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A prospective study of lumbo-pelvic coordination in patients with non-chronic low back pain

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Abstract

Despite the current knowledge about abnormalities in the lumbo-pelvic coordination of patients with non-specific low back pain (LBP), it is unclear how such abnormalities change with time. Timing and magnitude aspects of lumbo-pelvic coordination during a trunk forward bending and backward return task along with subjective measures of pain and disability were collected at three-time points over a six-month period from 29 patients who had non-chronic LBP at the time of enrollment in the study. To enable investigation of abnormalities in lumbo-pelvic coordination of patients, we also included lumbo-pelvic coordination data of age and gender-matched back healthy individuals from an earlier study of our group. Finally, differences in lumbo-pelvic coordination between patients with moderate-severe LBP (i.e., those whose level of pain was ≥4 (out of 10) at all three data collection sessions; n=8) and patients with low-moderate LBP (n=21) were investigated. There were clear distinctions in measures of lumbo-pelvic coordination between patients with low-moderate and moderate-severe LBP. Contrary to our expectation, however, the abnormalities in magnitude aspects of lumbo-pelvic coordination were larger ($F>4.84$, $P<0.012$) in patients with low-moderate LBP. These abnormalities in patients with low-moderate LBP, compared to controls, included larger (>12°) pelvic and thoracic rotations as well as smaller (>10°) lumbar flexion. The abnormal lumbo-pelvic coordination of patients with non-specific LBP, observed at baseline, persisted ($F<1.96$, $P>0.156$) or worsen ($F>3.48$, $P<0.04$) over the course of study period despite significant improvement in their pain (18% decrease; $F=12.10$, $P<0.001$) and disability (10% decrease; $F=4.39$, $P=0.017$). Distinct but lingering abnormalities in lumbo-pelvic coordination, observed in patients with low-moderate and moderate-severe LBP, might have a role in persistence and/or relapse of symptoms in patients with non-specific LBP. Such inferences, however, should further be studied in future via investigation of the relationship between abnormalities in lumbo-pelvic coordination and clinical presentation of LBP.

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Conflict of Interest Statement
We declare that all authors have no financial or personal relationships with other persons or organizations that might inappropriately influence our work presented therein.

Keywords

Low back pain; Lumbo-pelvic coordination; Level of pain; Longitudinal assessment

Introduction

Most of immense total cost associated with low back pain (LBP) can be attributed to disability and treatment costs of patients with chronic and/or recurrent LBP (Apeldoorn et al., 2012; Becker et al., 2010; Fromoyer et al., 1991; Frymoyer and Gordon, 1989; Gatchel et al., 2003). These costs are likely driven by our poor understanding of the pathomechanisms and risks factors associated with LBP persistence and/or recurrence (Biering-Sørensen, 1982; Hides et al., 2001; Kovacs et al., 2005; Melloh et al., 2011). While only a small portion of patients with acute LBP develop chronic LBP, the recurrence rate is much higher and ranges from ~ 25% to ~ 55% (da Silva et al., 2017; Hoy et al., 2010; Melloh et al., 2011; Von Korff et al., 1993). Thus, it is clear that to impact the use of healthcare resources and improve the management of LBP, a furthered understanding of mechanisms contributing to LBP persistence and recurrence need to be developed.

The important role of spinal loads in experience of LBP is strongly supported in the literature (Adams et al., 2006; Coenen et al 2013; Coenen et al 2014), yet the potential role of abnormalities in spinal loads in clinical presentation of LBP is unknown. Determining differences in spinal loads between asymptomatic individuals and patients with LBP, particularly at different time points of LBP experience, can help identify the role of spinal loads in persistence or recurrence of symptom. Given difficulties associated with direct measurement of spinal loads, indirect methods, including kinematics, kinetics, and electromyography (EMG)-based methods, have been widely used to study abnormalities in spinal loads of patients with LBP (Bazrgari and Xia, 2017; Vazirian et al., 2016). The general trend from studies implemented kinematics-based methods is that patients with chronic LBP, compared to asymptomatic individuals, exhibit smaller lumbar range of rotation (flexion: 41.6° vs. 50.6°; lateral bending: 23.3° vs. 28.4°; axial twist: 22.4° vs. 25.7°) when reaching their trunk range of motion in three planes of motion (Laird et al., 2014). Additionally, patients with chronic LBP rotate their lumbar slower (i.e., exhibiting smaller peak velocity or acceleration) compared to people without LBP (Laird et al., 2014). Paquet et al. (Paquet et al., 1994) reported similar ranges of rotation but smaller peak angular velocity for lumbar and hip between 10 patients with non-chronic LBP and 10 asymptomatic individuals during trunk forward bending and backward return tasks. In another study, Aluko et al. (Aluko et al., 2011) reported smaller mean and peak angular acceleration of lumbar spine for patients with non-chronic LBP during trunk forward bending and backward return. For a similar task, we have also recently observed that patients with non-chronic LBP perform the task slower but, in contrast to report by Paquet et al. (Paquet et al., 1994), they exhibited smaller lumbar range of rotation as compared to asymptomatic individuals.

Despite the current knowledge about the abnormalities in trunk motion of patients with LBP that likely affect spinal loads, it is unknown how these abnormalities change with time and if they are different between patients with different pain intensities. Addressing such research gaps, the differences in trunk motion between patients with low-moderate and moderate-severe LBP at three time points over a six-month period were investigated in this study. Timing and magnitude aspect of lumbo-pelvic coordination during a trunk forward bending and backward return task, as measures of trunk motion, along with the level of pain and disability were prospectively collected from 29 patients with non-specific LBP who were enrolled into the study at the non-chronic stage of their LBP. As a reference and to enable investigation of abnormalities in lumbo-pelvic coordination of patients at baseline, we also included lumbo-pelvic coordination data of age and gender-matched back healthy individuals from an earlier study of our group (Shojaei et al., 2016b; Vazirian et al., 2017a). We hypothesized that abnormalities in timing and magnitude aspects of lumbo-pelvic coordination will be larger in patients with moderate-severe versus low-moderate LBP. We further hypothesized that abnormalities in lumbo-pelvic coordination of patients would reduce with reduction in pain.

