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ORIGINAL ARTICLE

Changes in spinal motor behaviour are associated with reduction in disability in chronic low back pain: A longitudinal cohort study with 1-year follow-up

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Abstract

Background: The need to improve spinal motor behaviour in chronic low back pain (CLBP) rehabilitation remains unclear. The objective of this study was to test if changes in spinal motor behaviour were associated with changes in disability after an interdisciplinary rehabilitation program (IRP) in patients with CLBP.

Methods: Seventy-one patients with CLBP participating in an IRP were included. Spinal motor behaviour was assessed with biomechanical (lumbar angular amplitude and velocity, erector spinae muscle activity and duration of the task), cognitive-emotional (task-specific fear [PRF]) and pain-related (movement-evoked pain [MEP]) measures during a lifting task before and after the IRP. Disability was measured before and after the IRP, and at 3-month and 1-year follow-ups.

Results: After adjusting for confounders, changes in disability were significantly associated with MEP changes (β adj. = 0.49, $p < 0.001$) and PRF changes (β adj. = 0.36, $p = 0.008$), but not with changes in any of the biomechanical measures. MEP at the end of IRP was also associated with disability at 3 months (β adj. = 0.37, $p = 0.001$) and 1 year (β adj. = 0.42, $p = 0.01$). Biomechanical measures at the end of the IRP were not associated with disability, except for the duration of the task that was significantly associated with reduction of disability at 3 months (β non-adj = 0.5, $p < 0.001$).

Conclusions: Pain-related and cognitive-emotional measures of spinal motor behaviour were associated with reduction in disability following an IRP. Future research is needed to further investigate causal relationships between spinal motor behaviour and disability.

Significance statement: This study supports a multidimensional understanding and analysis of spinal motor behaviour, integrating the cognitive-emotional, pain-related and biomechanical domains. It also supports the consideration of spinal motor behaviour as a potentially important treatment target in chronic low back pain management. Moreover, it suggests that reducing movement-evoked pain and task-specific fear may have more influence on disability than changing lumbar amplitude, lumbar angular velocity or erector muscle activity, which may have important implications for rehabilitation.

1 | INTRODUCTION

Interdisciplinary rehabilitation programs (IRP), combining exercise and education, are top choice treatment for chronic low back pain (CLBP) (Casey et al., 2020; Kwan et al., 2022; Zaina et al., 2023). Nevertheless, their mechanisms of action remain unclear and their effects on disability are generally small (Hayden et al., 2021). Having a better understanding of the factors that need to change to improve disability is strongly needed to improve rehabilitation strategies (Wood et al., 2020).

A major aspect in need of clarification concerns the necessity to improve spinal motor behaviour to decrease disability (Steiger et al., 2012; Wernli, Tan, et al., 2020). This is particularly important, as it is one of the most frequent treatment targets in CLBP rehabilitation (Karayannis et al., 2016; Wood et al., 2021; Wun et al., 2021), despite the report of small or inconsistent association between changes in spinal motor behaviour and changes in disability (Nzamba et al., 2023; Steiger et al., 2012; Wernli, Tan, et al., 2020). This discrepancy between clinical practice and research may be due to the measurement of spinal motor behaviour. Indeed, while the contemporary understanding suggest that motor adaptations to pain include different domains interacting with each other's (Hodges & Smeets, 2015), there is a lack of studies that analysed these different domains together.

Prior research has predominately considered spinal motor behaviour through the lens of biomechanical variables only (Steiger et al., 2012; Wernli, Tan, et al., 2020), as patients with CLBP frequently demonstrated lower spinal angular amplitude and velocity of movement, higher trunk muscle activity and reduced overall movement performance (Laird et al., 2014; Moissenet et al., 2021; Rudy et al., 2003). Yet, motor behaviour is also influenced by cognitive-emotional and pain-related factors (Butera et al., 2016; Christe, Crombez, et al., 2021; Hodges & Smeets, 2015; Ippersiel et al., 2022), such as task-specific pain-related fear and movement-evoked pain (e.g. the pain felt during movement) (Corbett et al., 2019; Fullwood et al., 2021; Vlaeyen et al., 2016). All these domains have been shown to be interrelated (Butera et al., 2016; Christe, Crombez, et al., 2021; Ippersiel et al., 2022) and can be all influenced by the IRP (Casey et al., 2020; Kamper et al., 2015). Therefore, assessing spinal motor behaviour with these three domains together, and not in isolation, appears critical to improve the understanding of the longitudinal association between spinal motor behaviour and disability and optimize CLBP rehabilitation (Butera et al., 2016; Hodges & Smeets, 2015).

