THE USE OF STATISTICAL PARAMETRIC MAPPING TO DETERMINE ALTERED MOVEMENT PATTERNS IN PEOPLE WITH CHRONIC LOW BACK PAIN

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Highlights

- Statistical Parametric Mapping differentiated segment movement contributions and timing
- Lumbar segments contributed more during flexion, extension, and lateral bending
- Thoracic segments contributed more in rotation during rotation in sitting
- Clinicians should observe relative contributions between segments

ABSTRACT

Kinematics studies have generally focused on the quantity of movement using discrete parameters such as maximum and minimum angles to compare between people with chronic low back pain (CLBP) and healthy individuals. However, discrete parameters cannot be used to fully describe movement patterns and segmental contributions. This study aimed to explore the use of Statistical Parametric Mapping (SPM) to characterize quality of movement by examining if differences in movement patterns exist between groups, and within-group segmental contributions, during active movement tests. Twenty-one individuals with CLBP and nine healthy individuals were recruited. Inertial Measurement Unit (IMUs) were attached at thoracic (T3) and lumbar (L1) spine, and pelvis (S1) to collect active trunk flexion, extension, rotation, and lateral bend. SPM was used to analyze between-group movement patterns and within-group segmental contributions. SPM revealed no significant differences (P>0.05) between groups. However, a greater lumbar contribution (P<0.001) was observed during 10-40% of flexion followed by a greater pelvic contribution (P<0.001) during 60-90% of flexion, while a greater lumbar than thoracic contribution (P<0.001) was observed during flexion and the return to upright position in individuals with CLBP. Individuals with CLBP used a greater thoracic contribution compared to lumbar contribution (P<0.001) during rotation, while a greater lumbar contribution compared to pelvic contribution was observed (P<0.001) during lateral bending. Our findings suggest that SPM approach was able to detect differences in thoracic, lumbar, and pelvic velocity contributions and timings between segments in individuals with CLBP. These findings may help improving inter-rater reliability of clinical observations.

Keywords: Statistical Parametric Mapping; Movement Patterns; Quality of Movement; Segmental contributions; Low back pain

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Abstract = 248
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1. INTRODUCTION

A recent clinical practice guideline suggests clinicians should use specific muscle activation and movement control exercises for patients with chronic low back pain (CLBP) who have underlying movement control impairments (George et al., 2021). This would suggest the need to assess active trunk movement in patients with CLBP. Clinical observations of aberrant movement patterns during active trunk movements in different planes (flexion/extension, rotation, and lateral bend) are a critical component in physical examination (Biely et al., 2014; Gombatto et al., 2007; Hicks et al., 2005; Marich et al., 2020; O'Sullivan, 2000). Although studies have demonstrated the ability of clinical observations to identify patients with CLBP, the reliability of such clinical observation studies have shown the inter-rater reliability to be less than the intra-rater reliability (Hicks et al., 2003; Rabin et al., 2013). This could be due to different clinicians considering different segments or references to determine the presence, or not, of aberrant movements.

Several studies have attempted to characterize movement patterns in patients with CLBP and healthy individuals (Laird et al., 2014; Zheng et al., 2022). These studies focused on the quantity of movement, rather than quality of movement (Laird et al., 2014; Zheng et al., 2022). One systematic review showed that patients with LBP had less lumbar motion and moved slower than healthy individuals (Laird et al., 2014). However, findings were derived from discrete parameters (e.g., maximum range of motion and velocity). This over-simplification of discrete parameter analysis may limit the clinical utility of such results. In addition, clinical observations of aberrant movement patterns primarily focus on the quality of movement (e.g., segmental contributions and timing) of the thoracic and lumbar spine and pelvis (Biely et al., 2014; Hicks et al., 2005; Marich et al., 2020; O'Sullivan, 2000; Rabin et al., 2013). Those aberrant movement patterns are commonly described in terms of movement control and/or segmental coordination in the same patient, rather than comparing against healthy individuals. For instance, altered lumbopelvic rhythm is defined as a greater lumbar contribution in the early phase of active forward bending. This suggests that the within-group characterization of movement patterns, particularly in people with CLBP, would be valuable to explore. Although kinematic data revealed that patients with LBP had reduced lumbar range of motion and velocity compared with healthy individuals (Laird et al., 2014), it is difficult for clinicians to determine whether patients had altered range of motion and velocity. Therefore, the inclusion of the objective assessment of movement contributions and timing into any analysis into clinical practice may help our understanding of the efficacy of, and response to, interventions in individuals with LBP.

