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Motor adaptations during stair ascent and descent in individuals with chronic primary low back pain

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ABSTRACT

Altered neuromuscular strategies, such as lumbar muscle activity spatial redistribution, have been observed in individuals with chronic primary low back pain (CLBP), particularly during intense isometric efforts, but not during low-effort functional tasks. This cross-sectional study aimed to determine whether lumbar muscle activity distribution and trunk kinematics differ between individuals with CLBP and healthy controls during a dynamic, moderate-effort task, namely stair ascent and descent, and to investigate the relationship between muscle activity distribution and psychological factors of CLBP. Forty adults (20 CLBP, 20 controls) completed stair ambulation trials while lumbar high-density surface electromyography and kinematic data were recorded. Spatial redistribution and RMS amplitudes of electromyography were analyzed during ascent and descent, and across swing and stance phases. Participants with CLBP exhibited spatial redistribution of muscle activity on the left side during both phases of ascent, and during the swing phase of descent. Higher RMS amplitudes were observed bilaterally in CLBP participants across all tasks and phases, except during the stance phase of descent. No kinematic differences were found between groups. No relationship was found between muscle redistribution activity and psychological factors. These results suggest that CLBP participants exhibit altered neuromuscular strategies during stair ambulation, a moderately challenging functional task.

1. Introduction

Low back pain (LBP) is the leading cause of disability worldwide for all ages and genders (Alperovitch-Najenson et al., 2023). Chronic primary low back pain (CLBP) is one of the most prevalent type of low back pain and is characterized by pain whose precise cause cannot be determined (Ferreira et al., 2023; Hartvigsen et al., 2018; Knezevic et al., 2021). This condition can alter functional capacities while performing daily activities such as walking and stair climbing, thereby reducing the quality of life of the affected individuals (Hartvigsen et al., 2018).

Given the substantial impact of CLBP, a comprehensive understanding of underlying pain-adaptation mechanisms is crucial. Neuromuscular strategies are observed in the presence of pain, which may protect sensitive tissue. While this appears to be true in acute LBP, theoretical models of pain-related motor control suggest that when pain becomes chronic, these strategies may become maladaptive (Alperovitch-Najenson et al., 2023; Hodges and Tucker, 2011; Knezevic et al., 2021). For instance, redistribution of lumbar muscle activity in individuals with CLBP has been reported during demanding tasks involving sustained isometric trunk extension or functional lifting tasks (Abboud et al., 2014; Arvanitidis et al., 2022, 2021; Falla et al., 2014; Martinez-Valdes et al., 2019; Sanderson et al., 2024). These adaptations may represent protective or compensatory adjustments that modulate the contraction of lumbar muscles, potentially redistributing mechanical loading to reduce nociceptive input. Conversely, during less challenging tasks, such as maintaining a seated posture, no differences in muscle activity redistribution have been observed between CLBP and healthy individuals (Ringheim et al., 2019). Similar findings have been reported in dynamic tasks, such as walking, where no significant redistribution of

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muscle activity has been observed (Serafino et al., 2021). However, an increase in the activation of the erector spinae muscles has been observed in individuals with CLBP during walking (Arendt-Nielsen et al., 1996; Lamoth et al., 2004; Smith et al., 2022), and this increase becomes more pronounced as walking speed increases (van der Hulst et al., 2010). These observations suggest motor tasks eliciting higher activation of back muscles (e.g. walking at higher speed, load lifting) may be required to fully capture neuromuscular adaptations in CLBP individuals (Abu Bakar et al., 2023; Smith et al., 2022).

Stair climbing involves higher physical demands compared to other locomotion tasks. Specifically, increased joint amplitude, range of motion at the hips, knees, ankles, and trunk in the sagittal plane have been observed during stair ascent and descent compared to walking (Bible et al., 2010; Schulte et al., 2023a). These increases in joint angles range of motion are even more pronounced at the ankle and knee joints during stair descent (Schulte et al., 2023a). Despite the importance of stair ambulation and the increases in physical demands that could negatively impact individuals with CLBP, this task has received limited attention in CLBP research. To date, only a few studies assessed adaptations in muscle activity using bipolar electromyography (EMG) (Becker et al., 2018; Lima et al., 2018), both reporting an increase in lumbar muscle activation during stair ascent in CLBP individuals. Results from another study found an increased pelvic range of motion in the frontal plane during stair descent in individuals with CLBP (Namnik et al., 2019). Nonetheless, the use of high-density surface EMG (HDsEMG) capable of identifying change in the redistribution of muscle activity within and between-muscles has not been used in this task. This precludes the understanding of the neuromuscular adaptations (i.e. muscle activity redistribution) in individuals with CLBP.

Psychological factors may also contribute to altered neuromuscular control in CLBP, as suggested by the motor adaptation to pain theory (Hodges and Tucker, 2011). For example, pain-related fear has been associated with alterations in the redistribution of erector spinae muscle activity (Liechti et al., 2022), while high level of pain catastrophizing have been correlated with increase muscle activation amplitude (Pakzad et al., 2016). Assessing the relationships between regional activation within the lumbar muscles during functional and demanding tasks and clinically relevant domains is necessary to determine whether psychosocial and clinical factors are associated with altered neuromuscular control in individuals with CLBP.