The general aim of this study was to explore the plausibility of causal associations between changes in spinal motor behaviour and reduction in disability following an IRP (Kamper, 2020). Specifically, the first objective of this study was to test if changes in biomechanical, cognitive-emotional and pain-related measures of spinal motor behaviour were associated with changes in disability during the IRP. The second objective was to test if these spinal motor behaviour measures at the end of the IRP were associated with disability at 3-month and 1-year follow-ups. Measures at the end of the IRP are particularly relevant, as they can help clinicians determine what needs to be achieved at the end of rehabilitation for positive future outcomes. For both objectives, we hypothesized that larger spinal amplitude and velocity of movement, lower muscle activity, better overall performance, lower task-specific pain-related fear and lower movement-evoked pain would be associated with lower disability (Crombez et al., 2012; Knox et al., 2022; Moissenet et al., 2021).

2 | METHODS

2.1 | Design

This study is a prospective longitudinal cohort study with assessments at four timepoints and is reported according to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) criteria (von Elm et al., 2007). Spinal motor behaviour and disability were measured in a university hospital setting with similar procedures twice, before (T1) and at the end (T2) of the IRP. Disability was also measured at 3 months (T3) and 1 year (T4) after the end of the IRP using online questionnaires. This study was registered in ClinicalTrials.gov (NCT03499613).

2.2 | Participants

Recruitment was performed from April 2018 to September 2020. All the patients participating in the IRP at our University Hospital were contacted for recruitment if they met the following criteria: women and men from 18 to 65 years old, chronic non-specific LBP with or without leg pain and sufficient French level to understand the study instructions and the questionnaires. The study team was not involved in the IRP, including in the selection of the patients for the IRP. Patients were excluded from the study in case of: pregnancy, signs of specific low back pain, important spinal deformities, previous back surgery limiting spinal mobility (e.g. fusion), concomitant condition that could compromise the evaluation of spinal motor behaviour (e.g. neurological disease) and a body mass index (BMI) above 32 kg/m^2. All participants signed an informed consent form before enrolment in the study

approved by the local Ethics Committee (CER-VD 2018-00188). Because there is no prior research with similar spinal motor behaviour outcomes, the sample size was determined based on the rule of the thumb of a minimum of 10 participants per independent and confounding variables (Steyerberg et al., 2000). Considering the inclusion of five confounding variables and a drop out of 20%, this study aimed to include 75 patients.

2.3 | Interdisciplinary rehabilitation programme (IRP)

Participants to the IRP came daily to the university hospital for 3 weeks to receive a total 100 h of individual and group treatments, provided by an interdisciplinary team of medical doctors, physiotherapists, occupational therapists and psychologists. The IRP included aerobic, proprioceptive, mobility and strength exercises. Behavioural approaches and education were also included to improve confidence in performing movements and activities and decrease pain-related fear and unhelpful beliefs (see AppendixS1 for details).

2.4 | Outcomes

2.4.1 | Spinal motor behaviour measures (independent variables)

Primary spinal motor behaviour measures included biomechanical, cognitive-emotional and pain-related measures during a lifting task (Figure 1). This task was selected because measuring spinal motor behaviour during painful and difficult daily-life tasks has been recommended to allow a more representative analysis of motor behaviour alterations in CLBP patients (Christe, Aussems, et al., 2021; Wernli, O'Sullivan, et al., 2020; Wernli, Tan, et al., 2020). Standardized instructions were given with a video recording. Then, the lifting task was recorded three times. Procedures are described in detail in Christe, Aussems, et al. (2021).