The measurement of joint and segment kinematics using inertial measurement units (IMUs) have demonstrated concurrent validity against optoelectronic system, and between-session test-retest reliability to track lumbopelvic motion in three-dimensional space (Bauer et al., 2016; Bauer et al., 2015; Seel et al., 2014), opening up the opportunity for assessments of quality of movement and stability within clinical settings (Budini et al., 2018). Due to the portable nature and relatively low cost of IMUs, these can be used to evaluate a variety of physical activities and even have the potential to assess movement in the community (Fennema et al., 2019). Therefore, kinematic data from IMUs may provide information to help clinicians better identify aberrant movement patterns, thereby improving interrater reliability.

Statistical parametric mapping (SPM) has been recently utilized to investigate time-series data including kinematics, electromyography, and ground reaction force data (Papi et al., 2020; Pataky et al., 2013; Robinson et al., 2015). Papi et al. (2020) utilized SPM to analyze movement patterns during functional movements including sit to stand and walking in patients with LBP. The findings support the advantage of SPM over discrete parameter analysis as it takes the amplitude and timing over the whole time series into consideration (Papi et al., 2020). Therefore, this approach can be used to investigate movement patterns, as well as contribution and timing during active movement tests which is a critical part of the physical examination for patients with CLBP. This may help refine clinical observations, particularly when considering the timing and relative segmental contributions during specific movement tasks.

Therefore, this study aimed to compare movement patterns recorded using IMUs between people with CLBP and healthy individuals during active trunk flexion, rotation, and lateral bending, as well as within-group movement contributions and timing of the thoracic and lumbar spine and pelvis. We hypothesized that people with CLBP would demonstrate different movement patterns, segmental contributions and timing when compared with healthy individuals.

2. METHODS

2.1 Participants

Twenty-one individuals with CLBP and nine healthy individuals aged between 18 and 40 years were recruited as part of another ongoing study. The inclusion criteria for CLBP were having low back pain for over 3 months, or a recurrent pattern of LBP with at least two episodes that interfered with activities of daily living and/or required treatment. The inclusion criteria for healthy individuals were no previous history of LBP for 6 months. Participants were excluded if they had clinical signs of systematic disease, definitive neurologic signs (weakness or numbness in the lower extremity), previous spinal surgery, or any lower extremity condition that could alter trunk movement. All participants provided written informed consent before data collection, and the study was approved by the institutional review board of Mahidol University (COA No. MU-CIRB 2020/084.1806). We performed a sample size calculation to ensure that the data available was sufficient to perform the planned data analysis. The sample size calculation was based on a meta-analysis which demonstrated that patients with LBP had significantly slower movement than those healthy individuals with a standardized mean difference of 1.24 (Laird et al., 2014). The sample size calculation was performed using G*Power (version 3.1.9.6) using an independent one tailed t-test with the overall effect size (Cohen's d) of 1.24, an alpha value of 0.05 and an 80% power. This yielded a sample size of at least 9 participants in each group, indicating our sample would be sufficient for the planned statistical analysis.

2.2 Instrumentation

Three Trigno Avanti Inertial Measurement Units (Delsys Inc., MA, USA) were attached to the thoracic (T3), lumbar (L1), and sacral (S1) spinous processes (Figure 1). These data were used to record flexion, rotation, and lateral bending movement patterns during active movement tests. Data collection was performed using EMGworks 4.7.3 (Delsys Inc., MA, USA) at 370 Hz. This system has been used to investigate human movement in several studies (Costello et al., 2020; Khobkhun et al., 2020; Kolářová et al., 2022), and preliminary work demonstrated the average

coefficient of multiple determination was 0.85, indicating excellent test-retest reliability. The average cross-correlation coefficients between IMU and electromagnetic tracking system were 0.95, 0.88, and 0.95 in sagittal, frontal, and transverse planes, respectively. These findings indicate excellent concurrent validity.

