plane for axial twisting, and the coronal or frontal plane for lateral bending. For each task and condition, we calculated the 1) maximum thoracic rotation, 2) maximum pelvic rotation, 3) maximum lumbar rotation, and 4) lumbar-thoracic ratio (LTR). To find the value of maximum thoracic, pelvic, and lumbar rotations, the corresponding maximum rotations for all repetition of the task were averaged. If any of the thoracic rotations of each repetition were more than 3 standard deviations away from the mean, they were marked as outliers. Any repetition marked as an outlier was excluded from the thoracic, pelvic, and lumbar data, and new average values were calculated. Lumbar-thoracic ratio for each task was found by dividing the maximum lumbar rotation by the maximum thoracic rotation. Thoracic rotation reflects the overall trunk motion, so the LTR represents the contribution of the lumbar to the overall trunk motion (given as a percentage). This creates a measure of performance that is independent of individual variations in total range of motion.

$$LTR = \frac{Lumbar\ rotation}{Thoracic\ rotation} = \frac{Thoracic\ rotation - Pelvic\ rotation}{Thoracis\ rotation} \times 100\%$$

To eliminate possible confounding effects of orthosis induced changes in tasks performance (evaluated by the magnitude of thoracic rotation) and therefore enable comparison of lumbo-pelvic coordination at similar levels of task performance (i.e., determined by equal amount of thoracic rotation), lumbar and pelvic rotation as well as LTR were obtained for both orthosis conditions of each subject at thoracic rotations equal to 20, 40, 60 and 80 percent of their maximum thoracic rotation with no orthosis. This was only done for the forward bending and return tasks because it is one of the most researched movements in studies concerning LPC. Therefore, results could be easily interpreted and compared to the literature.

2.3.2 TIMING ASPECT

Timing aspects of forward bending and return are also commonly observed in the literature; therefore, a vector coding technique described in Needham et al (2014) was used to analyze timing aspects of LPC during forward bending and return. This was not done for the other tasks (lateral bending and axial twisting) because timing aspects of those tasks are not well understood.

To analyze the timing aspects of LPC, the lumbar and pelvic rotation data were first separated into bending and return phases for each repetition and normalized to 100 points, corresponding to each percentile of motion. Next for each repetition and phase (bending or return), a plot of pelvic rotation vs lumbar flexion was generated. From that plot, a measure referred to as the coupling angle was found for each time point by calculating the angle of a vector from each time point to the next, relative to the right horizontal axis. For all points, the corresponding coupling angles across all repetitions were averaged. Next, for each phase, all points were averaged to obtain one value of average coupling angle. This was repeated for all subjects under each condition (with and without orthosis). Additionally, using the average coupling angle signals, another measure, coupling angle variability (CAV), was found for each point using rotational statistics and was averaged to find one value for each subject.

The value of the coupling angle, ranging from 0° to 360°, allows us to place the LPC pattern into 4 different categories according to the classification system described in Needham et al (2015). These categories are shown in Fig 2.2 and are as follows: in-phase with proximal (lumbar) dominancy (white), in-phase with distal (pelvic) dominancy (light grey), anti-phase with proximal dominancy (dark grey) and anti-phase with distal dominancy (black). Here, in-phase refers to both segments moving in the same direction, and anti-phase refers to them moving in opposite directions. The grey numbers around the circle signify a percentage used to define segment dominancy. For example, D20-P80 indicates 80% of the movement is coming from the proximal segment (lumbar). Dominancy was defined as a percent over 50. CAV represents the variability of the coordination pattern at each time across all repetitions.

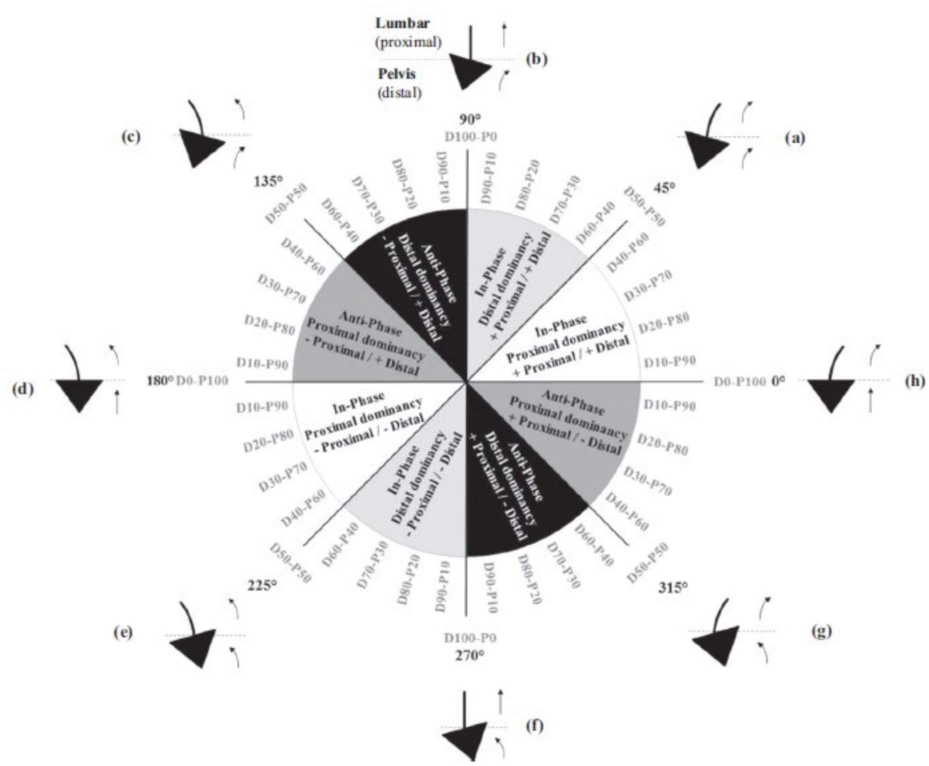

Figure 2.3: Coordination pattern classification system. Segmental dominancy is shown around the circumference of the polar plot (grey text) with the inclusion of visual illustrations to show the coordination pattern between the lumbar region (proximal) and the pelvic (distal) at specific coupling angles (a-h). (Needham et al., 2015)

2.4 STATISTICAL METHODS

The maximum thoracic, pelvic, and lumbar rotations, as well as the LTR during all tasks, as measures of magnitude aspect of LPC, along with average coupling and CAV during each phase of forward bending and backward return, as measures of timing aspect of LPC, were used for statistical analysis. For each dependent variable, a repeated measure mixed factor analysis of variance (ANOVA) test was used to evaluate the effect of condition (with versus without orthosis) as the within-subject factor and group (healthy versus LBP) as the between-subjects factor. A 95% significance level (p-value < 0.05) was used to determine statistical significance. For the forward bending and return tasks, this same test was also done using the thoracic, pelvic, and lumbar rotations and LTR at 20%, 40%, 60%, and 80% of maximum thoracic rotation during forward bending without orthosis. Post hoc analyses were performed using t-tests with an adjusted p-value of 0.0125.