The biomechanical domain included both specific and general measures. Based on the literature recommending multi-segment models (Christe, Aussems, et al., 2021; Moissenet et al., 2021; Papi et al., 2018), specific measures of lumbar angular amplitude, lumbar angular velocity and erector spinae muscle activity were used for fine quantification of spinal biomechanics. Briefly, sagittal-plane angular amplitude and velocity were measured at the lower and upper lumbar spine (LLS and ULS respectively) using a marker-based motion capture system (Vicon, Oxford Metrics, Oxford, United Kingdom) and a previously defined multi-segments model (Christe et al., 2016, 2017, 2020; Christe, Aussems, et al., 2021). The LLS angle was defined as the angle between the segment composed of L3, L5 and the in-between lateral markers and the pelvis segment, with markers at the posterior superior iliac spines, anterior superior iliac spines and iliac crest tips. The ULS angle was defined as the angle between the segment with the L3-L5 markers and the segment composed of L1, L3 and their lateral markers (Figure 2). Angular velocity curves were obtained by numerical differentiation of the angle curves. Erector spinae activity was collected synchronously with angular data as described in a previous study (Christe, Aussems, et al., 2021) using two pairs of electrodes (Myon, Schwarzenberg, CH) placed bilaterally parallel to the erector spinae fibres at the L3 level, following protocols from previous studies (Dupeyron et al., 2013; Wong et al., 2016). Electrodes were not placed at the L5 level, as the proximity with the L5 and PSIS markers could have perturbed the recording of the markers' trajectory. The minimal amplitude of the electromyography signals recorded throughout the entire session was identified and subtracted from the signals, effectively establishing a zero-value (0%) reference point for the electromyography data. Subsequently, to standardize the signals for both muscles, the amplitudes recorded at the beginning of each session during a submaximal voluntary contraction in the crook lying position were considered as 100%. The choice

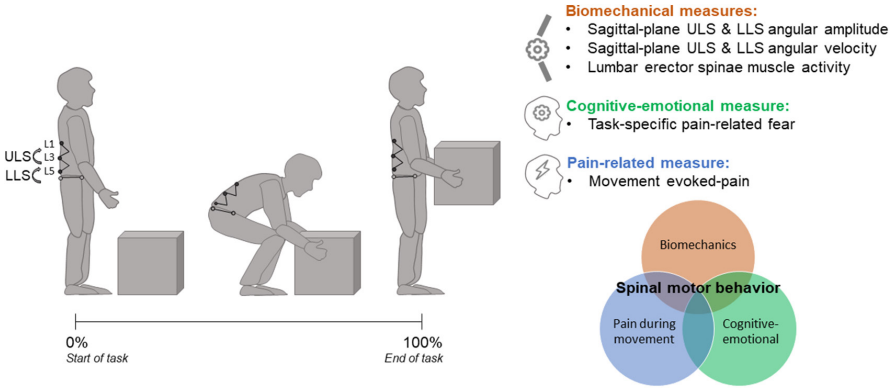

FIGURE 1 Spinal motor behaviour measures during the lifting task. LLS, lower lumbar spine; ULS, upper lumbar spine.

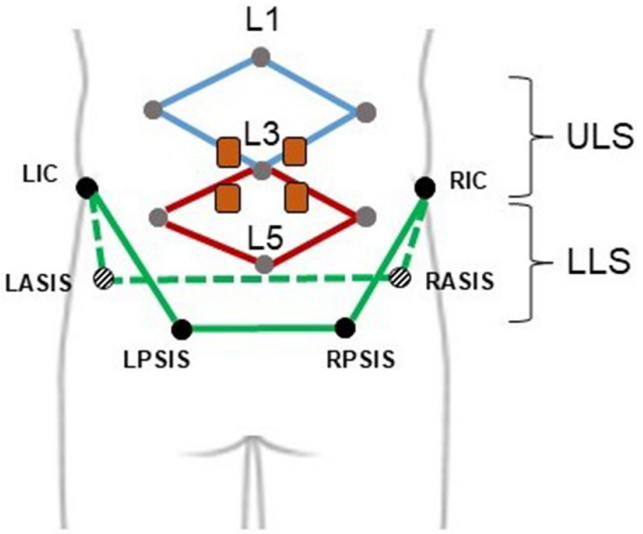

FIGURE 2 Biomechanical model. LASIS, left anterior superior iliac spine; LIC, left iliac crest; LLS, lower lumbar spine; LPSIS, left posterior superior iliac spine; RASIS, right anterior superior iliac spine; RIC, right iliac crest; RPSIS, right posterior superior iliac spine; ULS, upper lumbar spine.

of submaximal contraction for normalization was motivated by its demonstrated superior reliability compared to maximal contraction in individuals with chronic low back pain (Dankaerts et al., 2004). Following prior studies suggesting relevant discrete variables to characterize spinal biomechanics in the study of CLBP (Christe et al., 2016, 2017, 2020; Christe, Aussems, et al., 2021), the maximum flexion angle at the LLS (LLSa) and ULS (ULSa); the maximum flexion angular velocity at the LLS (LLSv) and ULS (ULSv) and the maximum left or right erector spinae normalized muscle activity during the descending phase of lifting (EMG) were considered as primary specific spinal biomechanical measures. All the measures were averaged over the three repetitions to have only one value per participant and timepoint. Between-day reliability of these biomechanical measures (ICC 2.1) was found to be moderate to excellent (Christe et al., 2022). A more general biomechanical measure related to the overall movement performance was obtained through the duration of the movement (duration, in seconds) (Rudy et al., 2003). Data processing and extraction have been described in detail elsewhere (Christe, Aussems, et al., 2021).