Methods

Study Design and participants

A prospective, repeated measure, study design was used wherein 29 (5 M, 24 F) patients with non-chronic LBP completed three data collection sessions over a six-month period (baseline, ~3 months, and ~ 6 months). At each session, patients completed a self-report questionnaire with items measuring pain using the Wisconsin Brief Pain Inventory (Daut et al., 1983; Zalon, 1999) and perceived functional disability using the Roland Morris Disability Scale (Stroud et al., 2004) questionnaires as well as a set of biomechanical procedures. Patients were allocated into low-moderate or moderate-severe pain group based on the severity of their perceived pain. Specifically, a patient was allocated to the moderate-severe LBP group if his/her pain level was ≥ 4 (out of 10) in all three data collection sessions, otherwise, the patient was allocated to the low-moderate LBP group. The patients with non-chronic LBP were referred to the study by their primary physician and asymptomatic controls in our earlier study, whose data were used as reference in this study, were recruited via advertisement. The differences in age, stature, body mass, and BMI between the participant groups were investigated using analyses of variance (ANOVAs) (Table 1).

Exclusion criteria for back healthy controls were any history of LBP during the past year, any history of musculoskeletal disorders, and occupational activities that could have substantially influenced the lower back biomechanics (Shojaei et al., 2016a; Shojaei et al., 2016b). Patients were excluded if their LBP had lasted more than 3 months as well as if they had significant cognitive impairment, intention to harm themselves or others, substance abuse, or did not have access to a telephone (Borson et al., 2000; Brown and Rounds, 1994). All participants in these studies completed an informed consent procedure, approved by the University of Kentucky Institutional Review Board, before participation.

Biomechanical Procedures

During each data collection session, participants completed two sets of trunk forward bending and backward return tasks at self-selected slow and fast paces in the sagittal plane. During these tasks, trunk kinematics were tracked using wireless Inertial Measurement Units (IMUs; Xsens Technologies, Enschede, Netherlands) attached to straps superficial on the T10 and the S1 spinous process (Shojaei et al., 2017b). During the task with self-selected slow pace, participants were instructed to stand in an upright posture, bend forward using a self-selected slow pace to reach their maximum comfortable trunk rotation, hold their bending posture for 5 seconds, and extend back up to the original upright position. For the task with self-selected fast pace, participants performed the same task as fast as possible but without a pause at the maximum trunk rotation. Before conducting these tasks, the desired method of performing them (i.e., with extended knees and arms being hanged in front at full flexed posture) was demonstrated to participants by one of research personnel. Each task was repeated three times and the task with slow pace was always performed prior to the task with fast pace. The sampling rate of the IMUs was set to 50 Hz. It is notable that the instructions for the tasks, placement of the straps and IMUs were similar for the current study and our earlier study on the control group and were supervised by the same person (Vazirian et al., 2017a).

Biomechanical data analysis

Rotation matrices for each IMU were extracted and used to calculate the pelvic and thoracic rotations, as rigid bodies, in the sagittal plane (Shojaei et al., 2017b; Shojaei et al., 2017c) relative to the initial standing posture. At each instant of time, lumbar flexion was calculated as the difference between the thoracic and pelvic rotations and was then used to calculate the lumbo-thoracic ratio (LTR) at that time instant as the ratio of lumbar flexion over thoracic rotation. Thoracic and pelvic ranges of rotation, lumbar range of flexion, and LTR at the maximum thoracic rotation were evaluated to represent the magnitude aspects of lumbo-pelvic coordination.

The timing aspects of lumbo-pelvic coordination were assessed using measures obtained from the continuous relative phase between rotations of thorax and pelvis according to our earlier studies (Shojaei et al., 2017c; Vazirian et al., 2017b). Specifically, two measures from the continuous relative phase were extracted: 1) the mean absolute relative phase (MARP) and 2) the deviation phase (DP). For forward bending and backward return phases of trunk motion separate MARP and DP were calculated. MARP values closer to 0 represent a more in-phase lumbo-pelvic coordination whereas MARP values closer to π represent a less in-phase coordination. Also, smaller values of DP represent a lumbo-pelvic coordination with less trial-to-trial variability or a more stable motion pattern.

Statistical analysis

The dependent variables used in statistical analyses were measures of magnitude and timing aspects of lumbo-pelvic coordination as explained in the previous section. Because biomechanical data from the back healthy group were only obtained at one data point, they were only compared with data obtained from the patients during the first session. Specifically, an analysis of variance (ANOVA) test was conducted on data obtained from each pace (i.e., slow and fast) and phase (i.e., bending and return; only for MARP and DP) of trunk motion to investigate the differences in the outcome measures between the groups (i.e., control, patients with low-moderate and moderate-severe LBP). To investigate the changes in lumbo-pelvic coordination, pain, and level of disability of patients with time, mixed-model ANOVA tests were used with group (patients with low-moderate and moderate-severe LBP) as the between-subjects factor and time (baseline, 3 months, 6 months) as the within-subject factors. A separate mixed-model ANOVA was used for biomechanical data obtained from each pace (i.e., slow and fast) and phase (i.e., bending and return; only for MARP and DP). All statistical procedures were conducted in SPSS (IBM SMSS Statistics 24, Armonk, NY, USA), assumptions for ANOVA and mixed-model ANOVA were verified, a p value ≤ 0.05 was considered to be statistically significant, and Tukey’s procedure was used when post hoc tests were required.