CHAPTER 3. RESULTS

3.1 STATISTICS

Summaries of statistical analyses along with mean values of measures characterizing the magnitude aspects of LPC during trunk forward bending and backward return, lateral bending, and axial twist are respectively presented in Table 3.1, Table 3.2, and Table 3.3. Table 3.4 includes summary of statistical analyses and mean values of measures characterizing the timing aspect of LPC only during trunk forward bending and backward return.

Table 3.1: Mean values and summary of statistics for the differences in thoracic, pelvic, and lumbar rotations as well as differences in lumbo-thoracic ratio (LTR) during trunk forward bending and backward return between orthosis and low back pain (LBP) conditions. p-value < 0.05, denoted by bold font, indicates significant difference

Magnitude Aspect of LPC During Forward Bending and Backward Return										
20% of Normal Thoracic Rotation										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Thorax Rotation	19.62°	19.61°	0.017	0.896	21.92°	17.30°	14.258	**0.001**	0.745	0.394
Pelvis Rotation	6.53°	3.50°	24.816	**<0.001**	6.07°	3.96°	3.802	0.059	2.97	0.093
Lumbar Rotation	13.08°	16.11°	24.988	**<0.001**	15.85°	13.34°	7.472	**0.009**	2.841	0.1
LTR	68.95%	83.37%	29.694	**<0.001**	73.44%	78.88%	1.517	0.226	2.624	0.114
40% of Normal Thoracic Rotation										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Thorax Rotation	39.25°	39.24°	0.088	0.768	43.84°	34.65°	14.001	**0.001**	0.037	0.849
Pelvis Rotation	14.43°	8.68°	31.143	**<0.001**	14.04°	9.07°	7.157	**0.011**	4.888	**0.033**
Lumbar Rotation	24.83°	30.55°	31.357	**<0.001**	29.81°	25.58°	6.427	**0.015**	4.978	**0.032**
LTR	65.18%	78.89%	37.2	**<0.001**	68.92%	75.15%	2.894	0.097	4.307	**0.045**
60% of Normal Thoracic Rotation										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Thorax Rotation	58.92°	58.89°	0.296	0.59	65.77°	52.04°	13.959	**0.001**	0.134	0.716
Pelvis Rotation	22.29°	14.38°	39.026	**<0.001**	22.31°	14.36°	9.096	**0.005**	8.467	**0.006**
Lumbar Rotation	36.63°	44.61°	38.807	**<0.001**	43.45°	37.68°	5.916	**0.02**	8.39	**0.006**
LTR	63.99%	76.60%	45.986	**<0.001**	66.90%	73.69%	4.131	**0.049**	7.411	**0.01**
80% of Normal Thoracic Rotation										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Thorax Rotation	78.50°	78.32°	2.182	0.148	87.54°	69.29°	13.73	**0.001**	0.408	0.527
Pelvis Rotation	31.74°	22.16°	54.163	**<0.001**	33.01°	20.98°	10.269	**0.003**	14.023	**0.001**
Lumbar Rotation	46.77°	56.17°	53.72	**<0.001**	54.53°	48.41°	4.117	0.05	13.988	**0.001**
LTR	61.52%	72.97%	60.736	**<0.001**	63.19%	71.30%	5.571	**0.024**	11.47	**0.002**
Maximum Thoracic Rotation										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Thorax Rotation	98.18°	93.49°	25.261	**<0.001**	106.83°	84.84°	12.896	**0.001**	0.397	0.532
Pelvis Rotation	43.98°	31.29°	65.463	**<0.001**	46.68°	28.59°	11.876	**0.001**	16.521	**<0.001**
Lumbar Rotation	54.20°	62.20°	44.083	**<0.001**	60.15°	56.26°	1.219	0.276	23.079	**<0.001**
LTR	57.37%	68.42%	74.617	**<0.001**	57.73%	68.06%	7.872	**0.008**	16.222	**<0.001**

Table 3.2: Mean values and summary of statistics for the differences in thoracic, pelvic, and lumbar rotations as well as differences in lumbo-thoracic ratio (LTR) during lateral bending to the left and right, between orthosis and low back pain (LBP) conditions. p-value < 0.05, denoted by bold font, indicates significant difference

Magnitude Aspect of LPC During Lateral Bending to the Left										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Thorax Rotation	27.03°	26.68°	0.408	0.527	26.58°	27.13°	0.063	0.803	0.149	0.149
Pelvis Rotation	5.28°	3.91°	17.115	**<0.001**	5.49°	3.71°	6.125	**0.018**	2.5	0.122
Lumbar Rotation	21.85°	23.06°	4.884	**0.033**	21.24°	23.68°	1.56	0.219	4.127	**0.049**
LTR	81.05°	86.47°	14.637	**<0.001**	80.17°	87.34°	8.736	**0.005**	6.458	**0.015**
Magnitude Aspect of LPC During Lateral Bending to the Right										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Thorax Rotation	28.80°	26.88°	5.382	**0.026**	27.338	28.342	0.195	0.662	0.01	0.922
Pelvis Rotation	6.18°	5.22°	7.599	**0.009**	6.117	5.229	1.074	0.307	1.073	0.307
Lumbar Rotation	22.82°	21.72°	2.095	0.156	21.25	23.299	0.958	0.334	0.142	0.708
LTR	78.79°	80.97°	2.235	0.143	77.362	82.399	2.542	0.119	0.516	0.477

Table 3.3: Mean values and summary of statistics for the differences in thoracic, pelvic, and lumbar rotations as well as differences in lumbo-thoracic ratio (LTR) during axial twisting to the left and right, between orthosis and low back pain (LBP) conditions. p-value < 0.05, denoted by bold font, indicates significant difference