Therefore, the primary aim of this study is to determine whether redistribution of lumbar muscle activity, trunk and pelvis kinematics during stair ascent and descent tasks differ between individuals with CLBP and healthy controls. The secondary aim is to evaluate the relationship between changes in redistribution muscle activity and clinical and psychological factors of CLBP. We hypothesized that CLBP group would exhibit both an increased overall lumbar muscle activity and a redistribution of lumbar muscle activity when compared to healthy controls during stair ascent and descent. This redistribution of muscle activation would further support the pain adaptation model, suggesting that stair ascent and descent provoke specific neuromuscular adaptations that contribute to these changes in activation patterns. Additionally, we anticipate a moderate correlation between muscle activity and psychosocial factors.

2. Methodology

2.1. Participants

Forty adult participants were recruited, including 20 individuals without CLBP (control group) and 20 participants with CLBP. Participants in the control group were included if they had not experienced any episodes of CLBP six months prior to the study onset and were aged between 18 and 65 years. We set the upper age limit at 65 years because elder people show neuromuscular changes, including alterations in muscle activity spatial distribution (Parrella et al., 2025). For participants with CLBP, the inclusion criteria required the presence of LBP located between the lower ribs and the gluteal folds for at least three months, with or without radiating pain to the lower limbs and aged between 18 and 65 years. Exclusion criteria for both groups included a history of spinal surgery, cancer, spinal fractures, spinal metastases, current pregnancy, or clinical signs of lumbar radiculopathy. Participants were recruited through social media advertisements and word of mouth. Most participants were recruited from the local community. Data collection took place between July 2023 and December 2024. No previous study has used centroid variables to investigate neuromuscular differences between individuals with CLBP and healthy controls during stair gait. Therefore, we selected a convenience sample of 20 participants per group. This sample size is consistent with an a priori power analysis conducted using G*Power (version 3.1.9.7), based on an independent *t*-test performed on centroid variables during a lifting task (Sanderson et al., 2024). Assuming a large effect size (Cohen's $d = 0.8$), a statistical power (1–β) of 0.80, and an alpha level of 0.05, the analysis indicated that 21 participants per group were required during a lifting task. Given that our primary variables of interest demonstrated significant between-group differences, we are confident that our study was adequately powered to address our objectives.

The project received approval from the Research Ethics Board for human research of the Université du Québec à Trois-Rivières (CER-23–300-07–03). All participants provided written informed consent. The study was conducted following the principles of the Declaration of Helsinki (World Medical Association, 2013). This cross-sectional study was designed and reported in accordance with the relevant recommendations of the STROBE guidelines, as applicable to our experimental protocol.

2.2. Preliminary participants' assessment

At the beginning of the experiment, all participants completed a series of French-validated questionnaires, including Oswestry Disability Index (ODI) (Denis and Fortin, 2012), Pain catastrophizing scale (PCS) (French et al., 2005), State and Trait anxiety (Stai_Y_anxiety) (Gauthier and Bouchard, 1993), Chronic Pain Self-efficacy scale (Lacasse et al., 2015), and Activity and Sedentary Behavior (Charles et al., 2021). Additionally, participants were asked to rate their current pain intensity on a 0–10 numerical rating scale. Next, participants were positioned in prone position on a 45-degree Roman chair to assess trunk extension maximal strength. In this position, they were asked to perform three trials during which they exerted their maximal force for five seconds against a strap placed on their shoulder connected to a force gauge (Model LSB350; Futek Advanced Sensor Technology Inc., Irvine, CA, USA) (Biviá-Roig et al., 2019; Dankaerts et al., 2004). Subsequently, participants performed one submaximal force in a standing position while bending their trunk at 45-degrees of flexion, controlled using an inclinometer placed at the L3 vertebra (Johnson, Level & Tool Mfg. Co., Inc, Magnetic Digital Angle Locator 2 Button, Model 1886–0000, Mequin WIS, USA). In this position, they held a 10 kg weight close to their chest for five seconds. Erector spinae muscle activation was measured for both maximal and sub-maximal strength assessment. This procedure was performed to obtain a Maximum Voluntary Contraction (MVC) reference value, which is essential for EMG amplitude normalization. Normalization allow EMG data to be expressed as a percentage of each muscle's maximum activation capacity and enabling comparisons between groups. The submaximal trial was included because the maximal contraction might not be achieved in individuals with CLBP. Therefore, a submaximal condition provides an alternative to MVC normalization methods if performance of maximum contraction is not possible (Besomi et al., 2020).

2.3. Stair ascent and descent protocol

Participants were asked to walk up and down a four-step staircase 20 times at a self-selected pace. To familiarize themselves with the protocol, they first performed 10 familiarization trials at a comfortable speed. This was followed by 10 recorded trials under standardized instructions. Participants stood in front of the stairs for five seconds (quiet standing 1) before initiating the ascent with their preferred leg and alternating feet while climbing. Upon reaching the top platform, they paused for five seconds (quiet standing 2), turned around, waited another five seconds (quiet standing 3), and then descended the stairs using their preferred leg. At the floor level, they paused for a final five seconds (quiet standing 4). A researcher counted each quiet standing period aloud using a stopwatch to ensure consistent timing but allowed participants to ascend and descend at a comfortable, self-selected pace. A five-minute rest period was provided before repeating the full sequence.

2.4. Data collection

2.4.1. HDsEMG

Muscle activity of the left and right lumbar erector spinae was measured using wireless HDsEMG, two grids of 64 electrodes each (Sessantaquattro + 8X8, 10 mm interelectrode spacing, 8 mm electrode diameter model HD10MM0808, OTBioelettronica, Torino, Italy). The electrode grids were positioned over the lumbar erector spinae muscles, centered at the L3 vertebral level and located approximately 1 cm lateral on each side of the lumbar spinous processes. The ground electrodes were placed over the T10 and T8 vertebrae. Prior to grid placement, the skin over the lumbar region was shaved, cleaned using fine-grade sandpaper (Red DotTrace Prep; 3 M, St. Paul, MN), and prepared with rubbing alcohol (ethyl alcohol 70 %). Signals from the HDsEMG were sampled at 2000 Hz and digitized using a 24-bit A/D converter.