Results

Baseline comparison with controls

Magnitude aspects of lumbo-pelvic coordination: All outcome measures in this category were significantly different between groups for both slow and fast paces of trunk forward bending and backward return (Table 2). Specifically, during slow pace task, thoracic rotation of patients with low-moderate LBP was larger (>12°) than that of the other two groups, pelvic rotation of patients with low-moderate LBP was larger (23°) than that of the control group, and lumbar flexion and LTR were smaller (lumbar flexion: >10°; LTR: >0.10) in both patient groups vs. controls (Table 2). During the fast pace task, thoracic and pelvic rotations were larger (>11° and >19°, respectively) and LTR was smaller (>11°) in patients with low-moderate LBP compared to the other two groups (Table 2). Also, lumbar flexion in patients with low-moderate LBP was smaller (13°) than that of the control group (Table 2).

Timing aspects of lumbo-pelvic coordination: During forward bending of slow paced task, DP of patients with low-moderate LBP was smaller (0.043) than that of the control group (Table 3). For forward bending of fast paced task, DP of patients with low-moderate LBP was smaller (>0.018) than that of the other two groups (Table 3). During the backward return of both slow and fast paced tasks MARP was, respectively, 0.09 and 0.08 smaller in patients with low-moderate LBP than the control group (Table 3).

Changes in lumbo-pelvic coordination, pain, and disability with time

Magnitude aspects of lumbo-pelvic coordination: The differences in thoracic and pelvic rotations between the patient groups (both larger in patients with low-moderate LBP) did not change with time (Figure 1). Lumbar flexion was not different between the groups but decreased with time (~ 6° at 6-month) for the fast paced tasks. LTR during the tasks with slow paced, was not different at baseline between the patient groups but it became different (F>3.61, p<0.042) at 3-month (low-moderate LBP: 0.41 ± 0.12 and moderate-severe LBP: 0.56 ± 0.14) and 6-month (low-moderate LBP: 0.38± 0.11 and moderate-severe LBP: 0.52 ± 0.13). Additionally, LTR of patients with low-moderate LBP became smaller (F=3.25, p=0.050) at 6-month (0.38 ± 0.11) compared to that of its baseline (0.45 ± 0.09). For the fast paced tasks, LTR was different between the patient groups (0.13 smaller in patients with low-moderate LBP) and became smaller with time (~ 0.05 smaller in 6-month compared to the other two days)

Timing aspects of lumbo-pelvic coordination: During forward bending of slow paced task, DP was not different between the patient groups at the baseline, but it became different (F>3.70, p<0.039) at 3-month (low-moderate LBP: 0.046 ± 0.02 and moderate-severe LBP: 0.083 ± 0.03) and 6-month (low-moderate LBP: 0.061 ± 0.04 and moderate-severe LBP: 0.098 ± 0.05). Also, for both patient groups DP was larger (>0.027) in 6-month compared to the baeline and 3-month (Table 4 and Table 5).

During backward return of slow paced task, DP was different (F=9.86, p=0.001) between the two patient groups only for 3-month (low-moderate LBP: 0.031 ± 0.02; moderate-severe LBP: 0.082 ± 0.03). DP of patients with low-moderate LBP patients changed (F=4.13, p=0.026) with time where DP in 3-month (0.030 ± 0.017) was smaller than that of baseline (0.043 ± 0.025) and 6-month (0.044 ± 0.025). Also, for both patient groups MARP was larger (0.05) in 3-month than 6-month (Table 4 and Table 5).

Level of pain and disability: The levels of pain and disability were, respectiely, 37% and 32% lower in patients with low-moderate vs. moderate-severe LBP (Table 6, Table 7, and Figure 3). The level of pain in patients continously decreased (18%) from baseline to 6-month, whereas the level of disability decreased (10%) only from baseline to 3-month (Table 6, Table 7, and Figure 3).

Discussion:

The differences in timing and magnitude aspects of lumbo-pelvic coordination during trunk forward bending and backward return tasks were prospectively investigated between patients with low-moderate and moderate-severe LBP. There were clear differences in measures of lumbo-pelvic coordination between patient groups but contrary to our hypothesis the abnormalities in lumbo-pelvic coordination, particularly under fast-paced tasks, were larger in patients with low-moderate LBP. Further, the abnormalities in lumbo-pelvic coordination of both patient groups did not reduce with reduction in pain, therefore, rejecting our second hypothesis.

Differences in lumbo-pelvic coordination at non-chronic stage

The magnitude aspects—Consistent with earlier reports (Laird et al., 2014; Vazirian et al., 2016), lumbar flexion and LTR at baseline were different between patients and controls during the slow paced task (Tables 2). Lumbar flexion and LTR of patients with moderate-severe LBP, however, did not proportionally (compared to the other two groups) decrease with increases in task pace such that they become similar to those of the control group under fast paced task. Such a lumbo-pelvic coordination of patients with moderate-severe LBP suggests that their lower back tissues experience larger stretches compared to patients with low-moderate LBP during the demanding fast paced task. The smaller lumbar flexion and LTR in both tasks in patients with low-moderate LBP was achieved by adopting larger thoracic and pelvic rotations compared to the other two groups. Such larger thoracic and pelvic rotations, while reduce the stretch of lower back tissues, increase respectively the moment and shearing demands of the task on the lower back (Shojaei et al., 2017a; Shojaei et al., 2016b). An increase in moment demand of task is associated with considerable increase in spinal load, given the small moment arms of lower back tissues for offsetting of the task demand (Bazrgari et al., 2008b).