Magnitude Aspect of LPC During Axial Twisting to the Left										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Thorax Rotation	51.90°	47.65°	6.458	**0.015**	49.86°	49.68°	0.001	0.971	1.384	0.247
Pelvis Rotation	36.47°	31.20°	12.105	**0.001**	36.26°	31.41°	1.628	0.210	0.901	0.349
Lumbar Rotation	15.84°	16.29°	0.414	0.524	13.70°	18.42°	4.044	0.051	14.593	**<0.001**
LTR	31.16°	36.00°	6.912	**0.012**	21.78°	34.08°	9.696	**0.004**	2.146	0.151
Magnitude Aspect of LPC During Axial Twisting to the Right										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Thorax Rotation	53.22°	47.70°	12.28	**0.001**	51.33°	49.60°	0.168	0.684	0.054	0.817
Pelvis Rotation	39.22°	33.47°	18.806	**<0.001**	37.80°	34.89°	0.597	0.445	0.106	0.747
Lumbar Rotation	13.99°	14.16°	0.04	0.843	13.43°	14.73°	0.395	0.534	0.075	0.785
LTR	26.88°	31.77°	8.095	**0.007**	25.54°	33.12°	2.882	0.098	0.002	0.965

Table 3.4: Mean values and summary of statistics for the differences in average coupling angle and coupling angle variability (CAV) during trunk forward bending and backward return between orthosis and low back pain (LBP) conditions. p-value < 0.05, denoted by bold font, indicates significant difference

Timing Aspect of LPC During Forward Bending and Return										
	Within Subjects				Between Subjects				Interaction	
Variable	Without Orthosis	With Orthosis	F	P-Value	Healthy	LBP	F	P-Value	F	P-value
Coup Angle Bending	39.49°	28.99°	23.562	**<0.001**	37.77°	30.68°	3.559	0.067	11.898	**0.001**
Coup Angle Return	219.00°	206.85°	33.900	**<0.001**	217.96°	207.89°	8.080	**0.007**	9.862	**0.003**
CAV Bending	21.38°	20.93°	3.024	0.084	23.70°	18.62°	411.215	**<0.001**	5.397	0.365
CAV Return	16.23°	15.61°	17.969	**<0.001**	17.99°	13.86°	76.470	**<0.001**	202.735	**<0.001**

3.2 INTERACTION BETWEEN GROUP AND ORTHOSIS CONDITION

3.2.1 FORWARD BENDING AND RETURN

There were significant interactions between group and condition on the maximum pelvic rotation, the maximum lumbar rotation, and LTR at maximum thoracic rotation. Maximum pelvic rotation was larger in healthy group [56.22° (18.6°) vs 31.74° (16.96°)], but only without orthosis. Although there were no significant group differences in pelvic rotation at 20% of normal thoracic rotation, we did see similar interactions at 40%, 60%, and 80% of normal thoracic rotation.

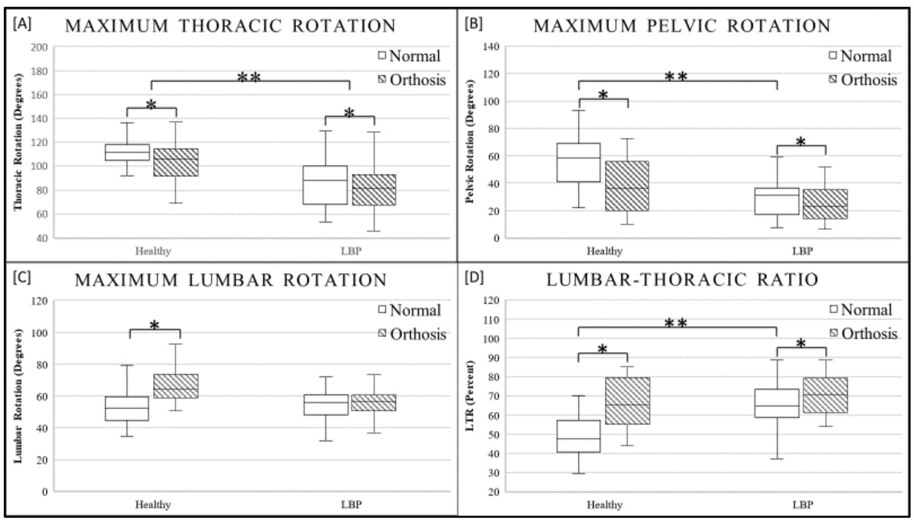

Figure 3.1: Mean and standard deviation of thoracic (A), pelvic (B), lumbar (C) rotations and LTR (D) with and without the hip orthosis among patients with low back pain (LBP) and asymptomatic controls during forward bending and return at maximum thoracic rotation. Stars indicate significant difference between means.

The maximum lumbar rotation increased with orthosis in the healthy group [53.25° (11.64°) vs 67.04° (12.14°)], but the orthosis induced change in the LBP group [55.15° (11.79°) vs 57.36° (11.51°)] was not statistically significant. Additionally, although there was no group difference in lumbar rotation at maximum thoracic rotation, lumbar rotation was significantly larger in the healthy group at 20% [17.88° (3.34°) vs 14.34° (3.35°)], 40% [33.81° (5.7°) vs 27.3° (6.79°)], 60% [49.23° (7.94°) vs 39.79° (9.33°), and 80% [61.62° (9.93°) vs 50.71° (11.04°)], but only with the orthosis.

LTR at maximum thoracic rotation was significantly lower in the healthy group [49.63% (12.29%) vs 65.11% (11.84%)], but only without the orthosis. This same interaction was also observed at 60% and 80% of normal thoracic.

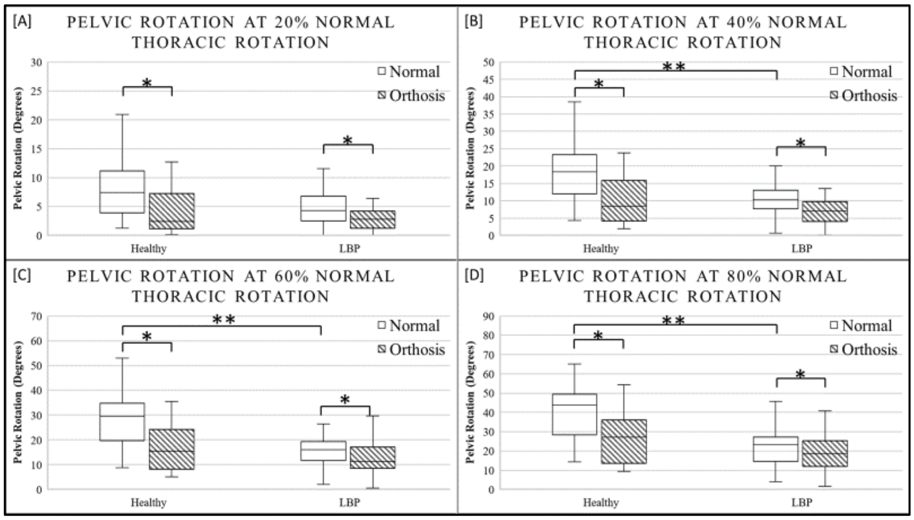

Figure 3.2: Mean and standard deviation of pelvic rotation with and without the hip orthosis among patients with low back pain (LBP) and asymptomatic controls during forward bending and return at 20 (A), 40 (B), 60 (C) and 80 (D) percent of normal thoracic rotation. Stars indicate significant difference between means.