2.4.2. Kinematic and Kinetic

Throughout the entire protocol, kinematic data were recorded at a sampling frequency of 200 Hz using a three-dimensional motion analysis system equipped with 12 cameras (OptiTrack; NaturalPoint, Corvallis, OR, USA). Forty-three passive reflective markers were placed on specific anatomical landmarks across each participant's body (trunk, pelvis, lower limbs) following the Rizzoli marker-set model (Leardini et al., 2011). Two floor-embedded AMTI force plates (OPTIMA BMS464508, Watertown, MA, USA), positioned beneath the instrumented staircase to cover all four steps, were used to record ground reaction forces at a sampling frequency of 1000 Hz.

2.4.3. Signal Processing and Preparation

Kinematic, HDsEMG, and force plate data were synchronized during acquisition using the OptiTrack eSync2 synchronization device (eSync2, NaturalPoint, Inc., DBA OptiTrack) integrated within the Motive software (version 3.0.0; NaturalPoint, Corvallis, OR, USA). Kinetic data were solely used to accurately segment the different phases of stair ascent and descent. Kinematic and HDsEMG data were segmented according to specific phases of stair ascent and descent: the swing phase and the stance phase (McFadyen and Winter, 1988). The swing phase was defined as the period during which the analyzed foot completely

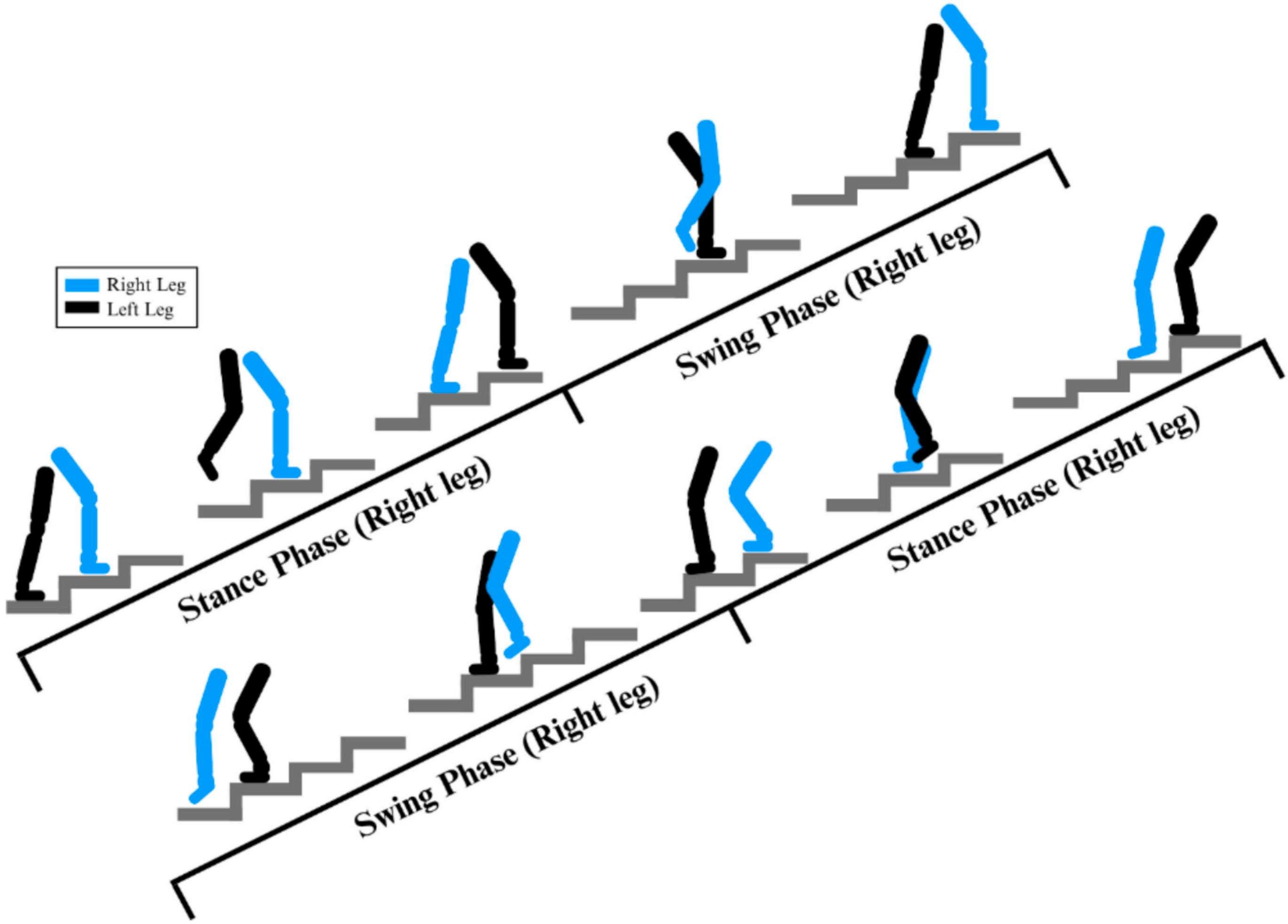

Fig. 1. Illustration of stair ascent and descent during swing and stance phase (Right Leg = Blue; Left Leg = Black). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

leaves the step and moves through the air until it contacts the forward step. This phase begins when the participant's toes lift off the rear step and ends at the first contact of the heel with the forward step. The stance phase is delimited by (i) both feet are simultaneously in contact with the stairs (i.e. with the stance leg positioned on the forward step and the swing leg on the rear step) and (ii) both feet are back simultaneously on the stair (i.e. the swing leg is now on the forward step and the stance leg on the same step [now the rear step]) (Fig. 1).