The timing aspects—Patients with low-moderate LBP demonstrated a more in-phase (i.e., smaller MARP during backward return) or a less variable (i.e., smaller DP during forward bending) lumbo-pelvic coordination compared to the control group at baseline. More in-phase and less variable lumbo-pelvic coordination, reflecting a phase-locked or rigid coordination (Mokhtarinia et al., 2016), has been suggested to be a protective motor control strategy to reduce the possibility of painful deformation of lower back tissues under dynamic tasks. However, such a strategy requires higher levels of trunk muscle activation and co-activation that can, in turn, lead to increased spinal loads and muscle fatigue (Bazrgari et al., 2008a; Marras et al., 2001). On the other hand, the MARP and DP of patients with moderate-severe LBP was not different from those of the control group in any cases. Such adopted lumbo-pelvic coordination, considering the level of pain these participants had during the experiments, is newly described and leads one to consider a neuromuscular impairment that preceded the pain and/or a neuromuscular failure to adopt a pain alleviating lumbo-pelvic coordination as potential etiologies for the persistence of their symptom.

Changes in lumbo-pelvic coordination with time

The magnitude aspects—Pelvic and thoracic rotations in patients with low-moderate LBP remained larger than those with moderate-severe LBP, regardless of time (Table 5 and Fig.1a,b,e,f). In patients with moderate-severe LBP, surprisingly, the magnitude aspects of lumbo-pelvic coordination remained, in general, closer to those observed in control group at baseline when compared to patients with low-moderate LBP. The increase in pelvic rotation and the decrease in lumbar flexion (though not significant) with time among patients with low-moderate LBP resulted in the observed differences in LTR between the patient groups at 3-month and 6-month during the slow paced task (Fig.1d). Such time-dependent changes in the magnitude aspects of lumbo-pelvic coordination of pateints with low-moderate LBP, however, were all diverging from those of the control group (Fig.1). During the fast paced task, while the LTR of patients with low-moderate LBP was always smaller than that of patients with moderate-severe LBP, both patient groups used smaller lumbar flexion/LTR at 6-month compared to the baseline and 3-month, hence further diverged from the controls at baseline (Table 5, Fig.1g,h). When considering the differences in the level of pain between the two groups and the associated changes with time, it is clear that a higher level of pain is not nessesarily associated with larger alteration (abnormalities) in lumbo-pelvic coordination as compared to healthy back individuals. Instead, there seems to be unique differences in neuromuscular adaptation and/or impairment of patients with LBP that might have a role in their symptom persistence or future recurrences.

The timing aspects—During the slow forward bending, while DP of the two patient groups were similar at baseline, DP of the patients with moderate-severe LBP became larger at 3-month and 6-month but remained, nevertheless, similar (and even further approached) to that of the control group at baseline (Table 5, Fig.2c). DP of patients with low-moderate LBP, however, did not change from baseline to 3-month but gradually increased from 3-month to 6-month such that when considering both patient groups together, DP at 6-month was larger than that of baseline or 3-month. During slow paced tasks, patients with low-moderate LBP consistently demonstrated a more in-phase and less variable (i.e., smaller MARP and DP) lumbo-pelvic coordination compared to controls and with small changes with time (Fig.2a, b, c, d). Patients with moderate-severe LBP, however, demonstrated both more and less in-phase and variable lumbo-pelvic coordination, compared to the control group at baseline, with large session to session changes (Fig.2a, b, c, d). Such differences in neuromuscular control of lumbo-pelvic coordination between the two patient groups, may also have a role in clinical presentation of their LBP. Specifically, while patients with low-moderate LBP used a consistent and more rigid motion strategy, patients with moderate-severe LBP used a variable and inconsistent lumbo-pelvic coordination. During the fast paced motion, however, patients with moderate-severe LBP used a more consistent lumbo-pelvic coordination that was more in-phase and less variable similar to that of the patients with low-moderate LBP, and the MARP and DP of both patient groups were always below those of the control group (Fig.2 e, f, g, h).

Clinical relevance—For clinical management of non-specific LBP, wherein the underlying etiology can't be determined, clinicians should rely on patient-report of symptom (pain and disability) to evaluate patient's response to treatment. Our results highlighted that abnormalities in lumbo-pelvic coordination, observed in non-chronic stage of LBP, persists despite reduction in pain. Such an observation raises an important question of whether symptom alleviation in these patients is achieved at the expense of (or accompanied with) detrimental changes in their lower back mechanics that can put them at higher risk for symptom relapse/recurrence. Addressing such a research question, given that a large number of patients with non-specific LBP experience symptom persistence or relapse, is clearly important. In other word, whether such abnormal lumbo-pelvic coordination has been an adaptation in response to pain or it preceded the pain, its persistence may have a role in future symptom relapse or persistence of current symptom.

The observed differences in lumbo-pelvic coordination between patients with moderate-severe and low-moderate LBP is also significant because such differences in biomechanical abnormalities may be linked to potential mechanical root causes of LBP. Notwithstanding the complexity and multifactorial nature of LBP, a neuromuscular failure in adaptation of an altered lumbo-pelvic coordination might have a role in persistence of an elevated level of pain in patients with moderate-severe LBP. Such a failure could be a result of neuro-musculoskeletal abnormality (e.g., hamstring tightness, core muscle weakness, impaired reflexive muscle behavior) and/or psychological (e.g., fear of pain) factors. These hypotheses, however, should be tested in future clinical trials to verify whether correction of lumbo-pelvic coordination via relevant physical and/or psychological treatment may affect the clinical presentation of LBP.

