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Associations of low-back pain and pain-related cognitions with lumbar movement patterns during repetitive seated reaching

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ABSTRACT

Background: Development of more effective interventions for nonspecific chronic low back pain (LBP), requires a robust theoretical framework regarding mechanisms underlying the persistence of LBP. Altered movement patterns, possibly driven by pain-related cognitions, are assumed to drive pain persistence, but cogent evidence is missing.

Aim: To assess variability and stability of lumbar movement patterns, during repetitive seated reaching, in people with and without LBP, and to investigate whether these movement characteristics are associated with pain-related cognitions.

Methods: 60 participants were recruited, matched by age and sex (30 back-healthy and 30 with LBP). Mean age was 32.1 years (SD13.4). Mean Oswestry Disability Index-score in LBP-group was 15.7 (SD12.7). Pain-related cognitions were assessed by the 'Pain Catastrophizing Scale' (PCS), 'Pain Anxiety Symptoms Scale' (PASS) and the task-specific 'Expected Back Strain' scale(EBS). Participants performed a seated repetitive reaching movement (45 times), at self-selected speed. Lumbar movement patterns were assessed by an optical motion capture system recording positions of cluster markers, located on the spinous processes of S1 and T8. Movement patterns were characterized by the spatial variability (meanSD) of the lumbar Euler angles: flexion-extension, lateral-bending, axial-rotation, temporal variability (CyclSD) and local dynamic stability (LDE). Differences in movement patterns, between people with and without LBP and with high and low levels of pain-related cognitions, were assessed with factorial MANOVA.

Results: We found no main effect of LBP on variability and stability, but there was a significant interaction effect of group and EBS. In the LBP-group, participants with high levels of EBS, showed increased $MeanSD_{lateral\text{-}bending}$ ($p = 0.004$, $\eta^2 = 0.14$), indicating a large effect. $MeanSD_{axial\text{-}rotation}$ approached significance ($p = 0.06$).

Significance: In people with LBP, spatial variability was predicted by the task-specific EBS, but not by the general measures of pain-related cognitions. These results suggest that a high level of EBS is a driver of increased spatial variability, in participants with LBP.

1. Introduction

Nonspecific chronic low-back pain (LBP) has a high prevalence and disabling consequences [1,2]. Its impact on health-care and society is severe, and because of the ageing population, it will most likely grow in the years to come [3]. Conservative physical, behavioral or combined interventions have similar but only modest effects [4–6]. To develop more effective interventions [2,7], a more robust theoretical framework regarding mechanisms underlying the persistence of LPB is needed. It has been hypothesized that altered lumbar movement patterns play a role in the persistence of symptoms in people with LBP [8,9]. Identification of such alterations and possible drivers of these alterations, may support the development of personalized, more effective interventions [9,10].

Recent literature emphasizes that alterations in movement behavior should be studied in conjunction with psychological factors [9,11,12]. Psychological factors, such as pain-related fear or catastrophizing, have been found to correlate with altered movement in people with LBP [9,11,13–17], but findings are variable [13,18] and effect sizes are small [19]. One explanation could be the focus on measures of capacity (e.g.

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range of motion), instead of measures that characterize movement patterns [19]. More sensitive, linear and non-linear measures to characterize spinal movement patterns, could help to delineate the relationship between psychological factors and movement behavior [20]. Second, while pain-related cognitions have been treated mostly as trait variables, relatively constant in any individual, they may also depend on the movement task to be executed. Task-specific assessment of pain-related cognitions might be more appropriate than general questionnaires [15,19].

Frequently used measures to characterize lumbar movement patterns, are variability and local dynamic stability (LDS) [21–23]. Movement variability can be expressed spatially and temporally. Spatial variability is quantified as the mean standard deviation of lumbar angles over repeated cycles of the same movement, MeanSD [24]. Temporal variability is quantified as the standard deviation of cycle times, CycleSD [25]. LDS expresses the rate of change of the movement trajectory after infinitesimally small perturbations (e.g. due to breathing), and thus the inverse of how fast perturbations of the movement pattern are corrected [21,24,26]. LDS is commonly expressed by the local divergence exponent (LDE), which quantifies the mean logarithmic rate of divergence between neighboring trajectories in lumbar kinematics state space [23,27].

