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Subgrouping People With Acute Low Back Pain Based on Psychological, Sensory, and Motor Characteristics: A Cross-Sectional Study

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ABSTRACT

Background: Clustering helps identify patient subgroups with similar biopsychosocial profiles in acute low-back pain (LBP). Motor factors are common treatment targets and are associated with disability but have not been included in acute LBP cluster development. This study aimed to identify subgroups of individuals with acute LBP based on motor, sensory and psychological characteristics and to compare these subgroups regarding clinical outcomes.

Methods: Ninety-nine participants with acute LBP were recruited, and motor (bending range of motion [ROM], flexion relaxation), pain sensitivity (pressure-pain thresholds, temporal summation of pain) and psychological factors (pain catastrophising, kinesiophobia, self-efficacy) were measured, along with pain, disability and demographics.

Results: Principal component analysis accounted for 66.03% of the variance. Four component scores were entered in a hierarchical linear clustering model, deriving 3 subgroups ('mild features' $n = 39$, 'sensorimotor' $n = 35$ and 'psychomotor' $n = 25$). Between-cluster comparisons revealed significant differences in motor, sensory and psychological variables ($p < 0.05$). Sensorimotor and psychomotor clusters had higher flexion–relaxation ratios (mean difference: > 0.2), greater disability (mean difference: > 7/100) and smaller ROM (mean difference: 7 cm) compared to the 'mild' group. The sensorimotor cluster mostly exhibited higher temporal summation of pain (mean difference: > 1.3/10) and lower pressure-pain thresholds (mean difference: > 1.2 kg/cm^2) than 'mild' and psychomotor clusters. The psychomotor cluster showed higher kinesiophobia (mean difference: > 6/44) and pain catastrophising (mean difference: > 12/52) than 'mild' and sensorimotor groups.

Conclusion: Findings indicate 3 subgroups, suggesting that motor factors may add granularity to acute LBP clusters. Stratified care based on these subgroups may help refine treatment pathways for acute LBP.

Significance Statement: Including motor factors in cluster development adds a clinically relevant metric to describe people with acute LBP and generates insight into underlying mechanisms of motor adaptation. Longitudinal testing is required to see if these subgroups are differentially related to short- and long-term pain and disability.

1 | Introduction

Low-back pain (LBP) affects approximately 619 million people globally, and this figure is on the rise (Ferreira et al. 2023). While acute LBP often resolves within 6 weeks, many individuals develop persistent pain and disability (Wallwork et al. 2024). Chronic LBP is a leading cause of disability, and current treatments yield only modest outcomes (Ferreira et al. 2023; Hartvigsen et al. 2018). Preventing the transition from acute to chronic LBP might reduce this burden.

LBP is a complex biopsychosocial disorder linked to psychological, neurobiological, social, lifestyle and physical factors (Hartvigsen et al. 2018). Systematic reviews have highlighted risk factors for persistent symptoms, including heightened pain hypersensitivity (Georgopoulos et al. 2019) and psychological distress (e.g., pain catastrophising and pain-related fear) (Wertli et al. 2014a, 2014b). Recently, clustering methods have been used to identify LBP subgroups with similar profiles (Chang et al. 2024b; Klyne et al. 2019; Marcuzzi et al. 2018). Two of these studies linked high-psychological distress in acute LBP subgroups to greater disability at 4–6 months, while elevated pain sensitivity alone was not associated with greater disability (Chang et al. 2024b; Marcuzzi et al. 2018). In contrast, others found high-pain sensitivity predicted negative outcomes in acute LBP, but only when combined with high-psychological distress (Klyne et al. 2019). Although trends may be emerging, few published studies preclude robust confidence in the findings.

Models of pain and movement emphasise the integration of psychosocial, sensory and motor control factors (Butera et al. 2016), but motor control has not yet been included in acute LBP clustering approaches. In the spine, motor control refers to 'movement quality' such as spinal range of motion (ROM) and trunk muscle activity. Many people with LBP demonstrate altered movement patterns compared to healthy individuals (Errabity et al. 2023; Laird et al. 2014, 2019), which may contribute to persistent pain and disability via sub-optimal tissue loading during movement and exercise (Hodges and Smeets 2015; Hodges and Tucker 2011). A systematic review found weak evidence linking low spinal ROM and increased disability in chronic and acute LBP, highlighting decreased ROM as a possible treatment target in some, but likely not all, LBP patients (Nzamba et al. 2024). Likewise, reduced trunk muscle relaxation (flexion–relaxation phenomenon) is common in LBP, associated with higher disability (Alschuler et al. 2009) and regarded as a possible marker for recovery (Gouteron et al. 2022; McGorry and Lin 2012; Neblett et al. 2010). While addressing psychological risk factors as treatment targets remains crucial, recent work has shown that motor factors are also important and may be impacted by psychological factors. Specifically, motor adaptations are related to psychological distress, where greater fear and pain catastrophising are associated with guarded behaviours (e.g., low ROM and high-paravertebral activation) (Christe et al. 2021; Ippersiel et al. 2022). Incorporating motor control variables into cluster development in acute LBP may enhance subgroup differentiation and offer new insights.

We aimed to identify acute LBP subgroups based on motor, sensory and psychological characteristics, and to explore differences in clinical outcomes and participant demographics. Broadly aligned with past work (Chang et al. 2024b; Klyne et al. 2019), we hypothesised four subgroups: high-psychological features and high-pain sensitivity; high-psychological features and low-pain sensitivity; low-psychological features and high-pain sensitivity; and low-psychological features and low-pain sensitivity. Considering psychological distress is associated with guarded motor control (Christe et al. 2021; Ippersiel et al. 2022), we expected the psychological distress groups to also exhibit this pattern (i.e., less ROM and less trunk extensor relaxation).

2 | Methods

2.1 | Study Overview and Procedures

This cross-sectional study is a secondary analysis of baseline data from a single-blind parallel group RCT (registered on ClinicalTrials.gov [NCT03986047]) and previously described in detail (Côté-Picard et al. 2020). Only the methods and measures pertinent to the current manuscript's objectives are described here. Participants attended a testing session at the Cirris research centre (Québec City, Canada), where they first completed standardised demographic forms and self-report questionnaires, followed by quantitative sensory and movement testing protocols.