2.3 Procedure

Demographic data including age, sex, BMI, and low back pain characteristics were recorded, and the IMUs attached. The participants were then asked to perform 3 consecutive repetitions of active movement tests including trunk flexion, extension, rotation to the right and left in sitting, and lateral bending to the right and left at a comfortable pace with 1-minute rest between tasks. One practice trial was allowed to check the data and to familiarize each participant with the tasks.

2.4 Data analysis

Data was exported in c3d format and analysis was performed using Visual3D (C-Motion Inc., MD, USA). All data were filtered using a lowpass Butterworth filter at 15 Hz, and the start and end points were defined which allowed the identification of the "Go" and "Return" phases for each repetition of the movements using the IMU positioned on T3. The data were then time-normalized to 101 data points to represent 100% of the movement. Data from T3 were used to represent trunk velocity. L1 relative to S1 represented lumbar velocity, while T3 relative to L1 represented thoracic velocity, and S1 relative to the global reference represented pelvic velocity. Therefore, total trunk, thoracic, lumbar, and pelvic velocities in the three planes of movement were derived. However, participants can have deviation in frontal and/or transverse planes either to the right or left during flexion and extension. Therefore, we used the absolute deviation during the movement for data analysis.

2.5 Statistical analysis

Statistical analyses were performed using SPSS program (SPSS version 21, IBM Corp., NY, USA) to compare demographic data between groups. SPM was used to determine differences in movement patterns between people with CLBP and healthy individuals and individual segment contributions and timing within each group. Python (version 3.9.4, Python Software Foundation, https://www.python.org) with open-source code were used to perform SPM analysis. The SPM two-sample t test is based on Random Field Theory (Adler & Taylor, 2007), which is the vector-field equivalent to the t-test which was calculated at each percent of movement to establish a smooth random curve and 95% confidence interval critical threshold (Pataky et al., 2013; Robinson et al., 2015). Significant difference occurs when the SPM curves (SPM(t)) cross the critical threshold (t*) at any percent of movement, and associated p-values were calculated using Random Field Theory (Adler & Taylor, 2007; Pataky et al., 2013; Robinson et al., 2015). When the t-values are greater than the upper border or less than the lower border this would be considered as statistical difference. In other words, the area outside the upper and lower critical t-value would demonstrate the presence of a statistical difference. SPM two-sample t tests were used to compare between group angular velocities for the movements in each plane of movement for each segment (total trunk, thoracic, lumbar, and pelvic angular velocity). In addition, within-group SPM paired t tests were performed between segments (thoracic vs lumbar spine and lumbar spine vs pelvis) for the primary planes of movement for each task for the two groups separately.

3. RESULTS

Demographic data and clinical characteristics are presented in Table 1. No significant differences (P>0.05) were seen for age, sex, and BMI between groups. People with CLBP had an average pain in the past 7 days of 4 out of 10. More than 11 (57.2%) had a history of pain for greater than one year, and 14 (66.7%) had pain for at least half the days or nearly every day. Results also demonstrated that LBP interfered with their daily living, work, social life, and chores. SPM revealed no significant differences (P>0.05) in movement patterns between people with CLBP and healthy individuals for each segment and each plane of movement.

Within-group segment contributions and timing comparisons between lumbar spine and pelvis (Figure 2; lumbar spine vs pelvis during forward bend) demonstrated that people with CLBP used a greater lumbar contribution during the early phase of movement (10-40%) followed by a greater pelvic contribution during the later phase (60-90%) during flexion, while healthy individuals used a shared lumbar and pelvic contribution in the early phase with a greater pelvic contribution during the middle phase (30-70%). During the return to an upright position (Figure 2; lumbar spine vs pelvis during return to upright), individuals with CLBP used a greater pelvic contribution during the early phase (0-30%) followed by a greater pelvic contribution (40-100%), indicating an over reliance on a particular segment within the different phases of the movement. Conversely, healthy individuals seemed to use a more shared pattern of movement between the segments. When considering the thoracic and lumbar contributions (Figure 2; thoracic vs lumbar spine), individuals with CLBP tended to use a greater lumbar contribution than healthy individuals during flexion and the return to upright position.