A few studies explored the relationship of variability and LDS with psychological factors, with mixed results [18,28–30]. Both positive [29,30] and negative [18] or no correlations [28] were found with negative pain-related cognitions. Diversity in research methods (population, movement studied, outcome measures, threat of a mechanical perturbation or pain stimulus) [8], make it challenging to draw unequivocal conclusions.

Previous studies on lumbar movement patterns focused on back-healthy people [18,30,31], did not associate the movement patterns with pain-related cognitions [10], lacked task-specific measures of psychological factors [15,19], or were limited to walking [28]. The latter can be considered an undemanding and non-threatening task, even for patients with LBP. Repeated seated reaching is a more challenging task compared to walking. Furthermore, seated reaching is a common movement in everyday life [32] and it offers the opportunity to focus on lumbar movement patterns, largely excluding effects of leg movements [33]. Recently, we demonstrated that variability and LDS of lumbar movements in seated reaching tasks are sufficiently reliable, to assess movement patterns in single-session experiments [34].

The aim of the present study was to characterize and compare lumbar movement patterns, during repetitive seated reaching, between groups of people with and without LBP and to investigate whether these movement patterns are related to pain-related cognitions. On the basis of results obtained with experimentally induced pain in back-healthy individuals [18,30], we hypothesized that people with LBP and more negative pain-related cognitions, show aberrant variability and LDS of lumbar movement patterns.

2. Methods

2.1. Participants

Thirty back-healthy participants and 30 participants with LBP (matched by age and sex) volunteered to participate (Table 1). They had been recruited through word of mouth by the researchers and students involved. Additionally, physical- and exercise therapists were asked to invite patients, who met the inclusion- and exclusion-criteria. In- and exclusion criteria were assessed using a self-administered questionnaire supervised by a paramedically trained researcher. Participants with LBP were included if: (1) they had experienced more than one episode of non-specific LBP or continuous non-specific LBP within the last two years; (2) duration of an episode of LBP was minimally two weeks; (3) pain intensity was affected by posture or movement. The latter was to focus on patients with pain originating from a nociceptive source.

Table 1
Participant characteristics.

	LBP (n = 30) Gender (M/F): 11/19	Back-Healthy (n = 30) Gender (M/F): 11/19
	Mean (SD)	Mean (SD)
Age (year)	32.1 (13.6)	32.0 (13.5)
Height (cm)	1.79 (0.10)	1.79 (0.08)
Weight (kg)	74.7 (14.1)	74.7 (10.3)
ODI/50	15.7 (12.7)	
STBST/9	1.6 (1.5)	
LBP intensity at day of testing/10	2.4 (2.1)	
	Median (IQR)	**Median (IQR)**
PASS/200	45 (35.75–63.50)	48 (38.75–72.00)
PCS/52	13 (8.75–18.25)	13 (7.00–15.50)
EBS/10	3 (2.00–4.25)	2 (2.00–4.00)
$EBS_{trial\ 3}$/10	2 (1.75–4.00)	2 (1.00–3.00)

ODI Oswestry Disability Index, STBST StarT Back ScreeningTool, PASS Pain Anxiety Symptoms Scale, PCS Pain Catastrophic Scale, EBS Expected Back Strain.

Inclusion criterion for back-healthy participants was to be free from episodes of LBP for at least 2 years. Exclusion criteria for both groups were (1) perceived balance problems; (2) BMI over 30 in combination with high abdominal circumference (males > 102 cm, females > 88 cm); (3) any systemic (e.g. diabetes mellitus), neurological or cardiovascular pathology, earlier spine surgery, infections, medication which might influence movement (antidepressants, analgesics, tranquillizers), pregnancy, respiratory ailments, or significant musculoskeletal injury in the past six months [34].