The cognitive-emotional domain of spinal motor behaviour included a task-specific measure of pain-related fear (PRF) assessed after visualizing the task to accomplish but before accomplishing it. This timing was selected because pain-related fear is thought to be influenced by the perceived harmfulness of the task (Christe, Crombez, et al., 2021; Ippersiel et al., 2022; Matheve et al., 2019). Participants rated on a 0–10 scale how much they think the lifting task was harmful for the back (0: not harmful; 10: extremely harmful) (Christe, Aussems, et al., 2021; Demoulin et al., 2013).

The pain-related domain of spinal motor behaviour included a measure of movement-evoked pain (MEP) assessed with the Numeric Pain Rating Scale (NPRS) (0: no pain at all; 10: worst imaginable pain) immediately after the accomplishment of the task (Butera et al., 2016; Corbett et al., 2019; Leemans et al., 2022). Measuring MEP and not only general measures of pain intensity has been recommended to better understand motor behaviour (Butera et al., 2016; Corbett et al., 2019; Fullwood et al., 2021; Leemans et al., 2022; Sullivan et al., 2009).

2.4.2 | Disability (dependent variable)

Disability was the dependent variable and was measured with the French version of the Oswestry Disability Index (ODI, 0–100 scale) (Fairbank & Pynsent, 2000; Vogler et al., 2008). The ODI is a reliable and valid measure of disability and has been recommended as a core outcome for LBP trials (Chiarotto et al., 2017).

2.4.3 | Confounding variables

Confounding variables need to have at least a possible causal influence on the dependent variable (disability) and be associated with the independent variable (spinal motor behaviour) (McNamee, 2003). Therefore, we included five confounding variables possibly associated with both spinal motor behaviour and disability to adjust the analyses (Chou & Shekelle, 2010; Christe, Crombez, et al., 2021; Zale et al., 2013). They included a general measure of pain-related fear, measured with the French version of the Tampa Scale of Kinesiophobia (TSK) (Vlaeyen et al., 1995), the mean back pain intensity during the previous week (BPI) measured with the NPRS (Downie et al., 1978), the French version of the Pain Catastrophizing Scale (PCS) (French et al., 2005; Sullivan, 1995), age and gender. BPI and TSK were particularly important to include to determine the specific effect of PRF and MEP, while adjusting for general measures of pain-related fear and pain intensity.

2.5 | Statistical analysis

Changes in spinal motor behaviour and confounding variables during the IRP (T2–T1) were tested with paired t-tests, whereas one-way repeated ANOVA and post hoc t-tests were conducted to compare the changes in disability between T1 and all follow-up timepoints (T2, T3 and T4).

To test the relationships between changes in spinal motor behaviour and changes in disability after the IRP, linear regression analyses were conducted with the change in each spinal motor behaviour measure as the independent variable and the change in disability as the dependent variable. In addition, we performed linear regression analyses with each spinal motor behaviour measure at T2 as the independent variable and disability at T3 or T4 as the dependent variable. Additional analyses for all the models were conducted when adjusting for confounders, as recommended for cohort study of aetiology and investigations of potential causal associations (Herbert, 2014; McNamee, 2003, 2005). Assumptions for linear regression were tested and extreme outliers identified in boxplots with SPSS (3 box-lengths away) were discarded from the analyses. Data analysis was performed with SPSS (Version 25, IBM, NY, USA), using a significance level at $\alpha < 0.05$. This study included diverse spinal motor behaviour measures based on prior recommendations. In accordance with the exploratory nature of the study, no correction for multiple analyses was applied, but results, particularly isolated statistically significant relationships, were interpreted critically.