Differences (P<0.001) were also seen in thoracic and lumbar contributions and timing during rotation and return to the central position (Figure 3). During rotation and return, individuals with CLBP tended to use a greater thoracic contribution and less lumbar contribution, while healthy individuals used a more shared pattern between the thoracic and lumbar spine. Similarly, differences (P<0.001) were observed between the lumbar and pelvic contributions during lateral bending and return to an upright posture (Figure 4) in which individuals with CLBP tended to use a greater lumbar contribution than pelvic contribution, whereas healthy individuals again used a more shared pattern of movement between the lumbar spine and pelvis. However, there were no significant differences (P>0.05) in the segment contributions and timings within-group during the active trunk extension task.

4. DISCUSSION

Using SPM analysis, we did not find any significant differences in movement patterns between people with CLBP and healthy individuals. Non-significant results indicate that both people with CLBP and healthy individuals have similar segment velocity profiles when performing trunk flexion, extension, rotation to the right and left in sitting, and lateral bending to the right and left. Our findings were not consistent with a previous systematic review which could be due to methodological differences in which the studies included used maximum velocity using discrete point analysis, where our approach considered the whole time-series data (Laird et al., 2014; Zheng et al., 2022). In addition, their results did not specify acute or chronic LBP, whereas our study included CLBP. Evidence suggests that individuals with acute and subacute low back pain use stiffening strategies to minimize pain exacerbation (Jones et al., 2012; Wattananon et al., 2022), which would result in lower lumbar velocities. However, in cases of CLBP,

individuals might have adopted a different movement strategy, resulting in adapting a higher lumbar segment velocity (van Dieën et al., 2019).

People with CLBP demonstrated greater lumbar contribution during the early phase of forward bend comparing with pelvis and thoracic spine. Greater lumbar contributions have been associated with increases in the risk of injury (Sahrmann et al., 2017; Van Dillen et al., 2003), and it has been suggested that excessive lumbar movement during daily activities can cause an accumulation of soft tissue stress leading to microtrauma and low back pain (Sahrmann et al., 2017; Van Dillen et al., 2003).

To the best of our knowledge, no previous study has investigated angular velocity during rotation in sitting. Only one study using the SPM approach has investigated range of motion in different spinal segments (thoracic, lumbar, and pelvic segments) and planes (sagittal, frontal, and transverse planes) (Papi et al., 2020). They found that patients with LBP had greater thoracic rotation than healthy individuals (Papi et al., 2020). Therefore, a greater thoracic contribution might be a compensatory movement to achieve the rotation task.

Similarly, individuals with CLBP used a greater lumbar contribution than pelvic contribution during lateral bending and the return to an upright posture. This was again in contrast to healthy individuals who tended to use a shared pattern of movement between the lumbar and pelvic segments. Such greater lumbar contribution could increase stress to the soft tissues surrounding the lumbar spine, thereby causing pain, or contributing to persistence or recurrence of low back pain (Sahrmann et al., 2017; Van Dillen et al., 2003).

Although our kinematic data did not show significant differences between individuals with CLBP and healthy individuals, within-group comparisons demonstrated significant differences in the contributions and timing between segments. These within-group findings are consistent with the assessment of quality of movement when clinicians observe aberrant movements during active trunk movement during physical examinations (Biely et al., 2014; Gombatto et al., 2007; Hicks et al., 2005; Marich et al., 2020; O'Sullivan, 2000). Our results suggest lumbar spine and pelvis as reference segments during trunk flexion which could be used to refine definition of aberrant movement; thereby improving inter-rater reliability of clinical observation.

The use of SPM allows the exploration of differences over the whole time series which has advantages over the more common approach of using discrete parameter analysis (e.g., peak, maximum, minimum, etc.) to represent the movement characteristics (Laird et al., 2014; Zheng et al., 2022). Discrete parameters do not represent movement patterns because they can occur at different time points during the movement (Papi et al., 2020). For instance, the contribution between the lumbar spine and pelvis during active trunk flexion and return in Figure 2 clearly showed that peak lumbar velocity occurred before peak pelvic velocity. However, using discrete peak velocity showed no differences in segmental contributions, which could lead to misinterpretation of findings. Unlike discrete parameter analysis, SPM approach takes both spatial and temporal data into consideration (Adler & Taylor, 2007; Pataky et al., 2013; Robinson et al., 2015). SPM can identify the time when significant differences between lumbar and pelvic velocity have occurred. In addition, SPM offers more control for both type I and II errors (Pataky et al., 2013; Robinson et al., 2015), and appears to provide a better approach when analyzing movement patterns.