Participants with LBP completed the Oswestry Disability Index (ODI) [35], with a minimum score indicating no disability and the maximum score indicating 100% disability, and the StarT back screening tool (SBST) [36], with a score 0–3 indicating low risk of psychosocial prognostic risk factors and a score ≥ 4 indicating high risk. Pain intensity was evaluated, by a numerical rating scale (NRS) (0 = no pain, 10 = worst imaginable pain). All participants provided informed consent, prior to participation. The protocol had been approved by the ethical committee of the Faculty of Behavioral and Human Movement Sciences, VU University of Amsterdam (VCWE-2020–070).

2.2. Materials

As described previously [34], a custom-made chair, without back rest and arm supports, was rigidly attached to a DynSTABLE (Motek Medical Amsterdam, Netherlands). A motion capture system consisting of four Vicon Bonita3 cameras (VICON-612 system, Oxford Metrics, UK) was used to track reflective markers, and sampled with D-Flow software at approximately 100 samples/s (Motek Medical Amsterdam, Netherlands). Two clusters of three markers were used, to assess lumbar movement patterns. Clusters were fixed to the spinous processes of T8 and S1 using adhesive tape (Fig. 1) [34].

2.3. Experimental procedure

Participants performed three trials with a pause in between. To prevent fatigue, participants could step off the DynSTABLE between trials, if necessary. Each trial consisted of 45 slightly asymmetric reaching movements, performed while seated with one arm crossed in front of the chest, at self-selected speed (Fig. 2) [34]. To get familiarized, participants practiced the reaching movement five times, before the actual trials. Repeated forward reaching was performed from upright posture to a flexed position. To control movement amplitude, the button of a joystick situated in front of the participant, at knee level at a distance of 125% of the length of the upper limb, had to be pressed with the fingers of the dominant hand (Fig. 2) [34].

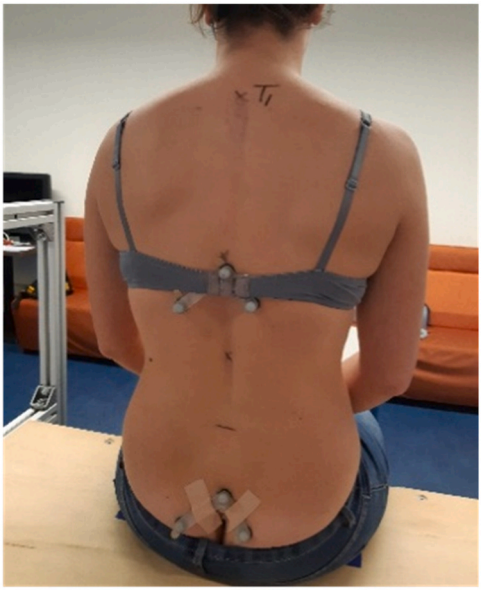

Fig. 1. Fixation of marker clusters on the thorax and pelvis (T8 and S1). Reprinted with permission [34].

To investigate if pain-related cognitions are state variables, dependent on expectations regarding the movement task, participants were warned for mechanical perturbations prior to the first trial, which would not actually occur during that trial. Participants were informed that the chair, would sometimes move unexpectedly in a random direction, this mechanical perturbation could be intense and they were allowed to grab the hand rails when losing their balance. They were instructed to recover as quickly as possible and keep on reaching to finish the trial. In the second trial, mechanical perturbations were actually administered. In the third trial, participants performed a steady-state movement, without the threat of a mechanical perturbation. Because our first interest was to investigate possible differences in movement patterns between participants with and without LBP during a steady-state and familiar task, only the third trial was used to address the research aim of this paper.

2.4. Pain-related cognitions

Prior to the three trials, participants completed the Pain Anxiety Symptoms Scale (PASS) [37], to assess pain-related fear and anxiety, and the Pain Catastrophizing Scale (PCS) [38], to assess catastrophizing. Additionally, to assess the 'Expected Back Strain' (EBS) associated with the first trial, they completed an 11-points color-marked scale (0–10) based on the RPE-Borg scale, before the execution of the first trial and after the introduction of the threat of the mechanical perturbation (Suppl. Material_2). This EBS-scale was completed again before trials 2 and 3.