2.4.4. HDsEMG

Signals were processed and analyzed using MATLAB software (version 2024b; The MathWorks, Natick, MA). HDsEMG signals underwent digital band-pass filtering using a fourth-order Butterworth filter with cutoff frequencies set at 20–400 Hz. Additionally, second-order Butterworth notch filters were implemented to reduce interference originating from the 60 Hz power line frequency and its harmonic frequencies. HDsEMG data were analyzed separately for the left and right sides. A visual assessment of both raw EMG signals and their fast Fourier transform (FFT) spectra was also conducted to detect electrodes compromised by poor skin contact, excessive noise, or artifacts. Problematic electrodes were corrected using interpolation by averaging signals from the two neighboring electrodes along the craniocaudal direction (muscle fiber orientation). Electrodes located in the first or last rows without two adjacent electrodes available for interpolation were removed from further analysis to preserve signal integrity. Entire recordings were discarded if more than 10 % of electrodes within a grid demonstrated unstable or poor-quality signals (Gallina et al., 2022). Bipolar HDsEMG signals were obtained by computing the difference between adjacent electrodes arranged along the craniocaudal axis. The final electrode grid consisted of 7 × 8 recording channels. The right-side HDsEMG grid was flipped during analysis to match the left-side orientation, ensuring consistent interpretation of the x-axis coordinate across both sides.

2.4.5. Muscle activity amplitude

HDsEMG signals were normalized to the peak Root Mean Square (RMS) value computed from multiple 1 s windows obtained by segmenting the entire dataset during maximal and submaximal back extension tasks. The highest RMS value among these trials was used for EMG normalization. For our 20 trials the peak RMS values were extracted using windows segmented into successive 1-second intervals, with a 10-ms overlap between each window (Besomi et al., 2020). RMS was calculated for each of the following conditions: swing phase and stance phase during stair ascent and descent, as well as during maximal and submaximal strength tasks. Only the preferred leg was considered in the analysis.

2.4.6. Centroid coordinates of muscle activity

We first calculated the RMS of each of EMG signals within each grid to create a topographical map of EMG amplitude, and then defined the coordinates as previously described to ensure consistent spatial interpretation. Then, to quantify the redistribution of lumbar muscle activity, the centroid coordinates were computed along both the mediolateral (X) and craniocaudal (Y) axes. The centroid was defined as the average position of the channels whose RMS values exceeded 70 % of the highest RMS observed among all channels (Gallina et al., 2022). Centroid coordinates were computed separately for the left and right sides for each of the following conditions: swing and stance phases during stair ascent and descent.

2.4.7. Kinematics

To process the kinematic data and force plate data, Visual 3D software (v6.01.36, C-motion, Inc., Germantown, MD, USA) was used. Local coordinate systems of the trunk and pelvis were defined, and joint angles were expressed as Cardan angles for all planes flexion (x), abduction (y), and rotation (z). The angle between the thorax and pelvis segments defined the trunk kinematics. The angle between the pelvis and a Cardan angle virtual lab segment defined the pelvis kinematics. Kinematic data during the stance phase swing were time normalized on 101 points for visual and statistical comparisons (0–100 % of the task) looking at the preferred leg.

2.5. Statistical analyses

The normality of HDsEMG data was evaluated through the Shapiro-Wilk test, which informed the selection of either parametric or non-parametric statistical tests. Participant characteristics including age, gender, weight, height, and body mass index (BMI) were compared between groups using independent students t-tests. The questionnaire results were compiled into a Microsoft Excel file (version 2024). Means were calculated and then compared between groups using Mann–Whitney U tests. Group comparisons of HDsEMG data were conducted using Mann-Whitney U tests. Spearman correlation analyses were conducted between the HDsEMG variables that showed significant group differences (centroid coordinates in X and Y axes and RMS values) and the questionnaire scores. A significance level of $\alpha < 0.050$ was used for all analyses. Statistical analyses were performed using SPSS Statistics version 29 (SPSS Inc., IBM Corp., Armonk, NY, USA).

Statistical parametric mapping (SPM) was used to compare kinematic data across groups over the entire movement cycle, allowing the identification of significant differences at any time point rather than at discrete instances. The kinematic data were first assessed for normality using the spm1d.stats.normality.ttest2 function. For normally distributed data, independent t-tests (SPM(t)) were applied. For data that did not meet normality assumptions, one-dimensional statistical nonparametric mapping (SnPM(t)) was used (Pataky, 2010). The temporal smoothness of SPM(t) was estimated based on its average temporal gradient, and thresholds for significance were calculated using random field theory to ensure that $\alpha \leq 0.050$. All analyses were implemented in MATLAB R2024b (The Mathworks Inc., Boston, MA, USA) using open-access scripts (www.spm1d.org).

3. Results

Demographic characteristics are presented in Table 1. Both groups did not significantly differ in any demographic variable. Results from the questionnaires are presented in Table 2, which overall showed that individuals with CLBP reported significantly higher levels of pain catastrophizing and disability, while no significant differences were observed in anxiety levels or self-efficacy.