2.2 | Study Participants

Adults (18–65 years of age) with acute LBP were recruited via the Québec Back Pain Consortium database (Pagé et al. 2020), University of Laval's email listings and social media (Facebook), from the region of Québec City (Canada). Acute non-specific LBP was defined as new onset LBP, with or without leg pain, lasting 6 weeks or less with a pain-free period of at least 3 months preceding the current episode (Van Tulder et al. 2003). Specific inclusion criteria were: acute LBP that limited activities for more than 1 day and a score of $\geq$ 10/100 on the Oswestry Disability Index (ODI). Exclusion criteria were: specific LBP (e.g., fracture, tumour (Maher et al. 2017)), peripheral or central neurological impairment (e.g., potential radiculopathy with corresponding altered sensation in the lower extremity such as tingling or numbness and reduction in muscle strength related to a peripheral lumbar root/nerve pathology), history of lumbar surgery, fibromyalgia, rheumatoid arthritis, pregnancy, cognitive impairment, recent change in medication that may influence pain (e.g., opioids) or recent cortisone injection ($<$ 6 weeks). Informed consent was obtained from participants, and ethical approval for this study was received from the local research ethics board.

2.3 | Primary Outcomes

Disability: The Oswestry Disability Index (ODI) is a valid and reliable tool used to evaluate LBP-related symptoms and functional limitations (Fairbank and Pynsent 2000). The ODI is a list of ten items ranging from 0 to 5 to assess pain intensity and the difficulty it has caused in performing different activities of everyday life. The score ranges from 0 to 100, where

greater scores indicate greater LBP-related symptoms and functional limitations.

Pain: LBP intensity was assessed using an 11-point numerical rating scale (NRS) (Childs et al. 2005), where 0 is 'no pain' and 10 is the 'worst imaginable pain'. Specifically, the NRS measured (i) average pain over the past 7 days and (ii) pain experienced during the bending task of our movement testing protocol (see section 2.4.3.).

2.4 | Secondary Outcomes

2.4.1 | Participant Demographics

To describe our sample, the following participant characteristics were collected using the Canadian minimal dataset for LBP (Lacasse et al. 2017): age, sex, height, weight, BMI, LBP symptom duration (days) and history of LBP (yes/no).

2.4.2 | Psychological Questionnaires

Kinesiophobia: The Tampa Scale of Kinesiophobia 11-item version (TSK-11) measures fear and movement and re-injury in relation to one's pain (Woby et al. 2005). This tool consists of 11 items on a 4-point scale. The scores range from 11 to a maximum of 44, where greater scores indicate greater pain-related fear. The TSK has strong internal consistency and construct validity (Dupuis et al. 2023).

Pain Catastrophising: The Pain Catastrophising Scale (PCS) measures pain-related catastrophic thinking (Sullivan et al. 1995). This tool, a 13-item scale, explores magnification of pain-related threats, feelings of helplessness related to pain, and rumination of pain symptoms. Total scores range from 0 to 52, where greater scores indicate greater pain catastrophising. The PCS has strong reliability and validity (Osman et al. 2000).

Self-efficacy: Self-efficacy was measured using the Chronic Disease Self-Efficacy Scale—short version (CDSES-6) (Lacasse et al. 2015). This tool is a 6-item questionnaire designed to assess an individual's confidence in adopting self-management behaviours and achieving their goals. Total scores range from 1 to 10, where greater scores indicate greater self-efficacy. This tool has good internal consistency and excellent construct validity (Lacasse et al. 2015).

2.4.3 | Motor Outcomes

Muscle relaxation: The flexion–relaxation phenomenon (FRP) was measured using wireless surface electromyography (sEMG), sampled at 1000 Hz (TrignoTM Wireless System, Delsys). Sensors were placed on the L5 and T12 erector spinae muscles on the most painful side of the back or on the right side if the pain was bilateral, following SENIAM guidelines (Hermens et al. 1999). These sensors have built-in inertial measurement units (IMU) that measure three-dimensional acceleration, sampled at 148 Hz. The skin was shaved and cleaned with an alcohol swab; then, sensors were fixed to the skin with double-sided tape.

Next, participants were asked to stand still for 3 s, progressively bend forward without bending the knees over 5 s, remain in the fully bent position for 3 s, and progressively return to the upright position over 5 s. This procedure was repeated 3 times, with a 30-s interval in between.

Raw sEMG and accelerometry data were imported into MATLAB R2019a (The Mathworks inc., Natick, Massachusetts, USA) for processing using custom code. Raw sEMG signals were full-wave rectified and filtered using a 4th order Butterworth filter (frequency cut-offs of 20 and 450 Hz). To smooth the sEMG signals, a moving average sliding window (250 ms) was used. Raw sagittal plane (Y) acceleration data were extracted and resampled to match sEMG data. A MATLAB custom graphical user interface was used to superimpose the raw acceleration signal onto the processed sEMG signal, allowing for the identification of each movement phase: (i) standing, (ii) flexion, (iii) full flexion and (iv) extension. Next, the maximal (peak) sEMG values for the flexion, full flexion and extension phases were identified. This procedure was repeated for each trial (3) and for each sensor (L5 and T12) and the average of the 3 trials were used to calculate the FRP ratios.

To quantify the FRP, two flexion–relaxation ratios were calculated (Gouteron et al. 2022). The FRP-Flex metric is the ratio of peak sEMG during the full flexion phase to the peak sEMG during the flexion phase. The FRP-Ext metric is the ratio of peak sEMG during the full flexion phase to the peak sEMG during the extension phase. By this convention, smaller values indicate more muscle relaxation, while larger values indicate less muscle relaxation. These calculations were averaged across the three repetitions for both the L5 and T12 sensors, resulting in 4 measures of FRP (L5 FRP-Flex, T12 FRP-Flex, L5 FRP-Ext, T12 FRP-Ext) for each participant.

Spinal range of motion (Fingertip-to-floor test): During the trunk flexion sEMG testing, the participant was asked to place their hands together while keeping their fingers straight. The range of motion during the full flexion was measured with a tape measure (cm) from the tip of the 3rd finger to the floor at each trial. The mean of the three trunk flexion trials was calculated. This procedure has an excellent intrarater reliability for forward flexion of the trunk (Fraeulin et al. 2020).