2.5. Lumbar movement patterns

2.5.1. Joint kinematics

To exclude transients, the final 40 of the 45 repetitions in trial 3 were selected for analysis. To account for missing samples and correct for small fluctuations in sample rate, caused by D-flow software recording at 102/103 Hz, data were (cubic spline) interpolated to 100 Hz. Segment orientations were computed in the global axis system. Subsequently, relative orientations between thorax and pelvis were determined and decomposed into lumbar angles using Euler decomposition in the order flexion/extension, lateral-bending, axial-rotation [34].

2.5.2. Variability

The time series of the lumbar angles were divided into cycles, based on peak detection of the most forward sagittal plane orientation of the thorax (T8) in each cycle. Temporal variability was quantified as the standard deviation of the cycle durations (CyclSD). For spatial variability, lumbar angle data for each cycle were normalized to 101 samples (0–100%) for all three axes. Cross-correlation was used to optimally align all repetitions. Spatial variability was then calculated as the average of the standard deviations at all normalized time points across the cycles (MeanSD) [24].

2.5.3. Local dynamic stability

As the number of samples affects the LDE, lumbar angle time series were normalized to a fixed number of data points (300 times the number of cycles), using cubic spline interpolation [39]. The three lumbar angles were used to reconstruct a 6-dimensional state-space, with a 30-samples (10% of the average number of samples per cycle) time-delayed copy. To minimize effects of noise [27], we tracked divergence between kinematic states evolving from each data point and its 15 nearest neighbors. Divergence curves were logarithmically transformed, and averaged over the nearest neighbors per reference point and over reference points. LDE was determined as the slope of the best fitting line over the first 0.25 cycle of the resulting divergence curve [26]. The algorithm used is available at https://zenodo.org/record/4681213 [41].

2.5.4. Amplitude and velocity

Maximum and minimum lumbar angles per cycle were determined, for all three directions. Subsequently, mean maximum and mean minimum angle were subtracted to determine the range of motion. Average movement velocity was calculated by dividing the duration of the trial by the number of repetitions.

2.6. Statistical analyses

Statistical analyses were performed with IBM SPSS Statistics 25 software. Differences in movement patterns between people with and without LBP and with high and low levels of pain-related cognitions, were assessed with factorial MANOVA. High and low levels of pain-related cognitions were based on a median split. In case of significant MANOVA effects, univariate ANOVA using the same factors were performed, to assess which characteristics determined the multivariate effects. These analyses were performed separately for each of the measures

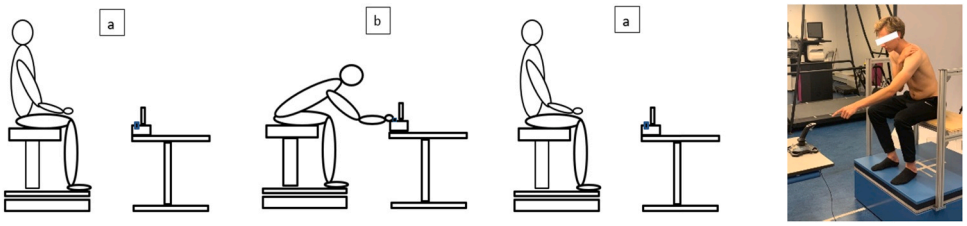

Fig. 2. Overview of the task performed by the participants. Starting position – upright sitting (a), forward reaching to a distance of 1.25 × length of the upper limb to reach the target (b), and starting position again (a). Reprinted with permission [34].

of pain-related cognitions. In case of effects of pain-related cognitions on movement characteristics, the relation between these variables was further assessed by means of Spearman correlations for the pooled group and in case of an interaction effect also for each group separately.