3.1. HDsEMG

3.1.1. Redistribution of the centroid (mediolateral coordinates)

During the swing phase, mediolateral displacement (x-axis) of muscle activity was found on the left side during both ascent ($p = 0.003$) and ($p = 0.040$) descent tasks. Specifically, individuals with CLBP showed a

Table 1
Participants' demographic characteristics.

Variable	LBP Group (n = 20) (mean ± SD)	Non-LBP Group (n = 20) (mean ± SD)	p-Value
Age (years)	46.2 ± 12.8	45.4 ± 16.2	p = 0.84
Sex	8 Male / 12 Female	8 Male / 12 Female	p = 0.39
Height (cm)	170.0 ± 9.0	169.2 ± 9.8	p = 0.98
Weight (kg)	80.6 ± 16.7	74.7 ± 16.1	p = 0.42
BMI (kg/m^2)	27.7 ± 4.8	25.9 ± 4.4	p = 0.51

Table 2
Questionnaires score for both groups.

Variable	LBP group (n = 20) (mean ± SD)	Control group (n = 20) (mean ± SD)	p-Value
Total physical activity (MET-mins)	1182.5 ± 1009.5	1005.31 ± 672.1	p = 0.69
PCS (/52)	14.8 ± 11.9	6.75 ± 5.9	**p = 0.019**
Stai_Y_anxiety_A (/80)	41.8 ± 15.1	46.56 ± 4.2	p = 0.64
Stai_Y_anxiety_B (/80)	49.6 ± 9.9	46.44 ± 3.5	p = 0.46
Oswestry (/100)	8.6 ± 7.0	0.69 ± 1.2	**p < 0.001**
Self-Efficacy score (/330)	265.7 ± 47.7	277.38 ± 51.9	p = 0.40
Pain intensity (/10)	2.52 ± 2.22	N/A	

more medially located centroid (closer to the spine) compared to controls. No difference was observed on the right side during the swing phase, either in ascent or descent tasks (p = 0.620 and p = 0.383, respectively). During the stance phase, the centroid was more medially located on the left side during ascent (p = 0.026) in CLBP participants compared to controls. This pattern was not observed on the right side during either ascent or descent tasks (p = 0.620 and p = 0.640, Table 3).

3.1.2. Redistribution of the centroid (craniocaudal coordinates)

During the swing phase, a significant difference was found on the left side during ascent (p = 0.020), with individuals with CLBP showing a more cranially (y-axis) located centroid compared to controls. No significant difference was observed on the left side during descent (p = 0.265). On the right side, no significant differences were found for either ascent or descent during the swing phase (p = 0.678 and p = 0.718, respectively). During the stance phase, a significant difference was observed on the left side during ascent (p = 0.017), characterized by a more cranial centroid location in the CLBP group. No difference was found during descent (p = 0.127). On the right side, no difference was found between groups during either ascent or descent (p = 0.602 for both; Table 3).

3.1.3. Muscle amplitude activation (RMS)

RMS normalization using maximal and submaximal contractions yielded comparable results, with no significant differences between methods. Therefore, only EMG results normalized using maximal contractions are presented. During the swing phase, significant between-group differences were observed. On the left side, individuals with CLBP exhibited higher RMS values compared to controls during both ascent (p = 0.002) and descent (p = 0.024) tasks. On the right side, RMS was also significantly higher in the CLBP group for both ascent (p = 0.010) and descent (p = 0.040) tasks. During the stance phase, the left side showed a significantly higher RMS in the CLBP group during ascent (p = 0.021), while no significant difference was observed during descent (p = 0.056). On the right side, a significant increase in RMS for the CLBP group was observed during ascent (p = 0.004), while no significant difference was found during descent (p = 0.076) (Table 3 and Fig. 2).

3.2. Kinematics

Of the 40 participants, 34 initiated stair ascent with their right leg and six with their left leg. For stair descent, 37 participants used their right leg and three used their left leg as the leading limb. There was no significant difference observed between groups for the kinematic variables related to pelvis and trunk motion across all phases of stair ascent and descent (Fig. 3).

3.3. Correlation between questionnaire scores and HDsEMG variables

Higher ODI scores were associated with higher RMS muscle activation during both swing and stance phases on the left side (swing ascent: ρ = 0.447, p = 0.004; stance ascent: ρ = 0.342, p = 0.031). Pain intensity reported at the beginning of the protocol also showed significant positive correlations with RMS, indicating that higher pain was associated with higher RMS values on left-side during the swing phase of ascent (ρ = 0.506, p = 0.001) and left-side during the stance phase of ascent (ρ = 0.391, p = 0.014). No other correlation was significant between questionnaire and RMS muscle activation. No significant correlation was found between the redistribution of muscle activity (centroid coordinates) and all questionnaires.

Table 3
Mean and SD for each variable of the lumbar extensor muscle on both left and right sides of the trunk.