2.4.4 | Sensory Outcomes (Quantitative Sensory Testing)

All quantitative sensory testing procedures were performed in the same environment with stable testing conditions (e.g., light, noise). Testing was performed locally (back) and distally (foot or tibialis anterior) to assess for characteristics of sensitisation at the site of pain (local) and remote (central), respectively. Testing order within each block was randomised. For familiarisation, pressure-pain thresholds (PPT) and temporal summation of pain (TSP) testing were applied once at a remote site (PPT: wrist flexors; TSP: dorsum of hand). These QST measurements were chosen because they are both commonly used measures of pain sensitivity that are complementary. PPT is a static measure of pain that reflects the basal state of pain perception, while TSP

is a dynamic measure of sensitivity that refers to the perception of increasing pain in response to repeated, stable stimuli (Uddin and MacDermid 2016). Further, these procedures have shown excellent within-session and relative reliability (Mailloux et al. 2021; de Oliveira et al. 2023) in people with and without chronic LBP.

Pressure-pain threshold (PPT): PPTs were tested at a rate of ~0.5 kg/cm^2 per second with a handheld digital algometer (1cm^2 probe–FPIX, Wagner Instruments). PPTs were measured at 2 sites: (i) on the lumbar erector spinae (LES) 2–3 cm lateral to the L4–L5 joint on the most painful side, or on the right side if the pain was bilateral; and (ii) on the tibialis anterior (TA), contralateral to the most painful side. Lumbar PPTs were tested in prone, while TA PPTs were measured in supine. Participants were given standardised procedural instructions based on the German Research Network on Neuropathic Pain (DFNS) recommendations (translated to French), and the pressure at which the sensation became painful was considered as the PPT (Rolke et al. 2006). Based on these recommendations, PPTs were measured three times at each site, with a 30 s pause between measurements. Following testing, a mean PPT was calculated for each site.

Temporal summation of pain (TSP): TSP was tested using a pinprick stimulator (256 mN, MRC Systems GmbH, Germany) and a series of ten punctuate stimuli at 1 Hz over (i) the L4-L5 intervertebral joint line (ii) the 3rd cuneiform bones on the dorsal aspect contralateral to the most painful side. Frequency of 1 Hz was monitored by a luminous metronome maintained out of the participant's sight. TSP is considered the difference between the highest pain NRS through the ten trials and the pain after a single stimulus (Mailloux et al. 2021; Patricio et al. 2023). This procedure was repeated 3 times, with a 30-s break in between. TSP testing was performed in prone and supine positions for the back and foot sites, respectively. The mean ratings of TSP, at each site, were used for analysis.

2.5 | Statistical Analyses

2.5.1 | Principal Component Analysis

Principal component analysis (PCA) was used to reduce the dimensionalities of our dataset (Ringnér 2008). To assess the suitability of our data for PCA, the Kaiser–Meyer–Olkin measure and Bartlett's test of sphericity were used. Next, PCA with varimax rotation and Kaiser normalisation was performed on the correlation matrix of our 13 variables. Missing data ($n = 14$ observations) were replaced with the mean (Dray and Josse 2015). Principal components with Eigenvalues of > 1 were retained (Costello and Osborne 2019). Variables with a loading factor of > 0.8 were considered as exerting important influence on the principal components and were used to describe our components (Kaiser 1974).

2.5.2 | Hierarchical Clustering

Unsupervised hierarchical clustering was used to identify patterns across the principal components. In line with similar work (Klyne et al. 2018a), the Ward clustering with the Euclidean distance method was used, the minimum number of participants per cluster was set to 10, and the optimal number of clusters was determined via inspection of dendrograms and heatmaps (ClustVis: http://biit.cs.ut.ee/clustvis/) (Metsalu and Vilo 2015).

2.5.3 | Main Analyses

Data were explored and descriptive statistics were calculated for all variables. Mean (standard deviation) or median (interquartile range) were reported for parametric and non-parametric data, respectively. One-way ANOVAs/Kruskal–Wallis or Chi-square tests (dichotomous variables) determined between-cluster differences in 7-day mean pain, disability, symptom duration, history of LBP (yes/no) and demographic variables, in addition to the 13 variables included in our PCA. In the event of a significant group effect, post hoc comparisons were performed using Tukey's HSD or Dunn's tests. Statistical significance was set at $p < 0.05$. All analyses were performed using IBM SPSS Statistics, Version 29.0.1.0. Raincloud plots were developed using open-source code in MATLAB (Allen et al. 2019).

3 | Results

3.1 | Participant Sampling

Three hundred and fifteen people expressed interest in participating in our study. Of these, 100 were eligible and consented to participate, and 100 completed the baseline assessment. One participant was excluded after the baseline assessment because they received a diagnosis of a lumbar vertebral fracture. Thus, a total of 99 participants were included in our analyses. Baseline characteristics for our sample are listed in Table 1 and raw QST data are included in Table S1.

3.2 | Principal Component Analyses

The Kaiser–Meyer–Olkin measure for sampling adequacy was 0.60 and Bartlett's test for sphericity was $p < 0.001$; thus, our analyses were deemed suitable. Our PCA resulted in 4 principal components, accounting for 66.03% of total variation in the data. Variables with loadings > 0.8 were considered to be exerting a significant loading on the PCs. For PC1, we included one variable below the threshold of 0.8 (T12 FRP-Ext: 0.769) due to its proximity to the cut-off and its strong relationship with the other EMG variables retained in PC1. The PCs can be described as follows: flexion–relaxation phenomenon ratios (PC1, 25.61% of the variance), pressure-pain threshold (PC2, 17.60%), temporal summation of pain (PC3, 13.48%) and psychological factors (PC4, 9.34%) (Table 2). PC scores were calculated for each participant and retained for cluster analyses. The PCA data are visually presented in Figures S1 and S2.

3.3 | Hierarchical Cluster Analysis

Based on inspection of dendrograms and heatmaps, our analyses identified 3 clusters with profiles characterised by

TABLE 1 | Sample demographics ($n = 99$) reporting mean (standard deviation) or median [interquartile range].