3 | RESULTS

Eligibility assessment included 125 individuals, of which 71 were included in the study. Inclusion had to be stopped because of the Covid-19 pandemics. Sixty-two patients had data available at T1 and T2, 56 at T3 and 51 at T4 (Appendix S2). At T1, 63% of participants were male, with a mean ± SD age of 40.9 ± 10.6 years old, LBP duration of 77.0 ± 75.3 months and ODI score of 35.0 ± 10.5 (see also Table 1). There were no statistically significant differences in T1 or T2 disability or spinal motor behaviour measures between the participants who answered or not the questionnaires at T3 and T4 (Appendix S3).

Disability statistically significantly decreased after the IRP (F (2.565, 120.546) = 40.42, $p < 0.001$). Compared to T1, there was a reduction in disability at T2 of 12.4 units (95% CI 9.9–14.9), at T3 of 11.2 units (95% CI 8.3–14.2) and at T4 of 12.0 units (95% CI 8.6–15.4) (Figure 3). No statistically significant change was observed during the IRP (T2–T1) in angular amplitude, angular velocity and muscle activity, except for ULSv. Conversely, the duration to perform the task, MEP, PRF, TSK and BPI all significantly improved during the IRP (Table 1).

TABLE 1 Spinal motor behavior and confounding measures before (T1) and at the end (T2) of the IRP, as well as their changes after the IRP (Δ = T2−T1).

	@T1	@T2	Changes (Δ = T2–T1)	
	Mean (SD)	**Mean (SD)**	**Mean (95% CI)**	***p*-value**
Spinal motor behavior measures				
MEP, range: 0–10	4.5 (2.8)	2.2 (2.4)	**−2.3** (1.6 to 3.0)	**<0.001**
PRF, range: 0–10	6.2 (3.2)	1.4 (2.3)	**−4.8** (3.9 to 5.7)	**<0.001**
Duration, s	4.1 (1.3)	3.2 (0.6)	**−0.9** (0.6 to 1.2)	**<0.001**
LLSa, °	−8.6 (4.3)	−7.4 (4.9)	1.2 (−2.6 to 0.2)	0.09
ULSa, °	−19.8 (8.1)	−20.9 (7.6)	−1.1 (−0.7 to 2.9)	0.21
LLSv, °/s	−15.1 (7.8)	−17.3 (8.5)	−2.3 (−0.5 to 5.0)	0.10
ULSv, °/s	−28.5 (11.4)	−36.6 (13.7)	**−8.0** (4.5 to 11.5)	**<0.001**
EMG, %	67.7 (32.6)	75.2 (34.3)	7.5 (−17.1 to 2.2)	0.13
Confounding variables				
TSK, range: 17–68	44.5 (8.0)	30.3 (7.4)	**−14.0** (12.2 to 15.9)	**<0.001**
BPI, range: 0–10	5.7 (2.1)	3.3 (2.1)	**−2.5** (1.9 to 3.1)	**<0.001**
PCS, range: 0–52	25.1 (11.6)	11.2 (9.9)	**−13.9** (11.6 to 16.2)	**<0.001**
Age	40.9 (10.6)			
Gender (% male)	63			

Note: T1 (baseline) and T2 (end of the IRP) data are reported as mean (standard deviation, SD), and changes as mean changes (95% confidence interval, 95% CI). Statistically significant changes are reported in bold ($p < 0.05$).

Abbreviations: BPI, mean back pain intensity during the previous week; Duration, duration of the task; EMG, maximum erector spinae normalized muscle activity; LLSa, maximum flexion angle at the lower lumbar spine; LLSv, maximum flexion angular velocity at the lower lumbar spine; MEP, movement-evoked pain; PCS, Pain Catastrophizing Scale; PRF, task-specific measure of pain-related fear; TSK, Tampa Scale of Kinesiophobia; ULSa, maximum flexion angle at the upper lumbar spine; ULSv, maximum flexion angular velocity at the upper lumbar spine.

The change in ODI after the IRP was significantly associated with MEP changes ($\beta = 0.57$ and β adj. $= 0.51$, $p < 0.001$) and PRF changes ($\beta = 0.42$, $p < 0.001$ and β adj. $= 0.36$, $p = 0.003$), but not with biomechanical measures changes (Table 2). Furthermore, MEP and PRF at T2 were associated with disability at T3 ($\beta = 0.63$, $p < 0.001$ and $\beta = 0.27$, $p = 0.04$ respectively) and T4 ($\beta = 0.55$, $p < 0.001$ and $\beta = 0.29$, $p = 0.04$ respectively) (Table 3). When adjusted for TSK and BPI, only MEP remained statistically significantly associated with disability at T3 (β adj. $= 0.33$, $p = 0.01$) and T4 (β adj. $= 0.36$, $p = 0.02$). Biomechanical measures at T2 were not associated with disability at T3 or T4, except for the duration of the task that was significantly associated with disability at T3 ($\beta = 0.5$, $p < 0.001$).