Condition	Phase	Side	Movement	Mediolateral redistribution magnitude score (X-axis)	Craniocaudal redistribution magnitude score (Y-axis)	Muscle activity amplitude score (RMS)	p-Value (X-axis)	p-Value (Y-axis)	p-Value (RMS)
LBP	Swing Phase	Left	Ascend	4.49 ± 0.29	5.10 ± 0.79	19.70 ± 10.90	**p = 0.003**	**p = 0.020**	**p = 0.002**
			Descend	4.35 ± 0.65	5.14 ± 0.83	16.01 ± 10.66	**p = 0.040**	p = 0.265	**p = 0.024**
		Right	Ascend	4.45 ± 0.45	4.96 ± 0.55	20.03 ± 11.40	p = 0.620	p = 0.678	**p = 0.010**
			Descend	4.33 ± 0.33	4.92 ± 0.69	15.57 ± 9.63	p = 0.383	p = 0.718	**p = 0.040**
	Stance Phase	Left	Ascend	4.60 ± 0.38	5.01 ± 0.82	19.64 ± 13.27	**p = 0.026**	**p = 0.017**	**p = 0.021**
			Descend	4.48 ± 0.46	4.93 ± 0.67	17.72 ± 13.74	p = 0.091	p = 0.127	p = 0.056
		Right	Ascend	4.62 ± 0.71	5.25 ± 0.94	21.91 ± 15.77	p = 0.620	p = 0.602	**p = 0.004**
			Descend	4.46 ± 0.79	5.30 ± 0.96	17.94 ± 13.23	p = 0.640	p = 0.602	p = 0.076
Control	Swing Phase	Left	Ascend	3.93 ± 0.73	5.70 ± 0.84	9.99 ± 5.28			
			Descend	4.14 ± 0.47	5.30 ± 0.65	9.41 ± 7.13			
		Right	Ascend	4.53 ± 0.45	5.01 ± 0.61	11.82 ± 9.15			
			Descend	4.40 ± 0.47	4.97 ± 0.70	10.19 ± 7.74			
	Stance Phase	Left	Ascend	3.98 ± 0.85	5.67 ± 0.87	11.06 ± 5.95			
			Descend	4.21 ± 0.59	5.21 ± 0.64	10.50 ± 7.37			
		Right	Ascend	4.66 ± 0.59	5.24 ± 0.65	11.09 ± 8.75			
			Descend	4.45 ± 0.59	5.08 ± 0.73	11.61 ± 8.33			

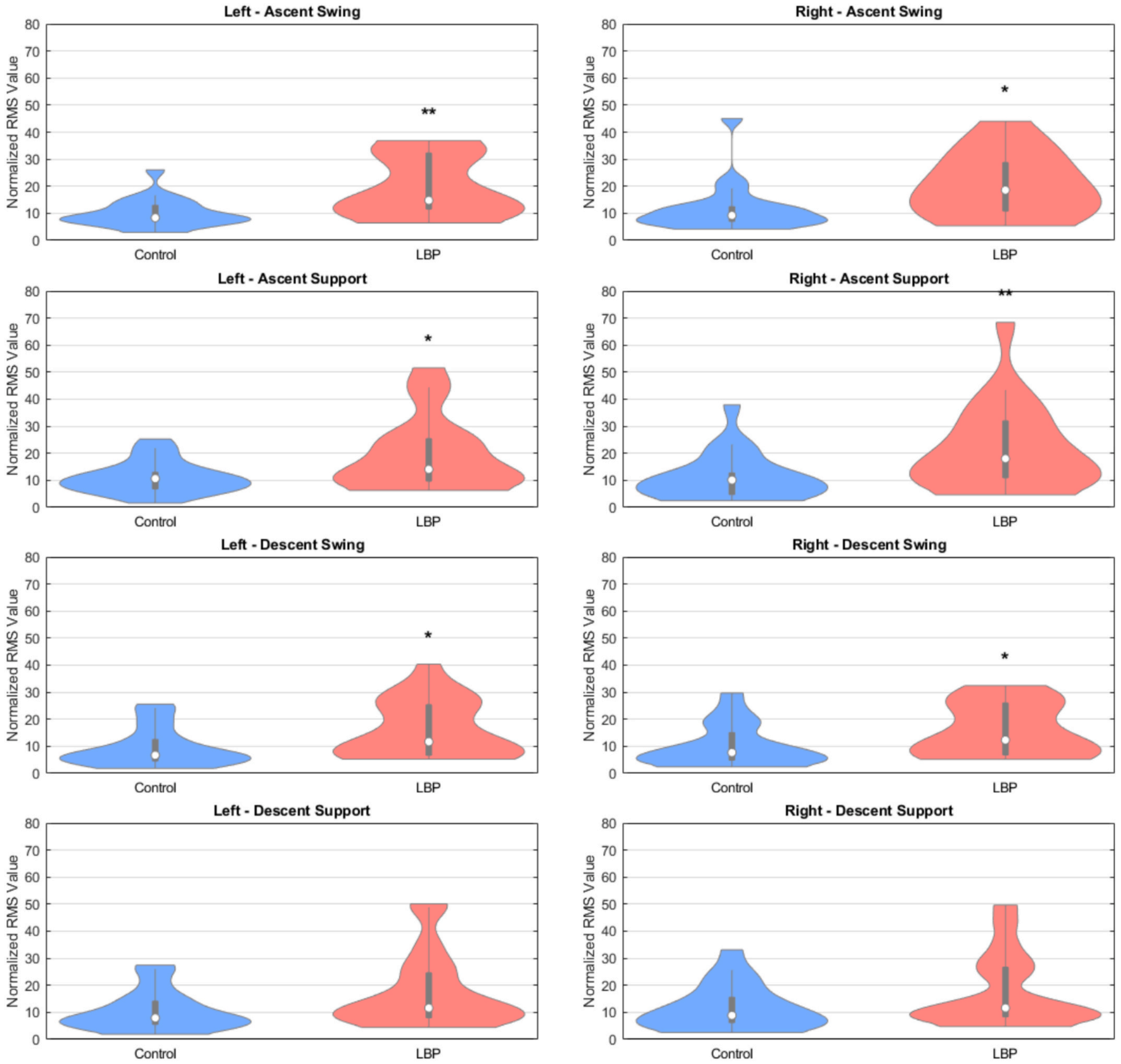

Fig. 2. Normalized RMS value comparisons between participants with chronic low back pain (LBP, in red) and healthy controls (in blue) across multiple stair ascent and descent phases, for Leg 1. Conditions include swing and support phases during both ascent and descent on the left and right legs. Significant differences between groups are indicated by *. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