Variable	Mean (SD)/ Median [IQR]
Age (years)	36 (13)
Sex (females)	61
Height (m)	1.70 (0.09)
Weight (kg)	77.67 (17.46)
BMI (kg/m^2)	26.68 (5.12)
Duration of the current episode (days)	25 (12)
History of LBP (Yes)	63 (64%)
Mean pain in past 7 days (NRS, /10)	5 [2]
Disability (ODI, /100)	23 (11)
Kinesiophobia (TSK-11, /44)	36 (7)
Pain Catastrophising (PCS, /52)	13 [42]
Self-efficacy (CPSES-6, /10)	8.17 [6.67]
Pain during movement (NRS, /10)	3 [8]

Abbreviations: CPSES-6, Chronic Pain Self-Efficacy Scale; LBP, Low-back pain; NRS, Numeric Rating Scale; ODI, Oswestry Disability Index; PCS, Pain Catastrophising Scale; TSK-11, Tampa Scale of Kinesiophobia.

TABLE 2 | Principal component (PC) analysis of sensory, motor, psychological and clinical variables.

	PC 1	PC 2	PC 3	PC 4
T12 FRP-flex	**0.845**	−0.022	0.036	0.058
T12 FRP-ext	**0.769**	0.017	−0.121	0.029
L5 FRP-flex	**0.810**	0.054	−0.012	−0.049
L5 FRP-ext	**0.815**	−0.086	−0.102	0.099
TSP Lumbar	−0.080	−0.154	**0.896**	0.061
TSP Foot	−0.066	−0.054	**0.910**	0.045
PPT Lumbar	−0.023	**0.934**	−0.056	−0.004
PPT Tibialis anterior	0.024	**0.910**	−0.157	0.038
Kinesiophobia (TSK-11)	0.001	0.061	0.173	**0.850**
Pain Catastrophising (PCS)	0.040	0.079	0.013	**0.821**
Self-efficacy (CPSES-6)	−0.249	0.145	0.039	−0.549
Pain during movement	0.372	−0.252	0.264	0.147
ROM flexion	0.585	0.026	−0.018	0.207

Note: Loadings indicate the contribution of each variable to the respective PC and bolded values denote PC loadings exerting important influence. PC1 is primarily associated with motor variables (FRP), PC2 with PPT, PC3 with TSP and PC4 with psychological factors.
Abbreviations: CPSES-6, Chronic Pain Self-Efficacy Scale; Ext, Extension from flexed position; Flex, Forward flexion; FRP, Forward Relaxation Phenomenon; LBP, Low-back pain; PCS, Pain Catastrophising Scale; PPT, Pressure-Pain Thresholds; ROM, Range of Motion; TSK-11, Tampa Scale of Kinesiophobia; TSP, Temporal Summation of Pain.

different motor, sensory and psychological contributions. Cluster 1 was termed 'Mild features' ($n = 38$), Cluster 2 was termed 'High-sensorimotor features' ($n = 32$), and Cluster 3 was termed 'High-psychomotor features' ($n = 24$). The names were chosen based on discriminating features for each cluster (Section 3.3.1). Sample clusters and corresponding heatmap are shown in Figure 1.

3.3.1 | Between Cluster Comparisons on Indicator Variables

Table 3 shows the means (SD)/medians (IQR) of the variables and statistical results of ANOVA/Kruskal–Wallis tests that confirm between-cluster differences ($p < 0.05$). Data are also displayed using raincloud plots in Figure 2 to better visualise the distribution of the variables and individual data for each variable and cluster.

For the motor variables, post hoc testing revealed that the sensorimotor and psychomotor clusters had a greater FRP ratio (i.e., less muscle relaxation) at L5 and T12 for both FRP-Flex and FRP-Ext ratios, compared to the 'mild features' cluster ($p < 0.001$). No difference in FRP was observed between the sensorimotor and psychomotor clusters ($p > 0.05$). Otherwise, the 'mild' cluster had a greater spinal ROM during bending, compared to the sensorimotor and psychomotor clusters ($p < 0.05$), and no difference was observed in spinal ROM between the sensorimotor and psychomotor clusters ($p > 0.05$).

For the sensory variables, the sensorimotor cluster had greater TSP and lower PPT compared to the 'mild' (all variables; $p < 0.05$) and psychomotor clusters (all variables $p < 0.05$, except PPT over the lumbar spine). Otherwise, the sensorimotor cluster had greater pain during movement (flexion task) than both psychomotor and 'mild' clusters ($p < 0.05$), while no difference was observed between psychomotor and 'mild' clusters ($p > 0.05$).

For the psychological variables, the psychomotor cluster had greater kinesiophobia, greater pain catastrophising and lower self-efficacy than both sensorimotor and 'mild' clusters ($p < 0.05$). No difference in psychological factors was observed between 'mild' and sensorimotor clusters ($p < 0.05$).

3.3.2 | Between Cluster Comparison on Clinical Outcomes and Demographics

Table 4 shows the results of ANOVA/Kruskal–Wallis tests for participant demographics and clinical outcomes. Broadly, the clusters did not differ on demographic variables, LBP duration or LBP history ($p > 0.05$). Clusters differed based on self-report disability ($p < 0.001$), with post hoc testing revealing that sensorimotor and psychomotor clusters had greater disability than the 'mild' group ($p < 0.05$); however, no difference in disability