The findings of this study should be considered in light of the following limitations. We used differences between group to calculate sample size. Therefore, our healthy individual sample size might be relatively small for

within-group comparisons. Replication of our study with larger sample size is necessary, and sample size calculation needs to be recalculated for each purpose (e.g., between-group and within-group comparisons). Although differences between segments were found in the CLBP group and not in the control group, indicating a different contribution of the different segments, a limitation is the differences in the two group sizes for the within group analysis, with the differences seen in the larger CLBP group (n=21). Therefore, it is possible that the lack of differences seen in the control group (n=9) could be due to the smaller group size. We investigated individuals with CLBP which could limit the generalizability to other low back pain populations. We attached IMUs on the skin which could introduce soft tissue noise affecting kinematic data, however this protocol was able to determine different relative contributions of segments within individuals with CLBP when compared with healthy controls. Lastly, our study aimed to explore the utility of the SPM approach to characterize quality of movement across the whole time series; therefore, we considered the contributions and timings of the movement of neighboring pairs of segments rather than all the spinal segments relative to the pelvis. We did not control for multiple comparisons for within-group segment contributions and timing comparisons or allow for confounder variables such as age, BMI, and sex.

5. CONCLUSION

The SPM approach was able to determine differences in thoracic, lumbar, and pelvic velocity contributions and timings between segment in individuals with CLBP. Our results suggest clinical observation should focus on the contribution and timing between lumbar spine and pelvis, as well as thoracic and lumbar spine during active trunk flexion, the thoracic and lumbar spine during rotation in sitting, and lumbar spine and pelvis during lateral bending. These findings may help improving inter-rater reliability of clinical observations.

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Table 1. Demographic data and clinical characteristics

Parameter	CON (n = 9)	CLBP (n = 21)
Age (year)	25.0 (6.6)	30.5 (6.9)
Sex (%female)	6 (75.0%)	11 (52.4%)
BMI (kg/m^2)	21.9 (3.7)	25.2 (4.3)
Average pain in the past 7 days		4.0 (1.8)
Duration		
- Less than 1 months		3 (14.3%)
- 1-3 months		3 (14.3%)
- 3-6 months		2 (9.5%)
- 6 months-1 year		1 (4.8%)
- 1-5 years		9 (42.9%)
- more than 5 years		3 (14.3%)
Frequency in the past 6 months		
- Every day or nearly every day		3 (14.3%)
- At least half the days		11 (52.4%)
- Less than half the days		7 (33.3%)
Daily interference		
- Not at all		3 (14.3%)
- A little bit		8 (38.1%)
- Somewhat		3 (14.3%)
- Quite a bit		5 (23.8%)
- Very much		2 (9.5%)
Work interference		
- Not at all		4 (19.0%)
- A little bit		8 (38.1%)
- Somewhat		3 (14.3%)
- Quite a bit		2 (9.5%)
- Very much		4 (19.0%)
Social interference		
- Not at all		7 (33.3%)
- A little bit		8 (38.1%)
- Somewhat		2 (9.5%)
- Quite a bit		0 (0%)
- Very much		4 (19.0%)
Chore interference		
- Not at all		4 (19.0%)
- A little bit		8 (38.1%)
- Somewhat		4 (19.0%)
- Quite a bit		2 (9.5%)
- Very much		3 (14.3%)