3. Results

3.1. Participants

Participants with and without LBP were comparable concerning age, sex, length, weight and pain-related cognitions (Table 1). Mean level of pain-intensity on testing day and ODI-score in the participants with LBP were respectively 2.4 (± 2.1) and 15.7 (± 12.7). Additionally, they had a low risk for chronicity (mean STBST score 1.6 (± 1.5)). The median of Pain-related fear (PASS) was 45 (IQR 35.75–63.50) in the back-healthy participants and 48 (IQR 38.75–72.00) in the LBP-group. The median PCS score in the LBP-group was 13 (IQR 8.75–18.25) and 13 (IQR 7.00–15.50) in the back-healthy-group. Expected back strain (EBS), was somewhat higher in the LBP-group compared to the back-healthy-group: median scores 3 (IQR 2.00–4.25) and 2 (IQR 2.00–4.00), respectively. Median $EBS_{trial\ 3}$ scores were 2 (IQR 1.75–4.00) in the LBP-group and 2 (IQR 1.00–3.00) in the back-healthy-group.

3.2. Movement patterns

$MeanSD_{flexion\text{-}extension}$, CyclSD Mean_$Amplitude_{axial\text{-}rotation}$, Mean_$Amplitude_{lateral\text{-}bending}$ and Velocity were skewed and therefore log transformed. Table 2 presents the movement characteristics for participants for the subgroups based on LBP and medians splits on pain-related cognitions. No effect of LBP was found on variability and LDS: Wilk's $\Lambda = 0.851$, $F(5,52) = 1.826$, $p \leq 0.124$, but there was a significant interaction effect of group and EBS: Wilk's $\Lambda = 0.811$, $F(5,52) = 2.422$, $p \leq 0.048$. Specifically, the LBP-group with a high level of EBS, had larger $MeanSD_{lateral\text{-}bending}$ than the other groups ($p = 0.004$, Table 3, Fig. 3). Partial eta squared effect size was 0.14, indicating a large effect. The interaction effect of group and EBS on $MeanSD_{axial\text{-}rotation}$ approached significance ($p = 0.06$), again indicating higher variability in the LBP-group with high EBS (Table 3). For the other measures of pain-related cognitions, PASS and PCS, no effect on movement variability and stability was observed.

There were no effects of group on movement amplitudes and movement velocity: Wilk's $\Lambda = 0.898$, $F(4,53) = 1.507$, $p \leq 0.213$. The main effect of EBS on amplitude and velocity approached significance Wilk's $\Lambda = 0.844$, $F(4,53) = 2.443$, $p \leq 0.058$. Specifically, high EBS coincided with large $Amplitude_{lateral\text{-}bending}$ ($p = 0.004$). There was a trend for an interaction effect of group and EBS: Wilk's $\Lambda = 0.863$, $F(4,53) = 2.099$, $p \leq 0.094$. The largest $Amplitude_{lateral\text{-}bending}$ was found in the LBP-group with high EBS ($p = 0.062$).

There were no correlations between pain-related cognitions and movement characteristics of the pooled group of participants with and without LBP ($N = 60$). In the LBP-group separately, there were positive correlations between EBS and $MeanSD_{lateral\text{-}bending}$ ($r = 0.497$, $p \leq 0.01$), $MeanSD_{axial\text{-}rotation}$ ($r = 0.399$, $p \leq 0.05$) and $Amplitude_{lateral\text{-}bending}$ ($r = 0.563$, $p \leq 0.01$).

Table 3
Results of univariate ANOVAs with group and EBS as independent and $MeanSD_{flexion\text{-}extension}$, $MeanSD_{axial\text{-}rotation}$, $MeanSD_{lateral\text{-}bending}$ CyclSD and LDE as dependent variables.