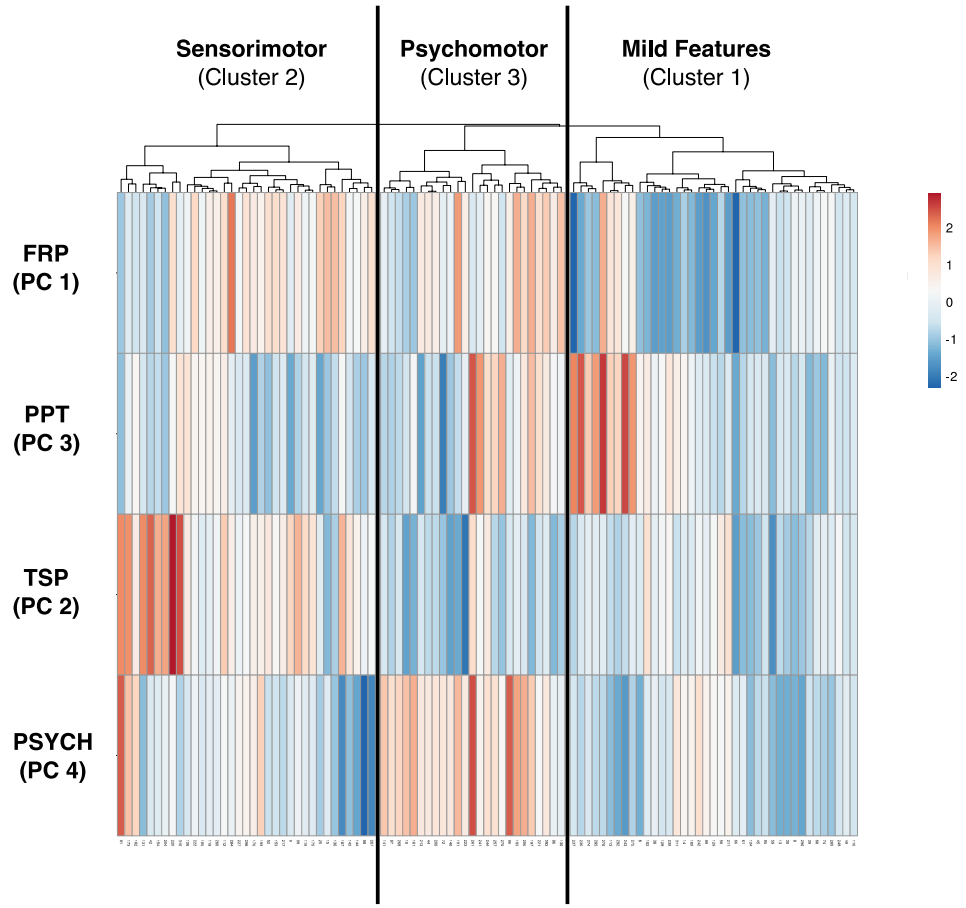

FIGURE 1 | Heatmap showing normalised (*Z*-scores) principal components reflecting FRP (flexion–relaxation phenomenon; i.e., muscle relaxation), pain-pressure thresholds (PPT), temporal summation of pain (TSP) and psychological factors (Psych). Each column represents a participant and each row represents a principal component. Red indicates that the principal component is greater, while blue indicates that the principal component is lower. Note that high PPT represents low sensitivity (high pressure is needed to produce pain). The dendrogram at the top is a result our hierarchical clustering procedure, which clustered participants into 3 groups: Cluster 1 'Low features', cluster 2 'Sensorimotor' and cluster 3 'Psychomotor'. Heatmap was developed using ClustVis (https://biit.cs.ut.ee/clustvis/).

was observed when comparing sensorimotor and psychomotor clusters ($p > 0.05$). In terms of pain, the psychomotor cluster had greater pain than the 'mild' group ($p < 0.05$), but otherwise, pain was similar between the other clusters (all $p > 0.05$) (Figure 2).

4 | Discussion

This work used PCA-based hierarchical linear clustering in an acute LBP cohort, resulting in 3 subgroups that were differentiated by their motor, sensory and psychological characteristics. Our findings extend similar work (Chang et al. 2023, 2024b; Klyne et al. 2018b, 2019) by integrating motor factors into cluster development and support a biopsychosocial view of acute LBP.

4.1 | Cluster Characteristics

The 'mild' cluster likely reflects individuals least impacted by their acute LBP. Their TSP and PPT ratings were aligned with healthy norms (Mailloux et al. 2021; Patricio et al. 2023) and pain catastrophising scores were below clinically meaningful thresholds (Sullivan et al. 2005). They had moderate kinesiophobia (Chimenti et al. 2021) and greater self-efficacy than chronic LBP patients (Lacasse et al. 2015). Motor behaviours, including ROM and muscle relaxation (FRP ratios), were similar to healthy individuals (Gouteron et al. 2022; Laird et al. 2014; Thomas et al. 1998). Clinically, they had minimal disability, moderate pain intensity and low pain during movement.

Relative to the 'mild' group, the sensorimotor and psychomotor clusters appeared more impacted by their acute LBP, as evidenced by moderate disability and pain intensity. Their motor characteristics aligned with data from acute and chronic LBP cohorts (i.e., reduced ROM and paravertebral muscle overactivity) (Demoulin et al. 2013; Gouteron et al. 2022; Grotle et al. 2004) and differed statistically from the 'mild' cluster. The sensorimotor cluster had the highest pain sensitivity (high TSP, low PPT, high pain during movement), similar to chronic LBP profiles (de Oliveira et al. 2023; Patricio et al. 2023), but with lower psychological distress than the psychomotor cluster. The psychomotor cluster exhibited high kinesiophobia (Chimenti et al. 2021), lower self-efficacy and high pain catastrophising scores which exceeded clinically relevant thresholds (Sullivan et al. 2005). Despite elevated psychological distress, their pain sensitivity was similar to the 'mild' cluster and healthy people (Mailloux

TABLE 3 | Mean (SD), Median [IQR] and results of ANOVA/Kruskal–Wallis tests for sensory, motor, psychological and clinical variables, separated by cluster.