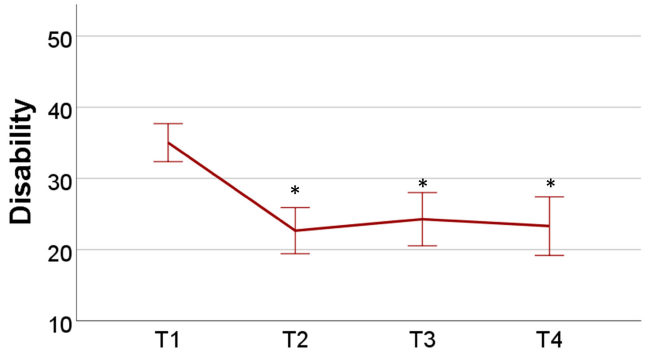

FIGURE 3 **Disability at the four timepoints.** The mean values and the 95% CI (vertical bars) are reported. Stars (*) indicate statistically significant differences with disability at T1 ($p < 0.001$).

4 | DISCUSSION

This longitudinal cohort study showed that improvements in all three domains of spinal motor behaviour were associated with reduction in disability, suggesting that spinal motor behaviour may be a relevant treatment target in CLBP rehabilitation. Specifically, this study showed that changes in overall movement performance, movement-evoked pain or task-specific pain-related fear, but not changes in specific spinal biomechanical measures, were associated with improvement in disability.

This study particularly supports the importance of considering movement-evoked pain as a relevant treatment target. It showed that movement-evoked pain at the end of rehabilitation was moderately associated with future disability, even when controlled by average pain intensity over the past week and other potential confounders. Given the effect sizes, it supports the plausibility of a causal association between reduction in movement-evoked pain and reduction in disability that would need to be further tested in future studies. It also encourages the measurement of movement-evoked pain in future studies, as prior CLBP studies mostly measured pain intensity with static measures (Corbett et al., 2019; Leemans et al., 2022). Moreover, this study showed that improvement in movement-evoked pain is possible without changes in spinal angular amplitude, angular velocity or trunk muscle activity, suggesting that movement-evoked pain may be reduced without changes in these specific spinal biomechanical variables.

By stressing the need to decrease pain-related fear of lifting, this study extended prior knowledge on the

TABLE 2 Standardized beta coefficients (95% confidence interval, 95% CI) for the association between the change (Δ = T2−T1) in spinal motor behavior measures and the change (Δ = T2−T1) in disability after the IRP.

	ΔODI			
	β (95% CI)	***p*-value**	**β adj. (95% CI)**	***p*-value**
ΔMEP	**0.57 (0.36 to 0.78)**	**<0.001**	**0.49 (0.27 to 0.72)**	**<0.001**
ΔPRF	**0.42 (0.19 to 0.66)**	**0.001**	**0.36 (0.09 to 0.58)**	**0.008**
ΔDuration	0.16 (−0.1 to 0.41)	0.23	0.11 (−0.14 to 0.35)	0.4
ΔLLSa	0.15 (−0.11 to 0.39)	0.26	0.08 (−0.17 to 0.31)	0.56
ΔULSa	0.12 (−0.14 to 0.37)	0.36	0.15 (−0.1 to 0.39)	0.23
ΔLLSv	0.09 (−0.18 to 0.35)	0.52	0.03 (−0.29 to 0.24)	0.85
ΔULSv	−0.03 (−0.29 to 0.22)	0.81	−0.07 (−0.31 to 0.17)	0.58
ΔEMG	0.01 (−0.25 to 0.27)	0.94	0 (−0.25 to 0.25)	0.99

Note: β: models including only the change in spinal motor behavior measure as independent variable. β adj.: models adjusted for changes (Δ = T2–T1) in TSK, BPI, PCS, age and gender. Statistically significant relationships are reported in bold ($p < 0.05$).