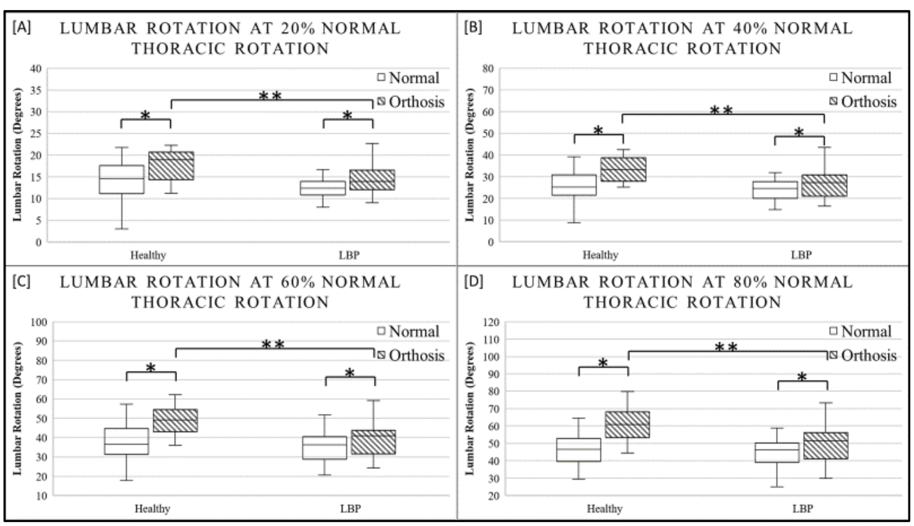

Figure 3.3: Mean and standard deviation of lumbar rotation with and without the hip orthosis among patients with low back pain (LBP) and asymptomatic controls during forward bending and return at 20 (A), 40 (B), 60 (C) and 80 (D) percent of normal thoracic rotation. Stars indicate significant difference between means.

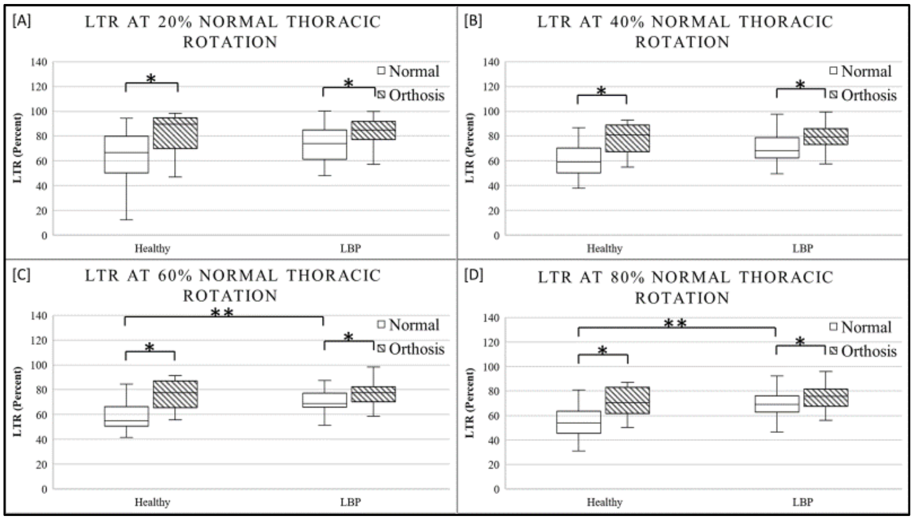

Figure 3.4: Mean and standard deviation of LTR with and without the hip orthosis among patients with low back pain (LBP) and asymptomatic controls during forward bending and return at 20 (A), 40 (B), 60 (C) and 80 (D) percent of normal thoracic rotation. Stars indicate significant difference between means.

3.2.2 LATERAL BENDING

There were significant interactions of independent variables on the maximum lumbar rotation and LTR during lateral bending to the left. Specifically, there were significant orthosis-induced increases in lumbar rotation [20.08° (4.57°) vs 22.40° (6.95°)] and LTR [75.66% (10.15%) vs 84.68% (7.39%)] only in the healthy group.

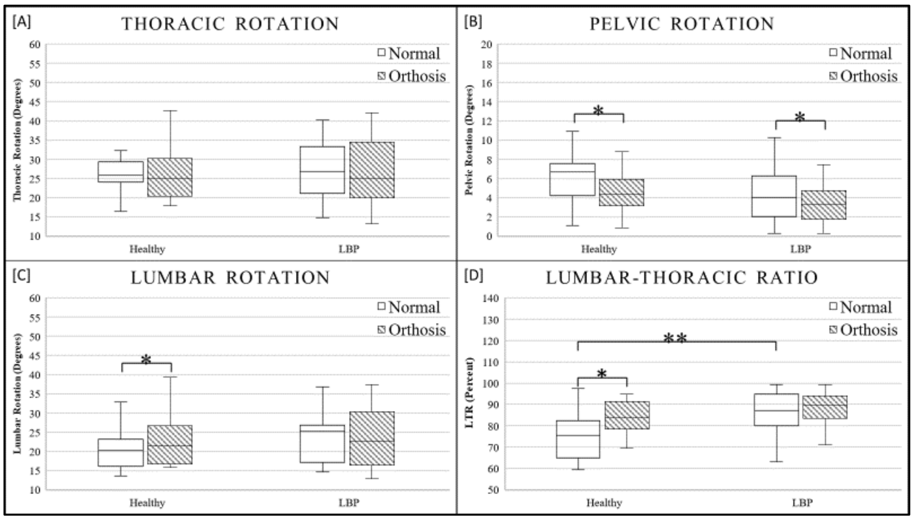

Figure 3.5: Mean and standard deviation of thoracic (A), pelvic (B), lumbar (C) rotations and LTR (D) with and without the hip orthosis among patients with low back pain (LBP) and asymptomatic controls during lateral bending to the left. Stars indicate significant difference between means.