Results from cross sectional studies comparing function and behavior of trunk muscles between patients with LBP and back healthy controls, have motived clinical trials that evaluated the efficacy of treatments aimed at improving behavior of trunk muscles (Maher et al 2017). Emerging evidence from these clinical trials is that such treatments, though better than nothing, are not more effective than any other treatment offered for LBP (Maher et al 2017). From a biomechanical point of view, mechanical function and behavior trunk muscles are among many factors affecting lumbo-pelvic coordination and ultimately spinal loads. For instance, pelvic motion is affected by the movements of joints and segments located below the pelvis in the lower extremities. Therefore, treating trunk muscles in isolation may not necessarily recover the observed abnormalities in the lumbo-pelvic coordination of patients with LBP in this study. Consistently, Shahvarpour et al (2017) found no changes in lumbo-pelvic coordination of patients following an eight-week of lumbar stabilization exercise that was aimed at retraining the optimal control and coordination of the paraspinal musculature. Pending future evidence in support of the relationship between the observed abnormalities in lumbo-pelvic coordination and persistence/recurrence of LBP, future clinical trials should take a more holistic way in assessment of the contributing factors to such abnormalities and offer a more personalized treatment that target more than one potential contributing factor (Cholewicki et al 2019).

Limitations: Our findings should be interpreted with consideration of our study limitations. Since we did not have the data on variation of lumbo-pelvic coordination of back healthy individuals with time, it is not clear how much of the between session changes in outcome measures of the patients are considered to be the inherent variability of our study protocol. Second, while our results raise some intriguing research questions, the relatively small sample of our patient group should be kept in mind. Third, since the patients were recruited after appearance of symptoms, whether the observed abnormal lumbo-pelvic coordination in patient was a consequence of LBP remains unclear. Finally, measures of lumbo-pelvic coordination only provide indirect insight into the neuromuscular control of trunk motion and loads experienced in lower back tissues.

In summary, patients with low-moderate LBP, compared to controls, demonstrated larger (>12°) pelvic and thoracic rotations and smaller (>10°) lumbar flexion during trunk forward bending and backward return. Interestingly, however, the abnormalities in magnitude aspects of lumbo-pelvic coordination were larger in patients with low-moderate versus moderate-severe LBP. More important, the abnormal lumbo-pelvic coordination of patients with non-specific LBP, observed at baseline, persisted or worsen over the course of study period despite respectively 18% and 10% improvement in their pain and disability. The likely role of such distinct and persistent abnormalities in lumbo-pelvic coordination of patients with non-specific LBP in clinical presentation of their symptom (i.e., recurrence or persistence) remains to be investigated in future.

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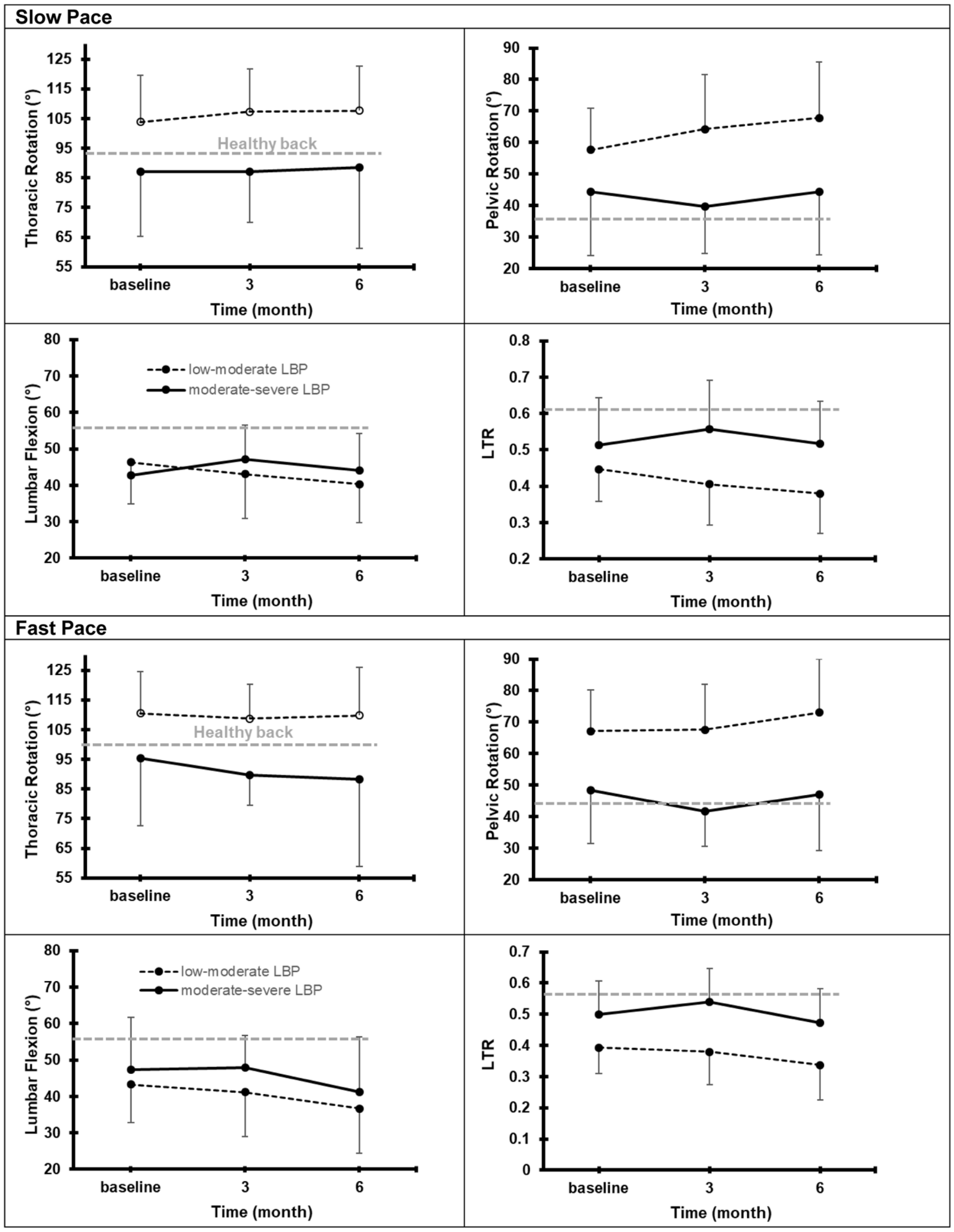