Source	Dependent variable	F ratio	p value	Partial Eta Squared
Group*EBS	MeanSD *flexion-extension*	0.266	0.608	0.005
	MeanSD *axial-rotation*	3.698	0.060	0.062
	MeanSD *lateral-bending*	9.168	0.004	0.141
	CyclSD	2.151	0.148	0.037
	LDE	0.259	0.613	0.005

4. Discussion

Our aim was to compare variability and stability of lumbar movement patterns in seated repetitive reaching between participants with and without LBP, and to investigate whether pain-related cognitions influence these movement characteristics. We aimed to study movement adaptations in LBP and thus designed the task to allow adaptations in timing or in distribution of movement over joints involved. Contrary to our hypothesis, we found no main effects of LBP. This was corroborated by an additional analysis after pooling the current data with data from a previous study [34], leading to a total of 45 participants with LBP and 51 back-healthy participants (Suppl. Material_1). These results resemble those of Asgari et al., who also found no effect of LBP on variability and stability ($LDE_{short\text{-}term}$) during a standing reaching movement [10] and are in line with the inconsistent effects of LBP on movement patterns mentioned in the introduction, which may stem from differences in pain-related cognitions between patients.

In line with our hypothesis, high EBS in the LBP group coincided with increased spatial variability, but this did not hold for general measures of pain-related cognitions (PCS and PASS). The increased variability is in line with the results of Ross et al., but in contrast with Ross et al. and Moseley et al., who found evidence for more rigidly controlled movement, in people with pain and more negative pain-related cognitions [18,30,31]. Possibly, more rigid control reduces variability in static postural tasks, but leads to increased variability during movement, because increased co-contraction or reflex gains, while functional in postural control, may hamper dynamic movement and cause more variability [8,20,30].

In contrast with Ross et al. [18,30], we found no association between general pain-related cognition questionnaires and lumbar movement, whereas we did find task-specific EBS to be associated with variability in the LBP-group. Other studies also suggested lack of movement changes in relation to general pain-related cognitions [15,19]. This suggests that

Table 2
Movement characteristics per subgroup, of steady-state reaching.

	LBP participants with high EBS N = 14 (mean ± SD)	LBP participants with low EBS N = 16 (mean ± SD)	Back-Healthy participants with high EBS N = 8 (mean ± SD)	Back-Healthy participants with low EBS N = 22 (mean ± SD)
$MeanSD_{flexion\text{-}extension}$ (degrees)	2.04 (0.9)	1.62 (0.4)	1.90 (0.6)	1.72 (0.4)
$MeanSD_{axial\text{-}rotation}$ (degrees)	1.00 (0.4)	0.75 (0.2)	0.88 (0.3)	0.91 (0.2)
$MeanSD_{lateral\text{-}bending}$ (degrees)	1.19 (0.4)	0.78 (0.2)	0.81 (0.2)	0.87 (0.2)
CyclSD (seconds)	0.11 (0.0)	0.12 (0.1)	0.11 (0.0)	0.09 (0.2)
LDE	3.84 (0.3)	3.86 (0.3)	3.90 (0.3)	3.86 (0.2)
$Mean\_Amplitude_{flexion\text{-}extension}$ (degrees)	18.76 (9.6)	18.79 (7.1)	22.90 (8.6)	22.78 (8.9)
$Mean\_Amplitude_{axial\text{-}rotation}$ (degrees)	10.56 (4.7)	8.90 (4.3)	8.20 (4.1)	9.12 (4.1)
$Mean\_Amplitude_{lateral\text{-}bending}$ (degrees)	13.39 (6.4)	6.67 (2.1)	9.11 (3.4)	8.12 (4.1)
Velocity (seconds/repetition)	2.60 (0.3)	2.98 (0.6)	2.72 (0.5)	2.60 (0.3)