	All	Cluster 1 (Mild) $n = 39$	Cluster 2 (Hi SM) $n = 35$	Cluster 3 (Hi PM) $n = 25$	Group effect (p-value)	Post hoc Tukey's HSD/Dunn's test (mean difference (p-value))		
						1 versus 2	1 versus 3	2 versus 3
T12 FRP-flex	0.82 (0.21)	0.69 (0.21)	0.91 (0.19)	0.90 (0.13)	**< 0.001**	**−0.22 (< 0.001)**	**−0.20 (< 0.001)**	0.01 (0.965)
T12 FRP-ext	0.56 (0.24)	0.42 (0.19)	0.62 (0.21)	0.70 (0.25)	**< 0.001**	**−0.20 (< 0.001)**	**−0.28 (< 0.001)**	−0.08 (0.356)
L5 FRP-flex	0.87 (0.26)	0.71 (0.28)	0.97 (0.22)	0.97 (0.18)	**< 0.001**	**−0.26 (< 0.001)**	**−0.26 (< 0.001)**	< 0.01 (0.998)
L5 FRP-ext	0.64 (0.28)	0.46 (0.23)	0.72 (0.26)	0.80 (0.22)	**< 0.001**	**−0.26 (< 0.001)**	**−0.34 (< 0.001)**	−0.08 (0.453)
TSP Lumbar (NRS, /10)	2.23 (1.33)	1.89 (0.96)	3.21 (1.35)	1.37 (0.89)	**< 0.001**	**−1.33 (< 0.001)**	0.52 (0.168)	**1.85 (< 0.001)**
TSP foot (NRS, /10)	2.27 (1.44)	1.73 (1.01)	3.39 (1.46)	1.53 (0.99)	**< 0.001**	**−1.66 (< 0.001)**	0.20 (0.787)	**1.86 (< 0.001)**
PPT Lumbar (kg/cm^2)	4.27 (2.42)	4.81 (2.61)	3.42 (1.72)	4.62 (2.72)	**0.032**	**1.40 (0.034)**	0.20 (0.943)	−1.20 (0.134)
PPT Tibialis anterior (kg/cm^2)	4.95 (2.20)	5.47 (2.80)	3.83 (1.54)	5.56 (2.20)	**0.003**	**1.64 (0.007)**	−0.10 (0.985)	**−1.74 (0.012)**
Kinesiophobia (TSK-11, /44)	36 (7)	33 (5)	36 (7)	42 (5)	**< 0.001**	−3 (0.072)	**−9 (< 0.001)**	**−6 (< 0.001)**
Pain Catastrophising (PCS, /52)	13 [42]	9 (27)	12 (33)	24 (33)	**< 0.001**	−3 (0.277)	**−15 (< 0.001)**	**−12 (< 0.001)**
Self-efficacy (CPSES-6, /10)	8.17 [6.67]	8.67 (5.00)	7.83 (1.96)	6.67 (6.67)	**< 0.001**	0.84 (0.075)	**2.00 (0.001)**	**1.16 (0.037)**
Pain during movement (NRS, /10)	3 [8]	2 [6]	4 [8]	3 [7]	**< 0.001**	**−2 (< 0.001)**	−1 (0.125)	**1 (0.041)**
ROM flexion (FFD, cm)	10 [12]	6 [32]	13 [54]	13 [55]	**0.027**	**−7 (0.018)**	**−7 (0.028)**	0 (0.966)

Abbreviations: CPSES-6, Chronic Pain Self-Efficacy Scale; Ext, Extension from flexed position; FFD, Finger to floor distance; Flex, Forward flexion; FRP, Flexion–Relaxation Phenomenon; Hi PM, High-psychomotor features; Hi SM, High-sensorimotor features; Mild, Mild features; NRS, Numeric Rating Scale; PCS, Pain Catastrophising Scale; PPT, Pressure-Pain Thresholds; ROM, Range of Motion; TSK, Tampa Scale of Kinesiophobia; TSP, Temporal Summation of Pain.