Figure 1:

Measures of magnitude aspect of lumbo-pelvic coordination and their changes with time in patients with low-moderate vs. moderate-severe LBP. For the sake of comparison, the normal level of lumbo-pelvic coordination, measured from the healthy back group at baseline, was included.

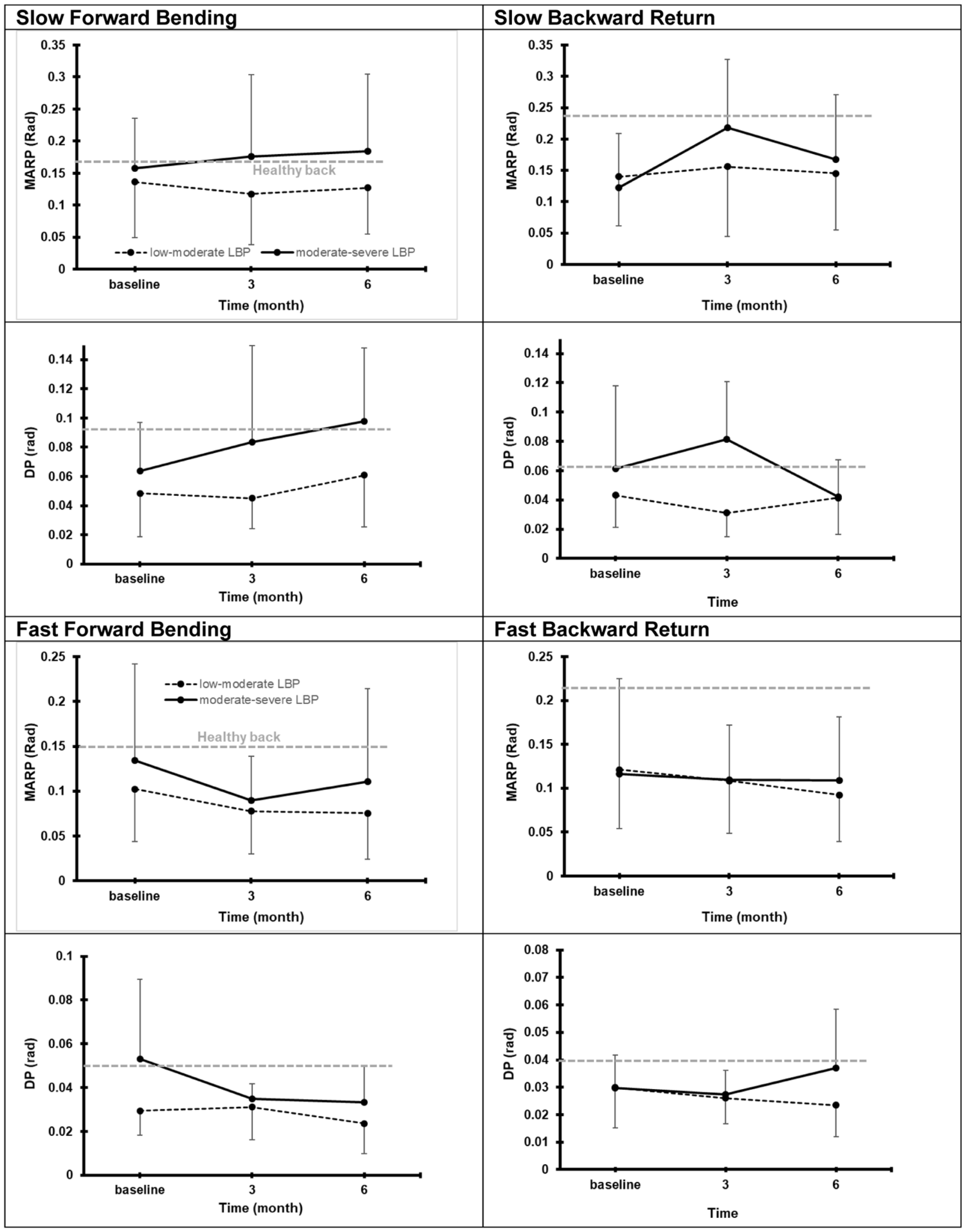

Figure 2:
Measures of timing aspects of lumbo-pelvic coordination and their changes with time in patients with low-moderate vs. moderate-severe LBP. For the sake of comparison, the normal level of lumbo-pelvic coordination, measured from the healthy back group at baseline, was included.