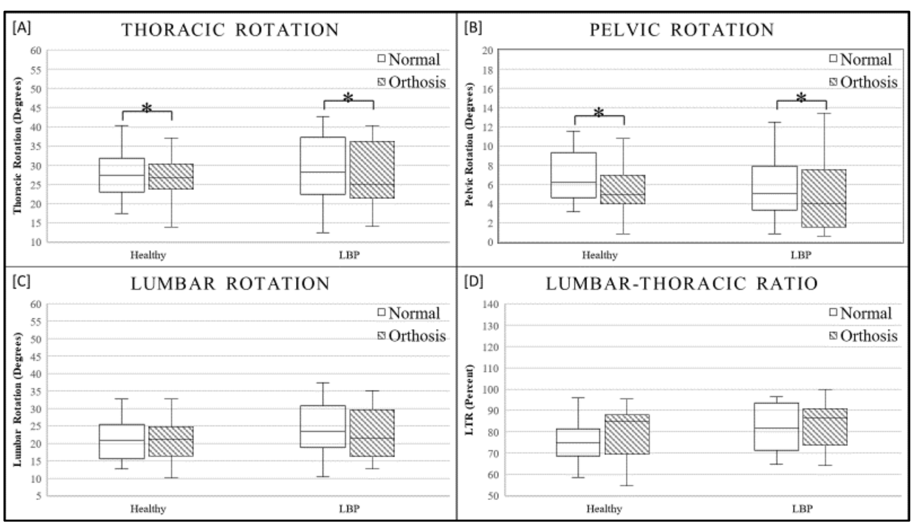

Figure 3.6: Mean and standard deviation of thoracic (A), pelvic (B), lumbar (C) rotations and LTR (D) with and without the hip orthosis among patients with low back pain (LBP) and asymptomatic controls during lateral bending to the right. Stars indicate significant difference between means

3.2.3 AXIAL TWISTING

There was a significant interaction of independent variables on lumbar rotation during axial twisting to the left. Specifically, lumbar rotation increased significantly [12.12° (6.32°) vs 15.26° (6.8°)] in healthy group but decreased [19.53° (9.26°) vs 17.31° (8.24°)] in LBP group with orthosis.

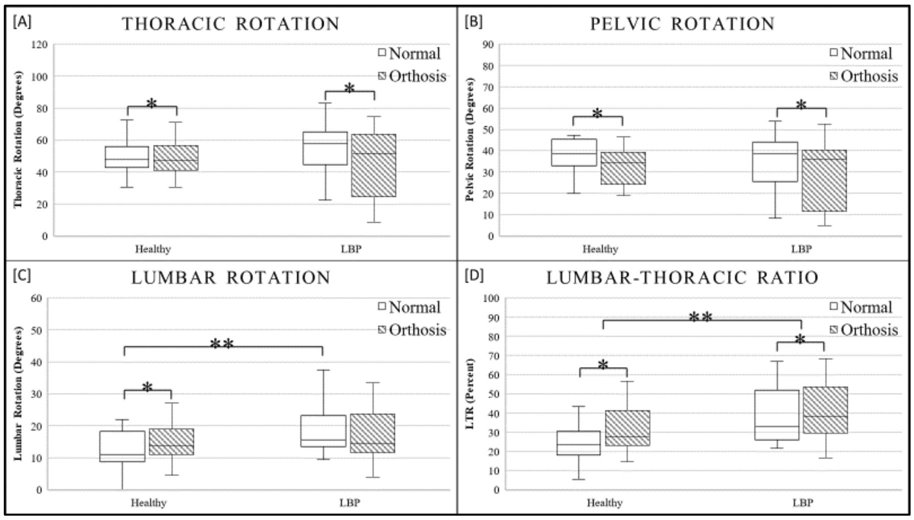

Figure 3.7: Mean and standard deviation of thoracic (A), pelvic (B), lumbar (C) rotations and LTR (D) with and without the hip orthosis among patients with low back pain (LBP) and asymptomatic controls during axial twisting to the left. Stars indicate significant difference between means.

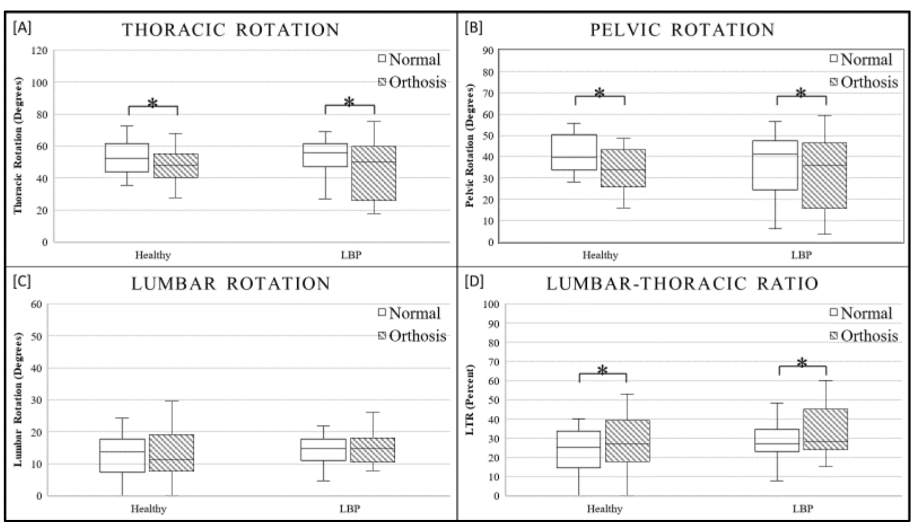

Figure 3.8: Mean and standard deviation of thoracic (A), pelvic (B), lumbar (C) rotations and LTR (D) with and without the hip orthosis among patients with low back pain (LBP) and asymptomatic controls during axial twisting to the right. Stars indicate significant difference between means.