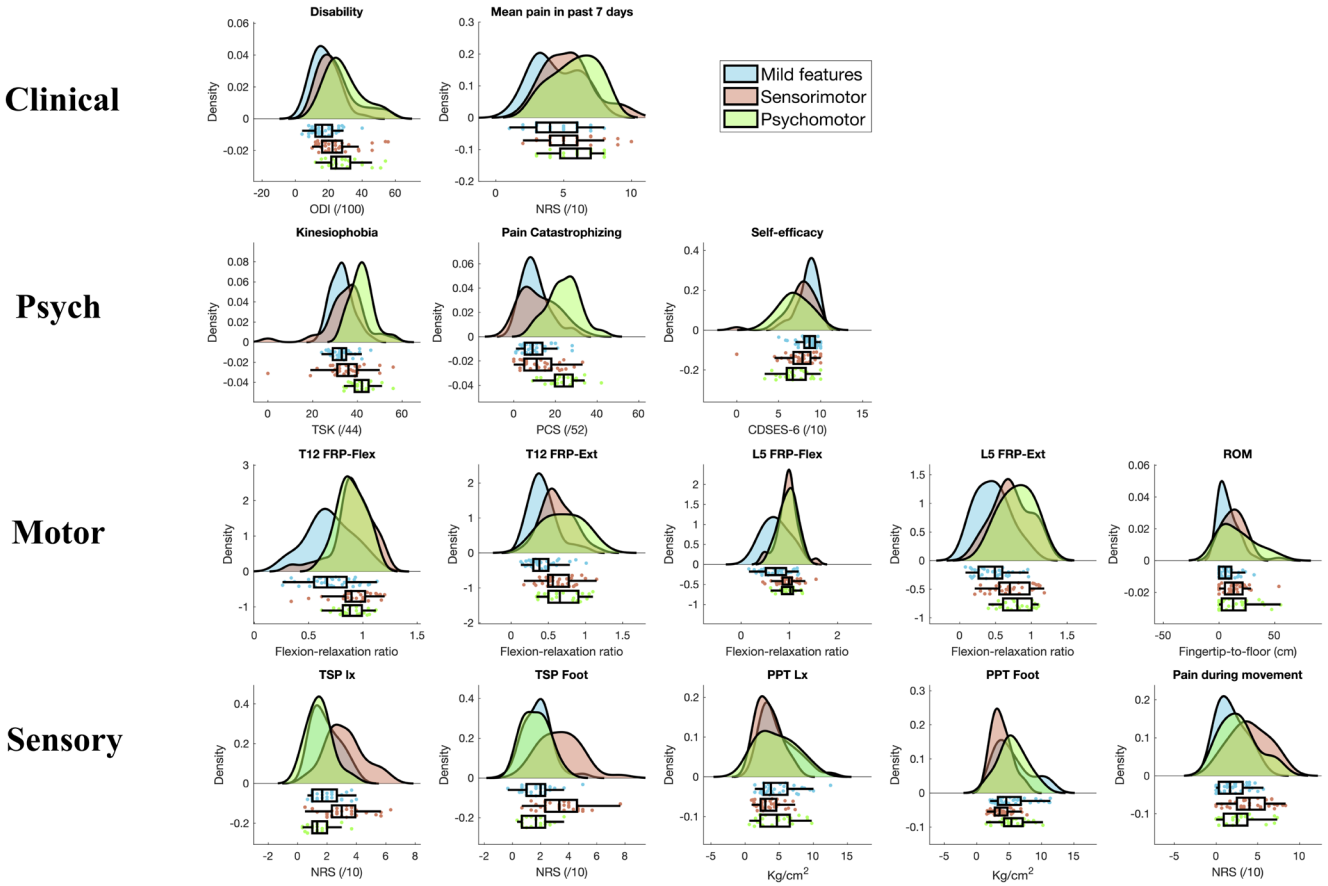

FIGURE 2 | Raincloud plots by cluster for clinical, sensory, psychological and motor variables in an acute low-back pain cohort. Individual plots depict Kernel Density Estimates (*y*-axis) and variable scale (*x*-axis). Mild features (blue), Sensorimotor (red) and Psychomotor (green) clusters are presented. Box plots show raw data, with vertical line denoting median value. Raincloud was developed using the following resource (Allen et al. 2019). CPSES-6, Chronic Pain Self-Efficacy Scale; FRP, Flexion–Relaxation Phenomenon; kPa, Kilopascals; Lx, Lumbar; NRS, Numeric Rating Scale; ODI, Oswestry Disability Index; PCS, Pain Catastrophising Scale; PPT, Pressure-Pain Threshold; ROM, Range of Motion; TSK, Tampa Scale of Kinesiophobia; TSP, Temporal Summation of Pain.

et al. 2021; Patricio et al. 2023), suggesting that these constructs are not always related in acute LBP. Table 5 represents a qualitative description of the clusters.

4.2 | Cluster Differences in Motor Characteristics

Elevated muscle activity in the psychomotor and sensorimotor clusters may reflect different underlying mechanisms. We suggest that in acute LBP, motor adaptations can arise from peripheral nociception (Hodges and Danneels 2019) and/or psychological factors (Van Dieën et al. 2017). While studies testing motor adaptations in acute LBP are limited, FRP and ROM deficits are common in chronic LBP and are associated with disability, pain and psychological factors (Alschuler et al. 2009; Ippersiel et al. 2022; Nzamba et al. 2024). For the psychomotor cluster, fear and pain catastrophising may reflect an elevated real or perceived threat of bending, eliciting paravertebral muscle overactivity as a guarding mechanism and limit movement (Van Dieën et al. 2017). Interestingly, despite similar ROM and FRP, the psychomotor group experienced less pain during bending than the sensorimotor cluster. This could suggest that the psychomotor group is intentionally avoiding end-range flexion, with these behaviours (reduced ROM and muscle relaxation) potentially driven (in-part) by fear and pain catastrophising (Geisser et al. 2004).

In the sensorimotor cluster, motor adaptations may stem from different mechanisms. Specifically, they showed no elevated psychological scores but reported the highest pain during flexion. We speculate that this subgroup may have high-nociceptive activity, a notion corroborated by their high-pain sensitisation (during movement and via QST) relative to the other clusters. Thus, the restricted bending ROM may be an adaptive mechanism to limit further provocative movements (Hodges and Smeets 2015; Hodges and Tucker 2011), potentially preventing trunk extensor relaxation (Geisser et al. 2004; Kevin et al. 2024). Unlike the psychomotor subgroup, the sensorimotor cluster may not avoid pain out of fear, but rather because pain and/or nociception may be (in)directly driving the altered motor behaviours (Dubois et al. 2011). This aligns with theories suggesting that pain and fear alter movement in individualised ways to protect the injured/threatened area (Hodges and Smeets 2015; Hodges and Tucker 2011). However, it remains unclear whether these strategies relate to long-term outcomes.

TABLE 4 | Mean (SD), Median [IQR] and results of ANOVA/Kruskal–Wallis tests for clinical outcomes and participant demographics, by cluster.

	All	Cluster 1 (Mild) $n = 39$	Cluster 2 (Hi SM) $n = 35$	Cluster 3 (Hi PM) $n = 25$	Group effect (p-value)	Post hoc Tukey's HSD/Dunn's test		
						1 versus 2	1 versus 3	2 versus 3
Age (years)	36 (13)	35 (12)	37 (13)	38 (14)	0.538			
Sex (females)	61 (62%)	20 (51%)	25 (71%)	16 (64%)	0.197			
Height (m)	1.70 (0.09)	1.71 (0.09)	1.70 (0.09)	1.69 (0.08)	0.494			
Weight (kg)	77.67 (17.46)	76.08 (16.53)	76.70 (15.78)	81.66 (21.07)	0.436			
BMI (kg/m^2)	26.68 (5.12)	25.76 (4.68)	26.49 (4.41)	28.44 (6.41)	0.124			
Duration of the current episode (days)	25 (12)	28 (12)	26 (11)	21 (12)	0.084			
History of LBP (yes)	63 (64%)	24 (62%)	19 (54%)	20 (80%)	0.117			
Mean pain in past 7 days (NRS, /10)	5 [2]	4 [3]	5 [2]	6 [3]	**0.008**	−1 (0.053)	**−2 (0.003)**	−1 (0.218)
Disability (ODI, /100)	23 (11)	18 (7)	25 (12)	29 (11)	**< 0.001**	**−7 (0.008)**	**−11 (< 0.001)**	−4 (0.085)

Abbreviations: Hi PM, High-psychomotor features; Hi SM, High-sensorimotor features; LBP, Low-back pain; Mild, Mild features; NRS, Numeric rating scale; ODI, Oswestry disability index.