The primary aim of this study was to determine whether the redistribution of lumbar muscle activity during stair ascent and descent tasks differs between individuals with CLBP and healthy controls. Additionally, a secondary objective was to explore the relationship between changes in redistribution of muscle activity and clinical and psychological factors of CLBP. Our initial hypotheses were partially supported by our results. Our results show that individuals with CLBP displayed a significantly more medial centroid position on the left side during both the swing and stance phases, and a more cranial location during the stance phase of stair ascent. A significant but small positive correlation was found between ODI scores and RMS values on the left side during both the swing and stance phases of stair ascent. Additionally, higher pain intensity was positively correlated with RMS values on the left side during the swing phase of ascent. No association was found between the redistribution of muscle activity and clinical outcomes of LBP.

4.1. *Impact of CLBP on redistribution of muscle activity*

Individuals with CLBP mostly recruited the medial region of the lumbar muscles on the left side for both stair ascent and descent. This suggests a shift in muscle recruitment toward the spine, potentially indicating an increased reliance on medial erector spinae fibers, as a strategy to enhance stability or avoid lateral shear forces (Hodges and Richardson, 1996; Mok et al., 2007). In individuals with CLBP, such forces might exacerbate symptoms or tissue strain, prompting the central nervous system to alter muscle recruitment to enhance segmental

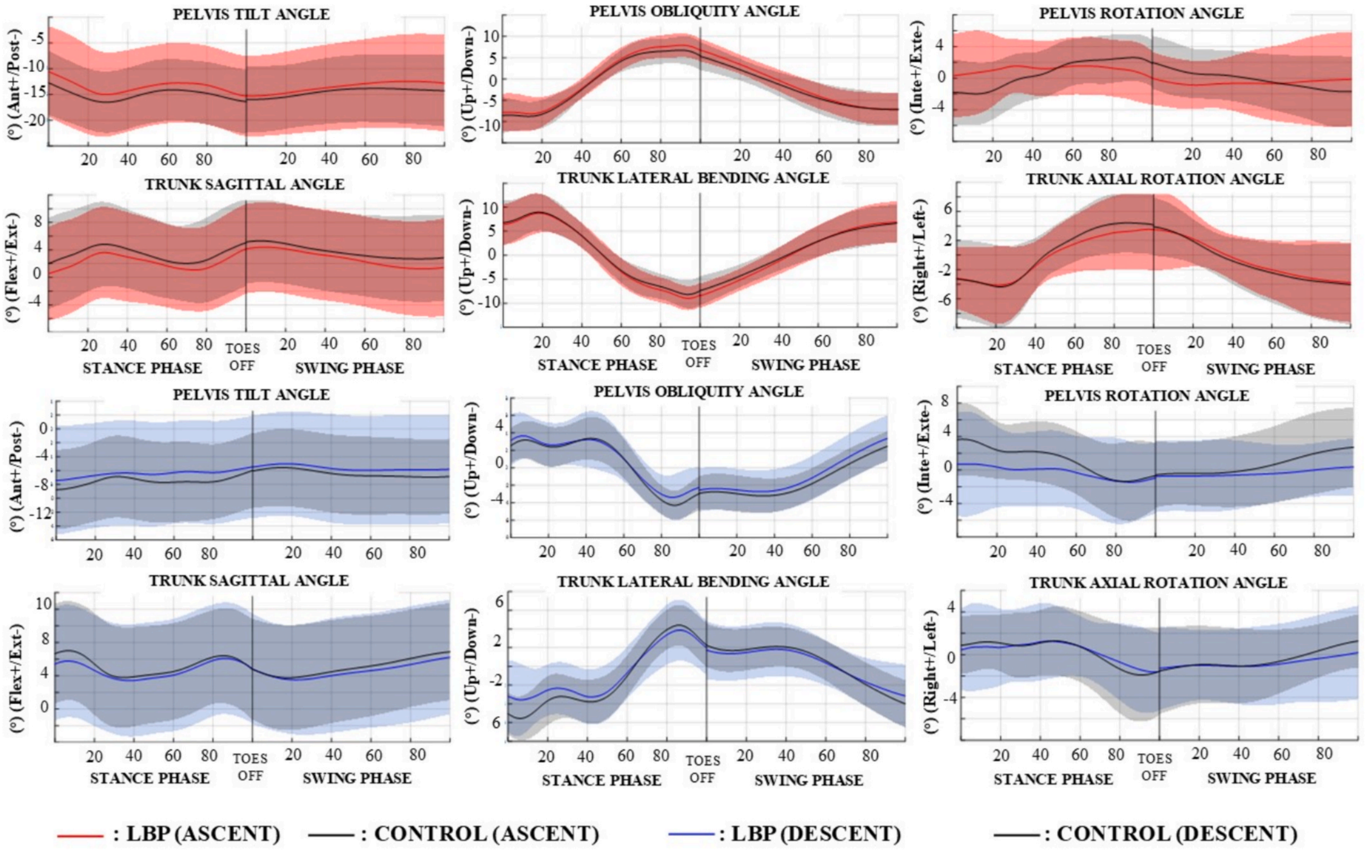

Fig. 3. Kinematic Differences in Trunk and Pelvis Joint Angles During Ascent and Descent: (Red = LBP, Black = Control) (Ascent); (Blue = LBP, Black= Control) (Descent). Data Presented Across the Stance Phase (0 % to Toe-Off) and Swing Phase (Toe-Off to 100 %) in All Three Planes of Motion. Ant = Anterior, Post = Posterior, Flex = Flexion, Ext = Extension, Med = Medial, Lat = Lateral, Inte = Internal, Exte = External. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

stability (Hodges and Tucker, 2011). This pattern was not observed on the right side, suggesting a side-specific adaptation or asymmetry. To our knowledge, there is currently no literature that fully explains the difference between sides on trunk neuromuscular control. It would be valuable for future studies to investigate whether this side-specific adaptation is directly related to the side of pain (Hao et al., 2020; Oddsson and De Luca, 2003).