3.2.4 TIMING ASPECTS OF FORWARD BENDING AND RETURN

There were significant interactions between condition and group on the average coupling angle during both bending and return, and CAV during return of trunk forward bending and backward return. Average coupling angle decreased with orthosis [46.73° (11.67°) vs 28.82° (14.74°)] during bending only in the healthy group, changing the movement pattern from pelvic dominant to lumbar dominant. When wearing no orthosis, the average coupling angle was larger in the healthy group compared to LBP group [46.73° (15.49°) vs 32.19° (12.34°) during bending, 227.32° (13.11°) vs 210.69° (14.59°) during return], indicating a pelvic dominant movement pattern in the healthy group, and a lumbar dominant movement pattern in the LBP group. CAV during return was higher in the healthy group [19.34° (5.67°) vs 13.12° (7.01°)], but only without orthosis

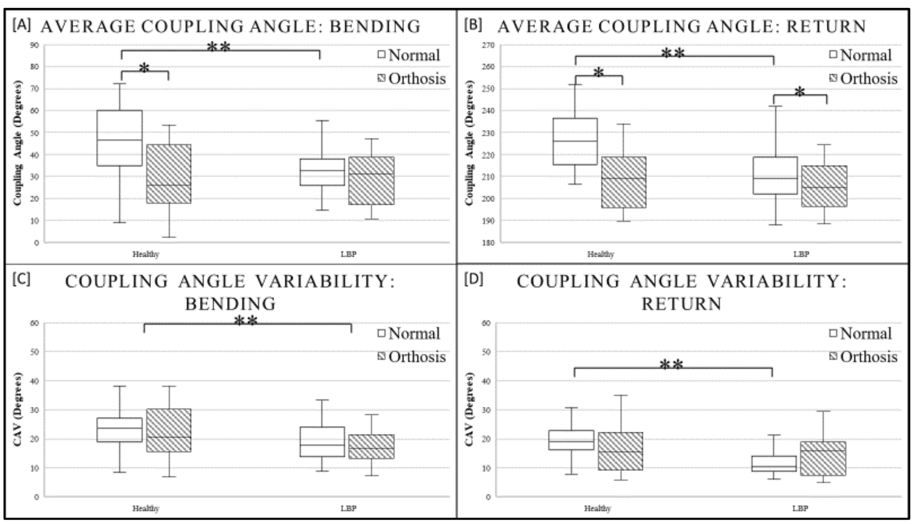

Figure 3.9: Mean and standard deviation of average coupling angle during forward bending (A), average coupling angle during backward return (B), CAV during bending (C) and CAV during return (D) with and without the hip orthosis among patients with low back pain (LBP) and asymptomatic controls. Stars indicate significant difference between means.

3.3 MAIN EFFECT OF ORTHOSIS ON LPC

3.3.1 FORWARD BENDING AND RETURN

The maximum thoracic rotation significantly decreased [97.98° (22.15°) vs 92.99° (22.19°)] with orthosis.

Maximum pelvic ROM was significantly reduced with orthosis [43.98° (21.5°) vs 31.29° (17.66°)]. Consistently, the orthosis produced significant decreases in pelvic rotation at 20% [6.53° (4.67°) vs 3.5° (3.32°)], 40% [14.43° (8.22°) vs 8.68° (5.94°)], 60% [22.29° (11.68°) vs 14.38° (8.35°)], and 80% [31.74° (16.03°) vs 22.16° (11.96°)] of normal thoracic rotation.

Lumbar rotation was significantly increased with orthosis at 20% [13.08°(3.64) vs 16.11° (3.76°)], 40% [24.83° (6.11°) vs 30.55 °(7.01°)], 60% [36.63° (8.3°) vs 44.61° (9.79°)] and 80% [46.77° (10.12°) vs 56.17° (11.74°)] of normal thoracic rotation.

LTR at maximum thoracic rotation increased significantly with orthosis [57.37% (14.26%) vs 68.42% (12.68%)].Consistently, the orthosis produced significant increases in LTR at 20% [68.95% (18.9%) vs 83.37% (13.5%)], 40% [65.18% (15.69%) vs 78.89% (12.02%)], 60% [63.99% (14.2%) vs 76.6% (10.94%)] and 80% [61.52% (13.97%) vs 72.97% (11.11%)] of normal thoracic rotation.

3.3.2 LATERAL BENDING

When wearing the orthosis during lateral bending, there was a significant decrease in pelvic rotation [5.28° (3.01°) vs 3.19° (2.23°) when bending to the left, 6.18° (3.05°) vs 5.22° (3.15°) when bending to the right). There was also a significant decrease in maximum thoracic rotation [28.80° (8.19°) vs 26.88° (6.92°)] with orthosis when bending to the right.

3.3.3 AXIAL TWISTING

When wearing the orthosis during axial twisting, there were significant decreases in maximum thoracic rotation [51.90° (15.18°) vs 47.65° (16.79°) when twisting to the left, 53.22° (13.2°) vs 47.70° (14.86°) when twisting to the right] and pelvic rotation [36.47° (13.15°) vs 31.20° (12.95°) when twisting to the left, 39.22° (11.59°) vs 33.47° (13.43°) when twisting to the right], and a significant increase in LTR [31.16% (15.6%) vs

36.00% (14.4%) when twisting to the left, 26.88% (14.96%) vs 31.77% (15.86%) when twisting to the right].

3.3.4 TIMING ASPECTS OF FORWARD BENDING AND RETURN

Average coupling angle during return was significantly reduced with orthosis [219.0° (16.07°) vs 206.85° (12.06°)], indicating increased amounts of lumbar dominant motion.

3.4 MAIN EFFECT OF LOW BACK PAIN ON LPC

3.4.1 FORWARD BENDING AND RETURN

The maximum thoracic rotation was significantly lower in the LBP group compared to the back healthy group [106.83° (16.99°) vs 84.84° (21.69°)]. Consistently, similar differences in thoracic rotation between groups were observed at 20% [21.92°(3.25°) vs 17.3°(4.32°)], 40% [43.84°(6.48°) vs 34.65° (8.7°)], 60% [65.77° (9.7°) vs 52.04° (13.00°)], and 80% [87.54° (13.04°) vs 69.29° (17.41°)] of the maximum thoracic rotations.

3.4.2 LATERAL BENDING

During lateral bending to the left, the LBP group had significantly lower pelvic rotation compared to back healthy individuals [5.49° (2.75°) vs 3.71° (2.4°)].

3.4.3 AXIAL TWISTING

During axial twisting to the left, the LBP group has significantly higher lumbar rotation [13.70° (6.67°) vs 18.42° (8.72°)] and significantly higher LTR [21.78°% (12.4%) vs 34.08% (15.21%)] compared to back healthy individuals.

3.4.4 TIMING ASPECTS OF FORWARD BENDING AND RETURN

CAV was significantly lower in the LBP group for bending [23.7° (3.09°) vs 18.62° (1.82°)], which would indicate that the LBP group had less variability in their coordination patterns.