Figure legends

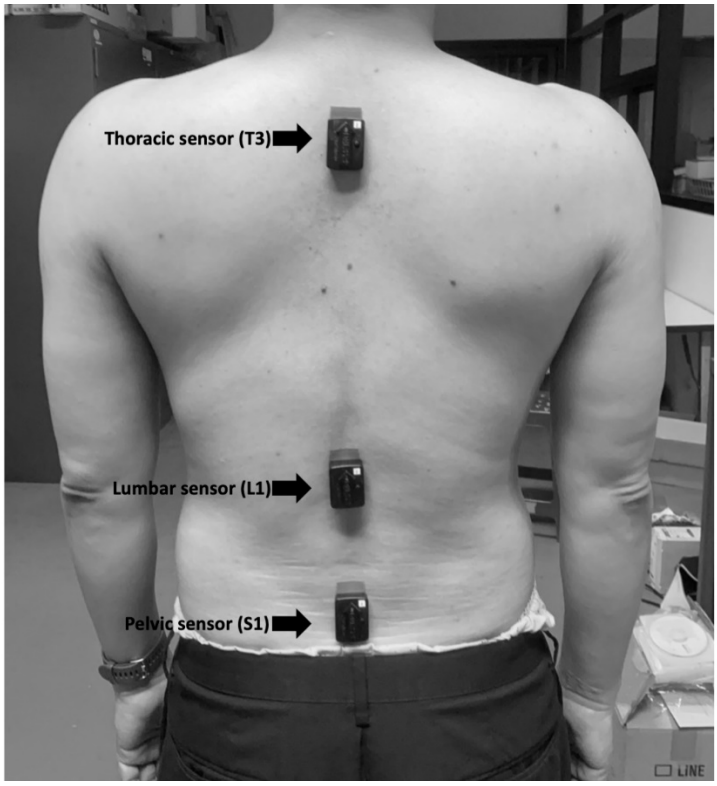

Figure 1. Positioning of IMUs on the thoracic (T3), lumbar (L1), and sacral (S1) spinous processes.