4.3 | Cluster Differences in Pain Sensitivity

Our findings of distinct pain sensitivity profiles align with studies identifying 'high' and 'low' sensitivity subgroups in acute LBP (Chang et al. 2023; Klyne et al. 2018b, 2019). Others identified high/low-sensitivity subgroups in chronic LBP, but also identified a third 'in-between' subgroup (Rabey et al. 2015). Like these studies, pain intensity in our cohort was unrelated to pain sensitivity; however, disability differed across clusters in our cohort. This may stem from our use of TSP, which reflects the wind-up phenomenon in dorsal horn neurons (Harte et al. 2018), while others used measures related to inhibitory pain mechanisms or thermal stimuli, which complicates comparisons (Schuttert et al. 2021). Cluster differences in pain sensitivity likely reflect peripheral and central sensitisation mechanisms. Acute injury typically triggers inflammation (e.g., cytokines), increasing nociceptor sensitivity and driving primary hyperalgesia (Latremoliere and Woolf 2009). High TSP and low PPT at lumbar sites in the sensorimotor group suggest this process, while lower pain sensitivity in the other clusters could suggest a resolving inflammatory process (e.g., less severe tissue injury), as nociceptive thresholds are nearing pre-injury levels. The sensorimotor cluster was also the sole group to show features of central sensitisation (via high TSP and low PPT values at remote sites), consistent with previous acute LBP research (Chang et al. 2023; Klyne et al. 2019). Central sensitisation reflects pain arising from altered function of pain-related sensory pathways both in the periphery and centrally and is characterised by widespread pain and hypersensitivity (Fitzcharles et al. 2021). This higher sensitivity might also be driven by individual factors like poor sleep, greater alcohol consumption and biological sex—71% of the sensorimotor cluster were female—which could contribute to pre-existing elevated sensitivity (Chesterton et al. 2003; Klyne et al. 2018b). The contribution of features of central sensitisation in acute LBP remains unclear (Curatolo 2023).

4.4 | Cluster Differences in Psychological Characteristics

The psychomotor cluster showed high-psychological distress, characterised by elevated pain catastrophising, kinesiophobia and low-self-efficacy, aligning with acute LBP studies (Chang et al. 2024b; Klyne et al. 2019). Chronic LBP research also identified a group characterised by 'high' psychological factors, although affective scores (stress, anxiety, depression) added further granularity (Rabey et al. 2016). Regardless, mean kinesiophobia (42/44) and pain catastrophising (24/52) scores in the psychomotor cluster indicate clinically important psychological distress, particularly given the predictive capacity of fear and pain catastrophising for long-term disability (Wertli et al. 2014a, 2014b). This group was more disabled than the 'mild' group, though not statistically different from the sensorimotor group, highlighting the importance of psychological factors in disability. Despite greater pain intensity than the 'mild' group, the psychomotor group did not differ from the sensorimotor group, challenging the idea that psychological factors influence pain severity more than pain sensitivity does (Quartana et al. 2009; Tagliaferri et al. 2022). These relationships may develop over time and be more evident in chronic pain. Regardless, this group had more pain than the 'mild' group, possibly via psychological

TABLE 5 | Qualitative description of clusters based on PCA on motor, sensory, psychological and clinical variables.

		Cluster 1 (Mild)		Cluster 2 (Sensorimotor)		Cluster 3 (Psychomotor)	
Motor	Muscle relaxation	+		−		−	
	Spine ROM	+		−		−	
Sensory	TSP	+		−		+	
	PPT	+		−		+	
Psychological	Kinesiophobia	+		+		−	
	Catastrophising	+		+		−	
	Self-efficacy	+		+		−	
Clinical	Pain during movement	+/−		−		−	
	Pain	+/−		−		−	
	Disability	+		+/−		+/−	

Note: For each individual variable, (+) indicates favourable score (i.e., similar to normative score in pain-free individuals), (−) indicates unfavourable score (i.e., significantly different from favourable score), (+/−) indicates moderately unfavourable score. Colours represent overall assessment for motor, sensory, psychological and clinical features. Negative scores for all variables within a domain (Motor, Sensory, Psychological) were identified as red; positive scores for all variables within a domain was considered green. For the clinical domain, yellow is considered as the cluster with lowest acute LBP impact, and red the highest LBP impact.
Abbreviations: PPT, Pressure-Pain Threshold; ROM, Range of Motion; TSP, Temporal Summation of Pain.

factors influencing pain via central nervous system regions involved with pain perception, emotional responses to pain or attention to pain (Linton and Shaw 2011; Quartana et al. 2009).

4.5 | Clinical Implications

Cluster characteristics may enhance stratified care for acute LBP. A meta-analysis reported very low-certainty evidence that stratified care has a small effect on pain reduction at 3 and 6 months, with no impact on disability (Chiodo and Haley 2024). Since stratified pathways are typically based on psychosocial factors (Delitto et al. 2021), our data could refine these approaches by considering pain sensitivity and motor behaviours. For instance, the 'mild' group might be similar to 'low-risk' individuals who simply require reassurance/education (Hill et al. 2011). If the sensorimotor cluster is indeed predominantly nociception-driven, they may need to 'respect their pain' and exercise appropriately to progressively re-load injured structures, stimulating tissue repair and reducing sensitisation (Khan and Scott 2009). Last, the psychomotor group may require a cognitive-behavioural based approach (Delitto et al. 2019, 2021). Sensorimotor and psychomotor groups may also benefit from interventions targeting motor impairments, as movement quality is important (Chang et al. 2024a; Wernli et al. 2020); however, depending on underlying mechanisms (nociceptive vs. cognitive) different interventions may be warranted (e.g., impairment-based (Alrwaily et al. 2016) versus behavioural experiments (O'Sullivan et al. 2018)). Validation of these subgroups and their long-term outcomes is required.

4.6 | Limitations

This work has limitations. First, there is considerable variability in QST protocols; thus, using additional measures (e.g., conditioned pain modulation) may have added further granularity to our subgroups and improved comparability with similar work. QST also relies on self-reporting of symptoms and is subject to motivational, cognitive and attentional biases (Attal et al. 2013); thus, this may have also influenced our results. Further, the cross-sectional design limits our ability to comment on longitudinal outcomes or establish causal relationships; thus, the clinical implications should be considered carefully. Additionally, our participant numbers were somewhat limited for hierarchical linear clustering analyses, which may have affected the reliability and results of our analyses. A small sample size may underrepresent the full variability of the population, leading to conclusions that are more specific to our data. Further, our use of a mixed-sex cohort limits our ability to uncover sex-specific effects. Considering sex may act as a confounding variable, future work might utilise a larger sample size and plan for sex-specific analyses (e.g., stratification) or statistically control for sex in the analyses to account for this shortcoming.

5 | Conclusion

This study provides evidence of distinct acute LBP subgroups characterised by motor, sensory and psychological features. Future work should determine if these subgroups are differentially related to short- and long-term pain and disability.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.