CHAPTER 4. DISCUSSION

Abnormal LPC, specifically larger pelvic and smaller lumbar contribution to trunk motion, is widely reported in patients with LBP. Recently, Ballard (2019) showed that a hip orthosis was able to decrease pelvic contribution and increase lumbar contribution for healthy individuals during several trunk movement tasks. The objective of this thesis was to determine if the hip orthosis would produce similar but larger changes in LPC for patients with LPB.

Our hypothesis that the orthosis would produce similar changes in the LBP was refuted, as the orthosis significantly decreased the maximum pelvic rotation of patients with LBP but did not significantly increase their maximum lumbar rotation. However, when comparing conditions at 20, 40, 60, and 80 percent of normal thoracic rotation during forward bending and return, we did see significantly smaller pelvic rotation and significantly larger lumbar rotation in all subjects. Our hypothesis that the orthosis would increase the amounts of lumbar dominant motion was supported partially, as we saw significant decreases in average coupling angle during forward bending and return in the healthy group, and during return in the LBP group. Our hypothesis that the orthosis would decrease CAV was also refuted, as there were no significant changes in CAV. Finally, our hypothesis that the orthosis induced changes in LPC would be greater in the patients with LBP was also refuted.

4.1 DIFFERENCES IN LPC BETWEEN HEALTHY INDIVIDUALS AND PATIENTS WITH LPB

4.1.1 MAGNITUDE ASPECTS

Without the orthosis, we found no significant difference in lumbar rotations between the two groups during all activities except axial twisting to the left, where lumbar rotation was larger in the LBP group. Additionally, we saw significantly smaller pelvic rotations in the LBP group during forward bending and return and lateral bending to the left. These same differences were also observed at 40, 60, and 80 percent of normal thoracic rotation

Similar lumbar rotations and smaller pelvic rotations resulted in smaller thoracic rotations (total trunk range of motion) and larger LTR in the LBP group. This is contrary to much of the literature, as well as previous studies by our own lab, which report decreased amounts of lumbar rotation and increased amounts of pelvic rotation in patients with LBP. (Marras and Wongsam, 1986; Ahern et al., 1988 ;Paquet et al., 1994; Porter and Wilkinson, 1997; O'Sullivan, 2005; Shojaei et al., 2017).

Although rare, there have been some studies that have also contradicted the general body of research. Porter and Wilkinson compared LPC of 15 patients with chronic LBP to 17 healthy individuals at different amounts of trunk forward bending and saw an overall reduction in lumbar rotation and maximum trunk range of motion in the patients with LBP. However, when observing the 8 patients who were able to achieve the same trunk range of motion as the controls, they found that the subjects split evenly into two subgroups. One half displayed movement similar to the healthy group, while the other displayed increased lumbar rotation and decreased pelvic rotation (Porter and Wilkinson, 1997). This suggests that some individuals with LBP may not display abnormal LBP, and others may have smaller pelvic rotations and greater lumbar rotations, as was seen in our study. Esola et al. compared patients with a history of LBP to healthy controls with no history of LBP during forward bending, and reported no significant differences in total amounts of lumbar or pelvic rotation, and also reported lower pelvic rotations in the LBP group during early stages of motion. (Esola et al., 1995). Wong and Lee observed that patients with LBP showed smaller pelvic rotations during forward bending compared to healthy controls, but also observed smaller lumbar rotation. (Wong and Lee, 2004)

One possible source of this discrepancy could be the young age of our study population. Lumbar contributions to forward bending and return tasks have been shown to decrease with age, with a significant decrease in individuals older than 50, and it was suggested that this may indicate differences in active and passive tissue contributions between younger and older individuals (Vazirian et al., 2017a). The LBP patients in our study had a mean age of 21 years, which is much lower than the mean age of other LBP study populations (28-58 years) referenced in this paper. Interestingly the LBP groups in Porter and Wilkinson and Esola et al., which reported LBP patients with similar or greater lumbar rotation than healthy individuals, had a mean age of 26 and 29.7 years, respectively, which is closer to the age of our own study participants. On the other hand, the LBP group in Wong and Lee, which reported lower lumbar rotations than healthy individuals, had a mean age of 40 years. It is possible age-related differences in lumbar rotation may have contributed to the smaller lumbar rotations seen in studies with older

LBP patients; therefore, it is possible that the younger individuals in this study were less susceptible to LBP induced changes in lumbar motion.

4.1.2 TIMING ASPECTS

Differences in average coupling angle during forward bending and return were consistent with magnitude aspects. Without orthosis, the healthy group displayed a pelvic dominant movement pattern, while the LBP group displayed a lumbar dominant pattern. These results are consistent with the values of LTR for both groups. (49.63% vs 65.11%); however, they once again contradict previous research, which has shown smaller amounts of lumbar dominant movement in patients with LBP. (Pelegrinelli et al,. 2019; Seay at al., 2011b).

CAV values during bending and return were significantly smaller in the LBP group, indicating less variability in coordination pattern. These results are consistent with previous research that have reported less variability in movement among patients with LBP. (Mokhtarinia et al., 2016; Seay et al., 2011a; Selles et al., 2001; Shojaei et., 2017b). Mokhtarinia et al. stated that less variable movement patterns among patients with LPB indicate an impaired ability to adapt to different external load demand (Mokhtarinia et al., 2016).

4.2 EFFECTS OF ORTHOSIS ON LPC

4.2.1 MAGNITUDE ASPECTS

The orthosis caused a significant decrease in maximum pelvic rotation for all activities. However, during the forward bending and return activity, the decrease caused by the orthosis was much larger in the healthy group than the LBP group (19.07 vs 6.32). Additionally, the orthosis produced a significant increase in maximum lumbar rotation during forward bending and return, as well as lateral bending to the left, but only among the healthy group. A possible factor in the smaller changes in pelvic and lumbar rotation among the LBP group could be the differences between the two groups. The LBP group in this study had significantly smaller maximum pelvic rotation than the healthy group and had a lumbar dominant movement pattern. It is reasonable to expect that individuals with smaller pelvic rotations would be less susceptible to reductions induced by the orthosis, and as a result, the corresponding increase in lumbar rotation would also be smaller. It is possible that using the orthosis on a group of patients that demonstrated larger pelvic rotations than the healthy subjects would have resulted in larger decreases in pelvic rotation, and therefore larger, statistically significant increases in lumbar rotation.