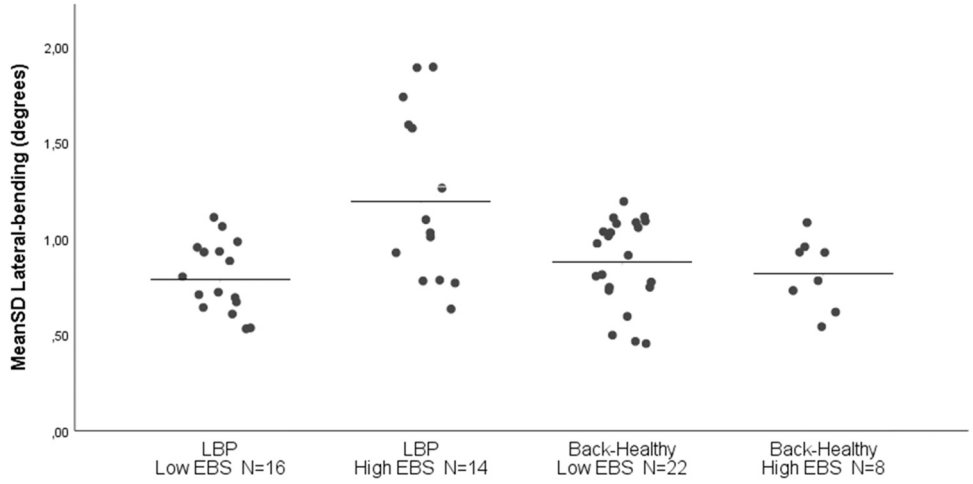

Fig. 3. MeanSD$_{lateral\text{-}bending}$ per subgroup, dots represent individual participants, horizontal lines represent the group mean.

pain-related cognitions are at least in part state variables, not only dependent on the subject, but also on the movement task to be executed. While the PASS-scores and PCS-scores in this study were strongly correlated ($r = 0.753$, $p \leq 0.01$), EBS and PCS were not correlated and EBS and PASS were only moderately correlated ($r = 0.358$, $p \leq 0.01$). Given these results, task-specific EBS, adds to the concept of pain-related cognitions.

The estimate of EBS was determined after participants were threatened with a mechanical perturbation. The purpose of this threat was to enlarge the effects of pain-related cognitions. The EBS was again measured before the steady-state trial analyzed here, when participants were aware that no perturbations would occur and they were also familiar with the task. The correlation between this EBS$_{trial_3}$ score and MeanSD$_{lateral\text{-}bending}$ remained, but was somewhat lower: $r = 0.369$, $p \leq 0.05$.

In our previous study, 40 repetitions resulted in optimal reliability without fatigue or pain, in a population consisting of people with and without low back pain [34]. Between trials, participants rested, while they were instructed for the next trial and were allowed to move their back as desired to relax their back muscles. If necessary, they could step off the Dynstable, similar to the procedure in the test-retest study [34]. Participants did not start the next trial until they indicated that the back was not tired or painful. Although fatigue was not directly asked about, it is likely that the EBS-scores would have reflected fatigue if present. The EBS-scores decreased over the 3 trials and no significant differences were found between participants with and without LBP.

This study found an effect in the LBP-group of pain-related cognitions on a linear variability measure (MeanSD) and not on the non-linear LDE. This is in line with the conclusion of Saito et al. that linear measures are more sensitive to pain-related cognitions than non-linear measures [20].

A strength of this study is the relatively large number of participants and the successful matching of participants with and without LBP. A limitation of this study is the low level of disability and lack of strongly negative pain-related cognitions among participants. The ODI-, PCS- and PASS-scores were comparable to other studies [13,15,18], and this reflects the challenge to include participants with strongly negative pain-related cognitions.

Adding measurements of the construct task-specific EBS, when assessing pain-related cognitions, is recommended in future scientific research, because of the unique association with movement variability.

5. Conclusion

This study found no differences in stability and variability of lumbar movement patterns between groups of people with and without LBP, during repetitive seated reaching. However, in people with LBP, increased spatial variability was predicted by a high level of task-specific EBS, but not by general measures of pain-related cognitions. The use of task-specific EBS is recommended in future research to further delineate the relationship between psychological factors and movement behavior.

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Declaration of Competing Interest

All authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Data availability

[Dataset] Data available at Open Science Framework: Dataset Lumbar Movement Patterns repetitive seated reaching. https://doi.org/10.17605/OSF.IO/9XSNP [40].

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2021.10.032.

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