Abbreviations: Duration, duration of the task; EMG, maximum erector spinae normalized muscle activity; LLSa, maximum flexion angle at the lower lumbar spine; LLSv, maximum flexion angular velocity at the lower lumbar spine; MEP, movement-evoked pain; PRF, task-specific measure of pain-related fear; ULSa, maximum flexion angle at the upper lumbar spine; ULSv, maximum flexion angular velocity at the upper lumbar spine.

TABLE 3 Standardized beta coefficients (95% confidence interval, 95% CI) for the associations between spinal motor behavior measures at the end of the IRP (T2) and disability at the three-month (T3) and one-year (T4) follow-ups.

	ODI @T3				ODI @T4			
	β (95% CI)	*p*-value	*β* adj. (95% CI)	*p*-value	*β* (95% CI)	*p*-value	*β* adj. (95% CI)	*p*-value
MEP @T2	**0.63 (0.4 to 0.81)**	**<0.001**	**0.37** (0.12 to 0.6)	0.005	**0.55** (0.3 to 0.76)	**<0.001**	**0.42** (0.11 to 0.71)	0.01
PRF @T2	**0.28** (0.03 to 0.53)	0.04	0.13 (−0.12 to 0.37)	0.3	**0.29** (0.01 to 0.54)	0.04	0.12 (−0.19 to 0.42)	0.46
Duration @T2	**0.5** (0.25 to 0.71)	**<0.001**	0.22 (−0.03 to 0.45)	0.09	0.27 (−0.02 to 0.55)	0.06	0.07 (−0.23 to 0.37)	0.63
LLSa @T2	−0.08 (−0.34 to 0.19)	0.56	0.01 (−0.21 to 0.22)	0.94	−0.21 (−0.5 to 0.08)	0.15	−0.08 (−0.36 to 0.2)	0.58
ULSa @T2	0.08 (−0.19 to 0.35)	0.56	0.09 (−0.15 to 0.33)	0.47	0.06 (−0.22 to 0.33)	0.7	0.08 (−0.21 to 0.36)	0.6
LLSv @T2	0.19 (−0.08 to 0.44)	0.17	0.07 (−0.15 to 0.28)	0.54	−0.14 (−0.46 to 0.16)	0.33	−0.23 (−0.51 to 0.03)	0.09
ULSv @T2	0.15 (−0.13 to 0.43)	0.28	0.11 (−0.12 to 0.33)	0.35	0.06 (−0.23 to 0.34)	0.7	−0.01 (−0.28 to 0.26)	0.94
EMG @T2	−0.04 (−0.31 to 0.24)	0.79	0.01 (−0.22 to 0.23)	0.96	−0.04 (−0.34 to 0.26)	0.8	0.03 (−0.25 to 0.3)	0.85

Note: *β*: models including only the spinal motor behavior measure as independent variable. *β* adj.: models adjusted for in TSK, BPI, PCS, age and gender at the end of the IRP (T2). Statistically significant relationships are reported in bold ($p < 0.05$).

Abbreviations: Duration, duration of the task; EMG, maximum erector spinae normalized muscle activity; LLSa, maximum flexion angle at the lower lumbar spine; LLSv, maximum flexion angular velocity at the lower lumbar spine; MEP, movement-evoked pain; PRF, task-specific measure of pain-related fear; ULSa, maximum flexion angle at the upper lumbar spine; ULSv, maximum flexion angular velocity at the upper lumbar spine.

importance to target fear in specific functional tasks in the treatment of CLBP (Caneiro et al., 2022; Lee et al., 2015; Wertli, Rasmussen-Barr, Held, et al., 2014; Wertli, Rasmussen-Barr, Weiser, et al., 2014). Importantly, the association between changes in task-specific pain-related fear and changes in movement-evoked pain reported in prior research showed that improvement in one of these factors may be related to improvement in the other (Christe et al., 2023), suggesting these two factors may need to be approached together in clinical practice. Recent mediation analyses of clinical trials also supported the importance of improving pain-related fear, catastrophizing or self-efficacy in CLBP rehabilitation (Cashin et al., 2023; Wood et al., 2023). In one study investigating the effect of education and graded sensorimotor retraining, improvement in psychological factors had larger mediating effects than improvement in physical factors (Cashin et al., 2023).