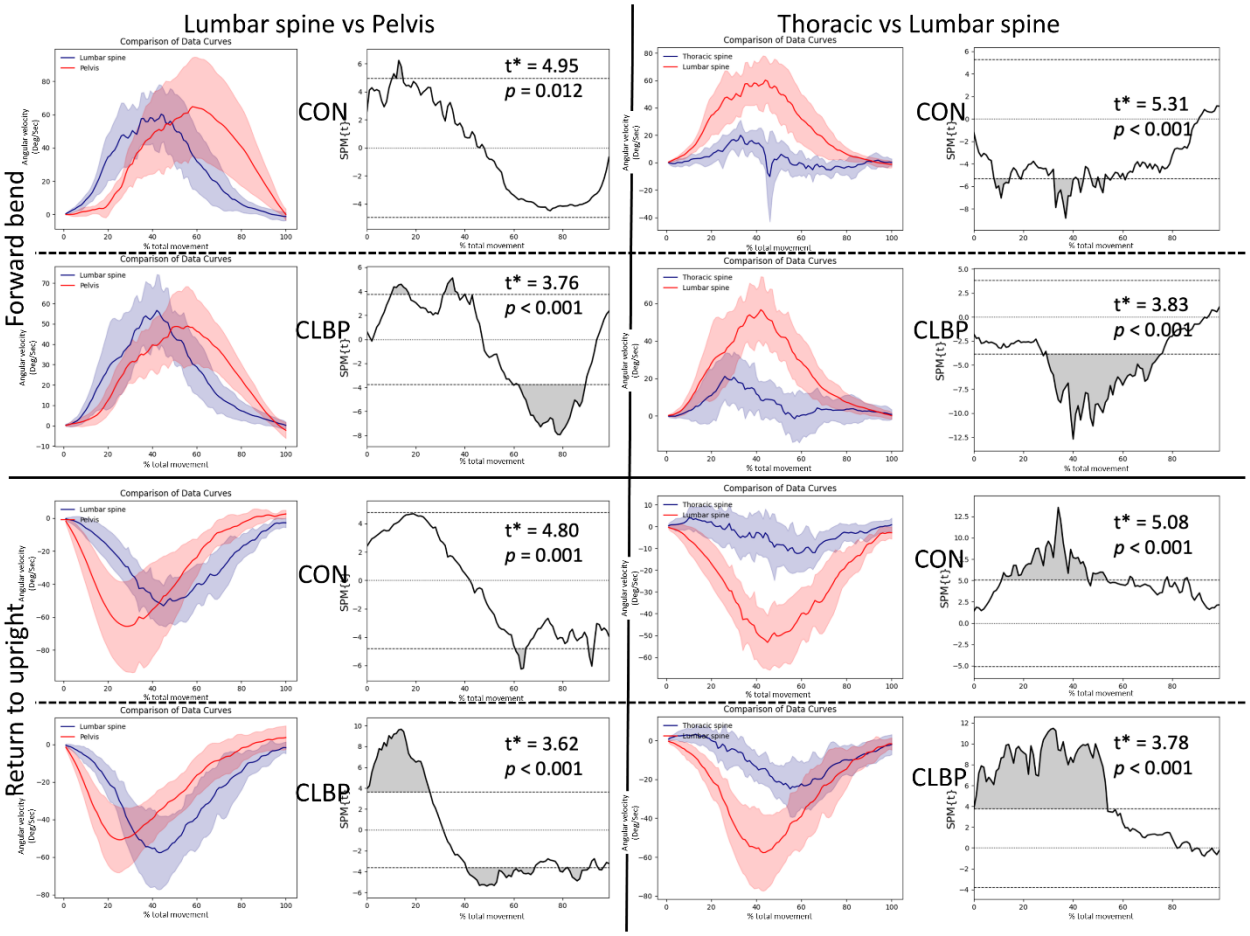

Figure 2. Differences in lumbar and pelvic contribution, as well as thoracic and lumbar contribution during flexion and return to upright

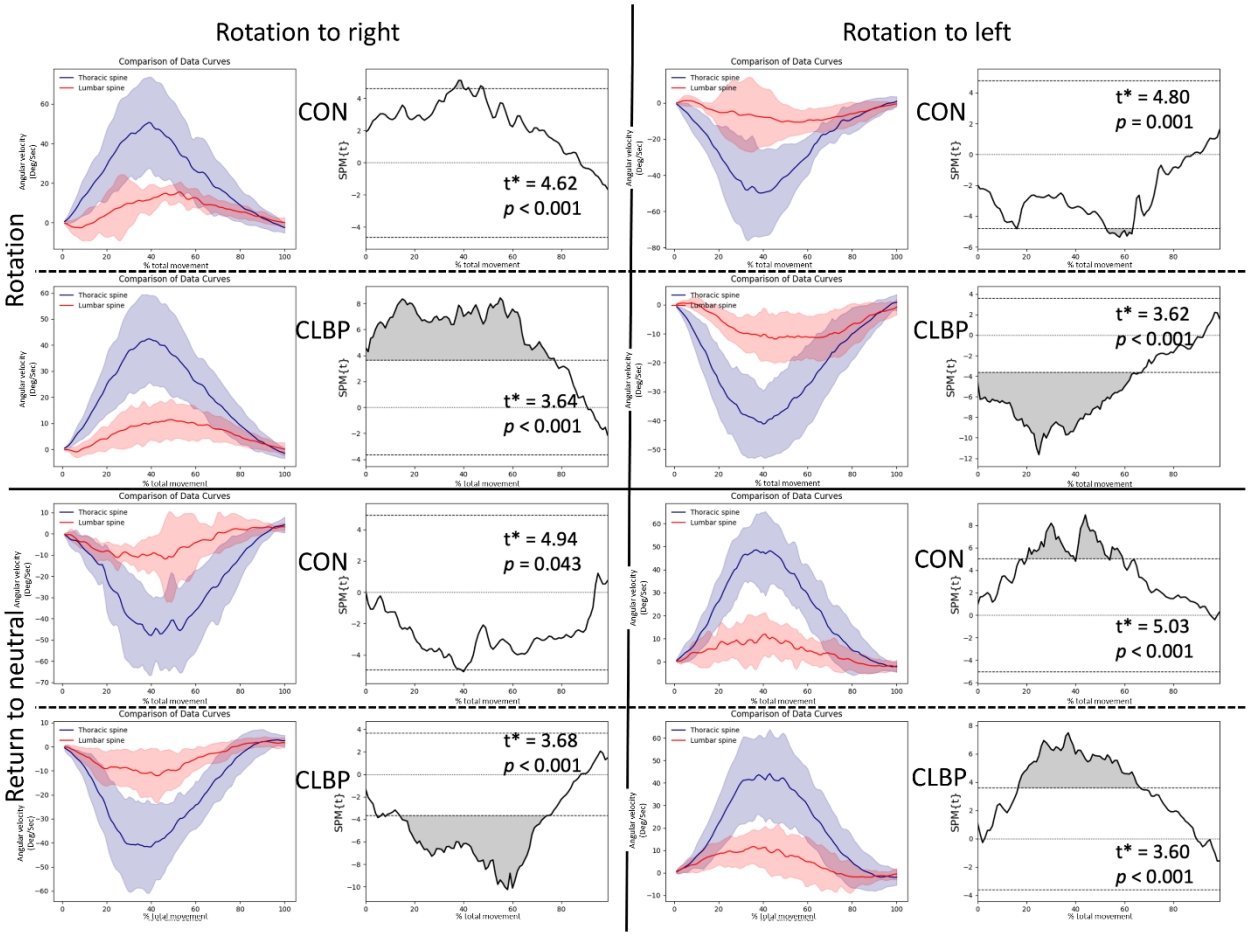

Figure 3. Differences in thoracic and lumbar contribution during rotation to right/left and return