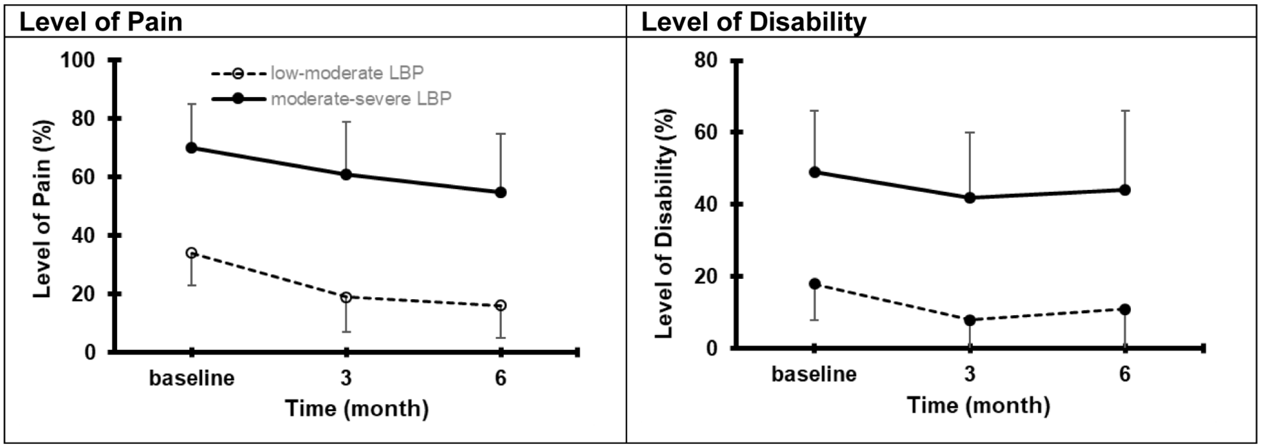

Figure 3:

Mean (SD) level of pain (left) and disability (right) and their changes with time in patients with low-moderate vs. moderate-severe LBP. Both pain and disability levels are presented as percent of maximum possible value (i.e., 10 for pain level according to the Wisconsin Brief Pain Inventory and 24 for disability level according to the Roland Morris Disability Scale)

Table 1:

Mean (SD) participants characteristics

Group	***Control***	***Low-moderate LBP***	***Moderate-severe LBP***	***F***	***p***
Age (year)	53(10)	55(10)	51(11)	0.45	0.638
Stature (cm)	168[a](9)	164[a](7)	177[b](7)	6.98	**0.002**
Body mass (kg)	70[a](13)	75[a](16)	98[b](20)	8.87	**<0.001**
BMI	25[a](3)	28[b](5)	31[b](5)	7.25	**0.002**

Boldface indicates significant effect

Table 2:

Mean (SD) of measures of magnitude aspect of lumbo-pelvic coordination for each group (control, low-moderate LBP, and moderate-severe LBP) under slow and fast paced forward bending and backward return task.

Variable	Groups: *Control*	Groups: *Low-moderate LBP*	Groups: *Moderate-severe LBP*	Statistics: *F*	Statistics: *P*
		Slow Pace			
Thoracic Rotation (°)	**92^{a}(15)**	**104^{b}(16)**	**87^{a}(20)**	4.84	**0.012**
Pelvic Rotation (°)	**35^{a}(12)**	**58^{b}(13)**	**44^{ab}(19)**	16.92	**<0.001**
Lumbar Flexion (°)	**56^{a}(15)**	**46^{b}(11)**	**43^{b}(9)**	5.31	**0.008**
LTR	**0.61^{a}(0.13)**	**0.45^{b}(0.09)**	**0.51^{b}(0.13)**	12.94	**<0.001**
		Fast Pace			
Thoracic Rotation (°)	**99^{a}(11)**	**110^{b}(14)**	**95^{a}(20)**	5.08	**0.010**
Pelvic Rotation (°)	**43^{a}(12)**	**67^{b}(13)**	**48^{a}(16)**	20.01	**<0.001**
Lumbar Flexion (°)	**56^{a}(13)**	**43^{b}(10)**	**47^{ab}(14)**	6.42	**0.003**
LTR	**0.56^{a}(0.12)**	**0.39^{b}(0.08)**	**0.50^{a}(0.11)**	15.30	**<0.001**

Boldface indicates significant effect

Table 3:

Mean (SD) of measures of timing aspect of lumbo-pelvic coordination for each group (control, low-moderate LBP, and moderate-severe LBP) under slow and fast paced forward bending and backward return task.

Variable	Group			Statistics	
	Control	*Low-moderate LBP*	*Moderate-severe LBP*	*F*	*P*
	Slow Forward Bending				
MARP (rad)	0.16(0.11)	0.14(0.09)	0.16(0.07)	0.38	0.686
DP (rad)	**0.091[a](0.05)**	**0.048[b](0.03)**	**0.064[ab](0.03)**	5.57	**0.006**
	Slow Backward Return				
MARP (rad)	**0.23[a](0.15)**	**0.14[b](0.09)**	**0.12[ab](0.09)**	4.35	**0.018**
DP (rad)	0.063(0.04)	0.043(0.03)	0.062(0.05)	1.94	0.154
	Fast Forward Bending				
MARP (rad)	0.15(0.10)	0.10(0.06)	0.13(0.09)	1.59	0.215
DP (rad)	**0.047[a](0.02)**	**0.029[b](0.02)**	**0.053[a](0.03)**	5.08	**0.010**
	Fast Backward Return				
MARP (rad)	**0.20[a](0.12)**	**0.12[b](0.07)**	**0.12[ab](0.10)**	3.71	**0.031**
DP (rad)	0.040(0.02)	0.030(0.01)	0.030(0.01)	2.24	0.117

Boldface indicates significant effect

Table 4:

Summary of statistics results for differences in measures of timing and magnitude aspect of lumbo-pelvic coordination between study groups (low-moderate and moderate-severe LBP) and time points (baseline, 3-month, and 6-month).