A more cranial redistribution of muscle activity in individuals with CLBP was observed on the left side of the lower back, during both swing and stance phases of stair ascent, indicating a redistribution of muscle activity toward the upper part of the lumbar muscles. This pattern toward cranial regional activation in individuals with chronic LBP has also been previously reported during high intensity isometric and lifting tasks (Arvanitidis et al., 2022, 2021; Martinez-Valdes et al., 2019; Sanderson et al., 2024). This shift may reflect a compensatory recruitment of higher thoracolumbar regions, potentially due to an inhibited or altered control of the lower lumbar stabilizers such as the deep multifidus (Danneels et al., 2000; Sanderson et al., 2024). These results highlight a consistent left-sided alteration in spatial muscle activation, particularly during stair ascent, a task that requires increased neuromuscular activation (Schulte et al., 2023b). Further research is needed to fully understand the different trunk neuromuscular adaptations between sides in challenging tasks.

4.2. *Impact of CLBP on muscle amplitude*

Individuals with CLBP exhibited a significantly higher amplitude of lumbar muscle activation, compared to healthy controls. This increase was observed bilaterally during the swing phase of both stair ascent and descent, and during the stance phase of ascent. These results are consistent with previous findings suggesting that individuals with CLBP adopt protective or compensatory activation strategies, potentially characterized by overactivation of superficial musculature to enhance trunk stability (Hodges and Moseley, 2003; Lima et al., 2018; van Dieën et al., 2003). Using HDsEMG, the current study allowed to provide further information to previous studies by capturing the whole lumbar region. The use of HDsEMG in the context of low back pain is still emerging, with most studies to date focusing on high intensity (Arvanitidis et al., 2022) or less challenging tasks such as level walking (Serafino et al., 2021). To our knowledge, this study is the first to use HDsEMG during a more dynamic and physically demanding task than walking and a more ecologically valid assessment of lumbar muscle function.

4.3. *Kinematic*

Our study did not reveal any significant differences in trunk or pelvic kinematic variables between groups during stair ascent and descent. This absence of kinematic alterations was unexpected, as previous studies have reported that individuals with CLBP exhibit reduced trunk mobility, greater trunk flexion, or altered lumbopelvic coordination during stair ascent and walking (Errabity et al., 2023; Lee et al., 2015; Seay et al., 2011). Our study builds upon previous work by employing a whole-body kinematic approach, simultaneously analyzing both upper and lower body movements. Moreover, we used SPM analysis to compare continuous kinematic data across the gait cycle. Therefore, SPM enables the assessment of entire kinematic curves, providing a deeper understanding of movement patterns rather than focusing on specific peak values (Pataky, 2010). This suggests that the absence of kinematic differences may reflect a true preservation of joint-level movement strategies during stair ascent and descent in individuals with CLBP, despite the presence of altered neuromuscular activation patterns. Another explanation for our contrasting findings may lie in the similar physical activity levels reported between groups in our study. Higher physical activity has been associated with better neuromuscular control and reduced movement avoidance in individuals with CLBP, potentially mitigating kinematic differences during daily tasks (Geneen et al., 2017; Roren et al., 2023).

5. Limitations

The biopsychological profile of individuals in the current study should be considered for interpreting the neuromuscular findings. Participants with CLBP exhibited low levels of self-reported pain intensity and disability, suggesting that the functional impact of their condition was relatively mild. Despite the presence of persistent pain, these individuals maintained a good level of physical activity, comparable to that of the control group. However, these characteristics indicate that our sample may not represent individuals with more severe CLBP, and therefore the generalizability of our findings to the broader CLBP population is limited. Another consideration is the relatively small sample size (n = 40), which may limit the statistical power and generalizability of the findings. Additionally, no corrections for multiple comparisons were applied, which may increase the risk of Type I errors. This should be considered when interpreting the results.

6. Conclusion

This study highlights that CLBP group exhibits higher medial and cranial lumbar muscle activation patterns during stair ascent and descent. Despite these neuromuscular adaptations, no significant trunk or pelvis kinematic differences were observed, possibly due to high physical activity levels. These findings suggest that muscle activation changes may occur independently of gross movement alterations, emphasizing the need for rehabilitation approaches targeting neuromuscular control rather than solely focusing on movement amplitude. Future interventions could incorporate biofeedback strategies, such as HDsEMG-based feedback, to help patients modulate muscle activation patterns and improve motor control.

CRediT authorship contribution statement

Guillaume Vadez: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Eléna Payen Schalkens:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Rubens A. da Silva:** Writing – review & editing, Conceptualization. **Louis-David Beaulieu:** Writing – review & editing, Conceptualization. **Hugo Massé-Alarie:** Writing – review & editing, Conceptualization. **Gabriel Moisan:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Jacques Abboud:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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