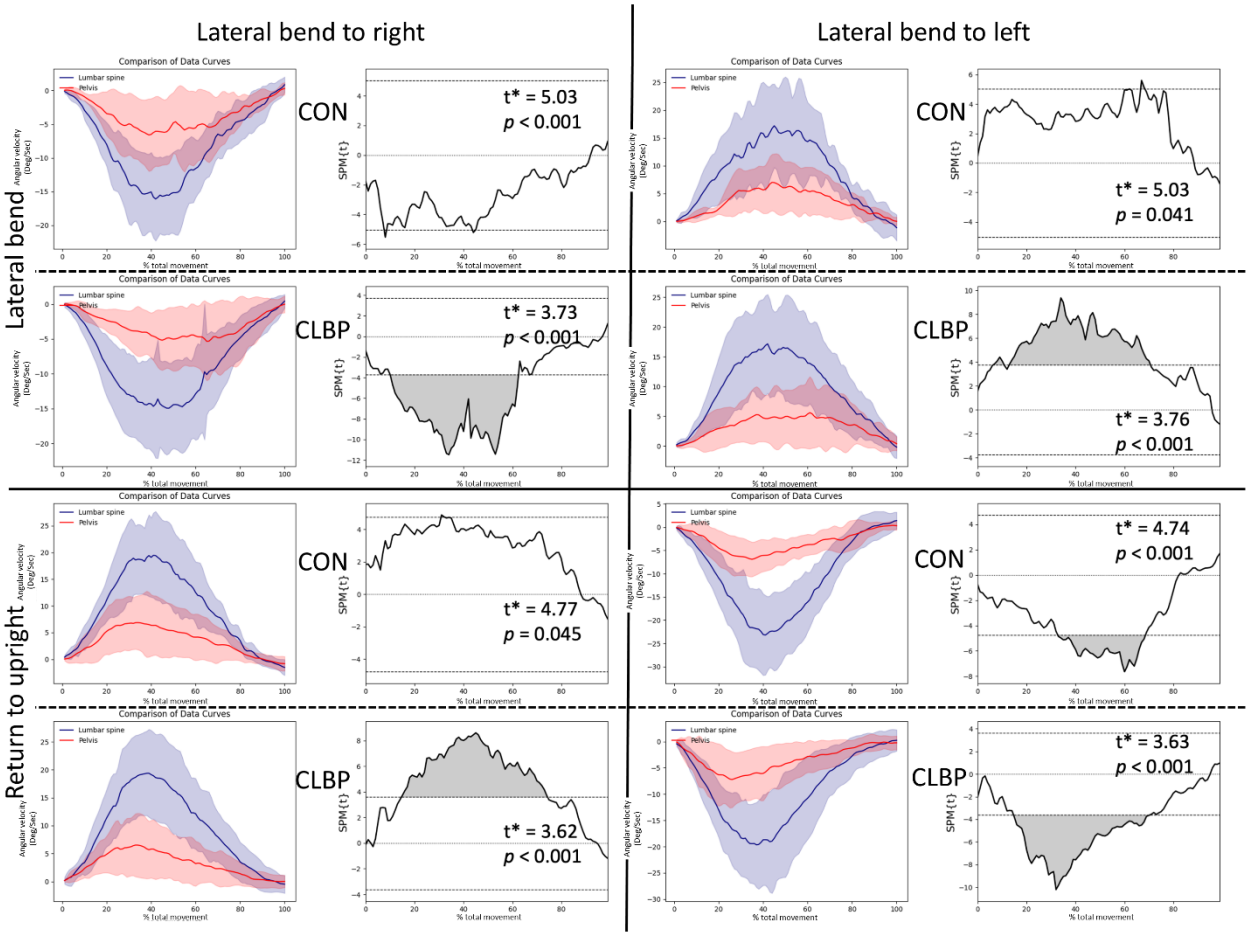

Figure 4. Differences in lumbar and pelvic contribution during lateral bend to right/left and return