Condition		***Group***		***Time***		***Group × Time***	
	Variable	***F***	***p***	***F***	***p***	***F***	***p***
Slow pace forward bending and backward return	*Thoracic Rotation (°)*	6.61	**0.018**	0.04	0.961	1.26	0.294
	Pelvic Rotation (°)	8.12	**0.010**	0.63	0.537	3.12	0.055
	Lumbar Flexion (°)	0.04	0.840	0.68	0.514	1.61	0.212
	LTR	5.25	**0.032**	0.76	0.476	3.58	**0.037**
Fast pace forward bending and backward return	*Thoracic Rotation (°)*	9.59	**0.006**	1.22	0.307	0.57	0.568
	Pelvic Rotation (°)	12.84	**0.002**	0.86	0.432	0.38	0.684
	Lumbar Flexion (°)	1.52	0.233	4.36	**0.020**	0.14	0.873
	LTR	7.88	**0.012**	3.73	**0.034**	0.308	0.737
Slow forward bending	*MARP (rad)*	1.60	0.220	0.32	0.726	0.11	0.894
	DP (rad)	5.74	**0.028**	9.62	**<0.001**	3.82	**0.031**
Slow backward return	*MARP (rad)*	0.70	0.412	3.48	**0.040**	1.06	0.354
	DP (rad)	3.39	0.082	1.64	0.207	7.38	**0.002**
Fast forward bending	*MARP (rad)*	2.30	0.147	1.92	0.161	0.25	0.781
	DP (rad)	2.00	0.175	1.29	0.288	0.71	0.498
Fast backward return	*MARP (rad)*	0.21	0.653	1.96	0.156	0.07	0.932
	DP (rad)	1.60	0.223	0.76	0.478	1.00	0.378

Boldface indicates significant effect

Table 5:

Mean (SD) of measures of timing and magnitude aspect of lumbo-pelvic coordination for each group (low-moderate and moderate-severe LBP) and time point (baseline, 3-month, and 6-month) under slow and fast paced forward bending and backward return task.

Condition	Variable	Group		Time		
		Low-moderate LBP	*Moderate-severe LBP*	*Baseline*	*3-month*	*6-month*
Slow pace forward bending and backward return	*Thoracic Rotation (°)*	**107(15)**	**89(19)**	98(18)	98(17)	99(19)
	Pelvic Rotation (°)	**64(16)**	**44(17)**	53(15)	53(19)	56(20)
	Lumbar Flexion (°)	44(11)	45(8)	45(10)	45(11)	43(10)
	LTR	**0.41(0.11)**	**0.53(0.12)**	0.46(0.10)	0.44(0.13)	0.41(0.13)
Fast pace forward bending and backward return	*Thoracic Rotation (°)*	**110(13)**	**92(19)**	105(16)	100(13)	99(20)
	Pelvic Rotation (°)	**70(14)**	**45(15)**	58(15)	55(17)	60(19)
	Lumbar Flexion (°)	40(11)	47(12)	**47^{a}(11)**	**45^{a}(11)**	**39^{b}(12)**
	LTR	**0.37(0.10)**	**0.50(0.11)**	**0.42^{a}(0.10)**	**0.41^{a}(0.13)**	**0.36^{b}(0.12)**
Slow forward bending	*MARP (rad)*	0.13(0.08)	0.17(0.10)	0.14(0.08)	0.15(0.08)	0.16(0.08)
	DP (rad)	**0.052(0.03)**	**0.088(0.05)**	**0.053^{a}(0.03)**	**0.065^{a}(0.03)**	**0.092^{b}(0.04)**
Slow backward return	*MARP (rad)*	0.14(0.09)	0.17(0.09)	**0.13^{a}(0.07)**	**0.18^{b}(0.10)**	**0.16^{ab}(0.09)**
	DP (rad)	0.039(0.02)	0.058(0.03)	0.043(0.03)	0.056(0.03)	0.046(0.02)
Fast forward bending	*MARP (rad)*	0.08(0.05)	0.12(0.08)	0.13(0.06)	0.08(0.04)	0.09(0.06)
	DP (rad)	0.028(0.02)	0.035(0.02)	0.033(0.01)	0.034(0.01)	0.028(0.01)
Fast backward return	*MARP (rad)*	0.11(0.06)	0.12(0.07)	0.14(0.07)	0.11(0.06)	0.10(0.05)
	DP (rad)	0.027(0.01)	0.033(0.01)	0.032(0.01)	0.027(0.01)	0.031(0.01)

Boldface indicates significant effect

Table 6:

Summary of statistics results for differences in the level of pain and disability between study groups (low-moderate and moderate-severe LBP) and time points (baseline, 3-month, and 6-month).

	Level of Pain		**Level of Disability**	
	F	*p*	*F*	*p*
Group (G)	53.79	**<0.001**	36.31	**<0.001**
Time (T)	12.10	**<0.001**	4.39	**0.017**
G X T	0.41	0.667	0.07	0.936

Boldface indicates significant effect

Table 7:

Mean (SD) of level of pain and disability for each study group (low-moderate and moderate-severe LBP) and time point (baseline, 3-month, and 6-month). Both pain and disability levels are presented as percent of maximum possible value (i.e., 10 for pain level according to the Wisconsin Brief Pain Inventory and 24 for disability level according to the Roland Morris Disability Scale)

	Group		**Time**		
	Low-moderate LBP	***Moderate-severe LBP***	***Baseline***	***3-monthx***	***6-month***
Level of Pain (%)	**24(13)**	**61(21)**	**43^{a}(21)**	**30^{b}(24)**	**25^{c}(19)**
Level of Disability (%)	**13(12)**	**45(21)**	**27^{a}(19)**	**17^{b}(19)**	**20^{ab}(23)**

Boldface indicates significant effect