Regarding the biomechanical domain, this work brought important clarifications with respect to previous research by measuring lumbar biomechanics with state-of-the-art measures during a painful and feared functional task. Even though the methodology used in this study was expected to be more sensitive, the results were comparable to prior works using global spinal measures (e.g. fingertip-to-floor test or global trunk flexion) or analysing spinal motor behaviour in non-functional tasks (Wernli, O'Sullivan, et al., 2020; Wernli, Tan, et al., 2020). Consequently, the current body of evidence agrees on at most small associations between changes in lumbar angular amplitude, angular velocity or muscle activity and changes in disability (Wernli, Tan, et al., 2020). A recent meta-analysis showed that increased spinal angular amplitude, mainly increased spinal flexion, is associated with reduction in disability with small effect sizes (Nzamba et al., 2023). In this study, a higher overall performance of the task was associated with lower disability at 3 months after the IRP. Therefore, it is possible that global measures are more sensitive to change than specific lumbar biomechanical ones (Nordstoga et al., 2019; Wernli, O'Sullivan, et al., 2020), and that having the capacity to perform a task quicker may be a relevant outcome for LBP rehabilitation (instead of having spinal mobility as an outcome). It is also possible that global measures are less impacted by the particularity of each patient and thus more prone to report inter-patient associations with disability.

Altogether these findings support the idea that helping patients with CLBP to move in functional activities with less pain and reduced fear seems important to reduce disability following rehabilitation. Changing biomechanics can be one way, among others, to decrease movement-evoked pain and fear (Caneiro et al., 2022; Lehman, 2018; Nzamba et al., 2023). Furthermore, these results support

that the biomechanical objectives of rehabilitation could be addressed more globally in order to improve the performance of the task, without the common target to increase spinal amplitude (Karayannis et al., 2016; Wood et al., 2021; Wun et al., 2021). These findings may help understand why movement-based interventions showed reduction in disability even in the absence of consistent changes in angular amplitude, angular velocity and trunk muscle activity (Steiger et al., 2012; Wernli, Tan, et al., 2020).

The first limitation of this study is related to the IRP, which is a combination of specific education, exercise and behavioural interventions. Therefore, it is not possible to determine which components were responsible for the improvements observed following the intervention. Moreover, only patients participating in this particular IRP were included, potentially limiting the external validity of the findings. Yet, the IRP was perfectly suited for this research questions as it showed clinically significant effects on disability that lasted at 1-year follow-up in patients with high levels of disability. Second, while the observational design was adapted to the objectives of the study, it cannot demonstrate a causal effect between changes in spinal motor behaviour and changes in disability. Furthermore, no correction for multiple analyses was performed. Yet, given the lack of knowledge on the variables associated with spinal motor behaviour, it was particularly important to first get insights into which spinal motor behaviour domains/measures were associated with disability. Now that it has been done, clinical trials that specifically target overall movement performance, movement-evoked pain and/or task-specific pain-related fear and using mediation analyses will be necessary to determine if the effect of the intervention on disability is mediated by improvement in these domains/measures (Lee et al., 2017). Including other possible confounders, such as self-efficacy, depression and proprioceptive accuracy, in future research is advised to further strengthen our understanding. Third, the drop out rate was relatively high, suggesting an attrition risk of bias. This may have impacted the power of the multiple statistical analyses, potentially causing type II errors. Finally, while we measured spinal biomechanics with state-of-the-art methods, it is possible that other biomechanical measures could have reported associations with disability. The limited and small changes observed in spinal biomechanics following the IRP may be also a reason for the lack of association with disability. In fact, it cannot be excluded that more specific interventions targeting spinal biomechanics during functional tasks may be necessary to improve spinal biomechanics, which may then influence the association with disability.

5 | CONCLUSION

This study demonstrated that, when adjusted for confounders, changes in movement-evoked pain and in task-specific pain-related fear, but not in spinal biomechanical measures, were associated with reduction in disability in patients with CLBP following an interdisciplinary rehabilitation programme. Given that spinal biomechanics features are among the most frequent targets of exercise, these findings may have important implications for CLBP rehabilitation. Future research should further investigate the causal effects of improving spinal motor behaviour to reduce disability.

AUTHOR CONTRIBUTIONS

GC contributed to the conception of the study, collected the data, analysed the data, interpreted the results and wrote the initial article. CB participated to the conception of the study and edited the article. BJ participated to the conception of the study, edited the article and supervised the project. JF contributed to the conception of the study, interpreted the results, edited the article and supervised the project. All authors approved the final version of the article. Both BJ and JF supervised this research and should be considered as last authors.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

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SUPPORTING INFORMATION

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