The orthosis significantly decreased maximum thoracic rotation during forward bending and return, lateral bending to the left, and axial twisting to the left and right, meaning the orthosis had a negative effect on task performance (evaluated by maximum trunk rotation). These results indicate that the orthosis is effective in reducing pelvic rotation, but reducing pelvic rotation does not cause an equal increase in lumbar rotation, which is supported by the fact that the maximum thoracic rotation was reduced. Additionally, the increase in LTR in the LBP group seems to come only from reducing pelvic rotation and not from increasing lumbar rotation. Overall, the results are troubling, as it appears that the orthosis did not achieve the desired effects for patients with LBP. One possible reason that lumbar rotation did not significantly increase in the LBP group is that all subjects were currently experiencing an LBP episode at the time of data collection. It has been suggested that the decreased lumbar rotation commonly seen in patients with LBP is a defensive mechanism to avoid aggravating symptoms (Shojaei et al., 2017). While our LBP group did not exhibit lower lumbar rotation than the healthy group, it is possible that currently experiencing pain would cause them to be more resistant to increases in lumbar rotation.

We saw more promising results for the forward bending and return task when comparing conditions at 20, 40, 60, and 80 percent of normal thoracic rotation. The results show significant orthosis induced reductions in pelvic rotation, and significant increases in lumbar rotation and LTR in both groups at all stages of motion. Although the orthosis did not have the desired effects on measures of LPC obtained at the subjects' maximum range of motion, it did have the desired effect on these measures of LPC throughout the motion. This may still be beneficial to patients and is worth investigating further. It is worth noting that, as above, the differences between condition, although statistically significant, were smaller in the LBP group.

4.2.2 TIMING ASPECTS

The orthosis had similar effects on timing aspects of LPC. In the healthy group, the orthosis produced large, statistically significant reductions in average coupling angle during bending and return, indicating a shift from a pelvic dominant movement pattern to a lumbar dominant movement pattern. However, in the LBP group, there was only small reduction in average coupling angle which was only significant during return. Similar to the arguments presented earlier, given that the LBP group already had a lumbar dominant movement pattern, it is possible that they may have been resistant to the orthosis inducing greater amounts of lumbar dominant movement. If the LBP group had shown more pelvic dominant motion as we had expected, we may have observed a greater change with orthosis.

CAV during bending and return did not change significantly with orthosis. This was unexpected, as we had had hypothesized that the orthosis restricting movement would cause less variability; however, it is good that this did not occur. As stated in Mohktarinia et al., variability in movement pattern indicates an ability of adapt to different task demands and reduce muscle fatigue. (Mohktarinia, el al, 2016). Therefore, it is more beneficial to patients that the orthosis does not reduce movement variability.

4.3 IMPLICATIONS

Research has shown that abnormal LPC could be detrimental to the lower back (Tafazzol et al., 2014; Shojaei et al., 2018). Physical therapy interventions, such as lumbar stabilization programs, are common treatment methods for LBP (Searle et al., 2015); however, Shahvarpour et al. found a lumbar stabilization program had no significant effects on LPC and that patients retained a lower lumbar spine range of motion (compared to healthy controls) after pain and disability had decreased (Shahvarpour et al., 2017). Mayer et al. showed that correction of abnormal LPC in patients with LBP using a functional restoration program was possible and resulted reduced pain levels, but the program was not able to correct LPC for all patients (Mayer et al., 2009). Therefore, more effective methods for correcting abnormal LPC in patients and having them maintain it long term are necessary. While the orthosis used in this study has shown some ability to improve LPC, it is still undetermined if the orthosis can correct LPC long term, and if this would be an effective method in reducing LBP severity and recurrence.

4.4 STUDY LIMITATIONS

The primary limitation of this study is the young age range of our subjects (18-28 years), which limits the ability to generalize these findings. Age-related differences in lower back biomechanics, particularly a larger resistance to passive deformation of the lumbar spine (Shojaei et al., 2016) and smaller lumbar contributions (Vazirian et al., 2017), are likely to influence orthosis-induced changes in LPC. Furthermore, it is clear from our results that the LPC presented by the LBP group in this study was not representative of patients with LBP represented in other studies. The effects of orthosis are likely to be different in a patient group that displays larger pelvic rotation and smaller lumbar rotation as described in the literature.

Another limitation is that the LBP group was not filtered by LBP subtype. Although they all suffered from non-specific LBP and reported similar levels of pain (mean=4.4, SD =1.3), the group may have included patients with either acute or chronic pain. Additionally, they were all experiencing pain at the time of the experiment. As stated previously, current pain may affect the ability of the orthosis to change movement, particularly lumbar movement, due to fear of aggravating symptoms. Furthermore, it is unknown how duration of current pain would affect LPC and the ability of orthosis of change LPC. It is possible that individuals who have been in pain for longer would be more resistant to changing their LPC. More research is needed to investigate the effects of the hip orthosis in different LBP subgroups, particularly in individuals who are not currently suffering from pain but are displaying abnormal LPC. Even if the orthosis cannot correct LPC in patients with current symptoms, correcting LPC in patients without current pain may still be beneficial.

Finally, this study only observed the immediate effects of the orthosis on LPC. It is undetermined if the orthosis can produce permanent changes in LPC that persists without wearing it. If the orthosis is unable to do this, it would be an ineffective method in long term treatment and prevention of LBP recurrence.

4.5 CONCLUSION

This study confirms our hypothesis that a hip orthosis can be used to increase lumbar contributions to trunk movement tasks by physically restricting pelvic motion in patients with LBP. While the brace was less effective in patients with LBP than we had hoped, this may be due to unexpected differences in LPC between the LBP group in our study and the LBP populations observed in other studies. To the best of our knowledge, no other groups have examined the possibility of using a hip orthosis to alter LPC with a long-term goal of treating LPB. Given the detrimental effects of abnormal LBP on the lower back, if current LBP treatments fail to address abnormalities in LPC, the possibility of LBP recurrence remains. Using an orthosis such as the one examined here could assist in reducing such recurrences.

4.6 FUTURE WORK

This study indicates that a hip orthosis does produce positive effects on LPC in both healthy individuals and patients with LBP. Given that we believe our results were affected by the presence of current pain, as well as differences between our patient group and groups from other studies, the next step would be a similar study that eliminates one or both of these factors. Performing the same experiment on a group of patients with no current pain, or at least patients who display the abnormal LPC we are trying to correct, would provide much stronger evidence of the effectiveness of the orthosis in correcting LPC. If the orthosis can be proven effective in correcting LPC in our target patient population, this will provide justification for research into using the orthosis as a training tool for long term correction of LPC, as well as investigations into the relation between LPC correction and LBP severity and recurrence rates.

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