DOI: 10.1111/papr.13191

RESEARCH ARTICLE

Reduction in pain-related fear is not associated with improvement in spinal biomechanics but with decrease in movement-evoked pain in patients with chronic low back pain

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Abstract

Background and aims: While a causal relationship between pain-related fear and spinal movement avoidance in patients with chronic low back pain (CLBP) has frequently been postulated, evidence supporting this relationship is limited. This study aimed to test if decreases in pain-related fear or catastrophizing were associated with improvements in spinal biomechanics, accounting for possible changes in movement-evoked pain.

Methods: Sixty-two patients with CLBP were assessed before and after an interdisciplinary rehabilitation program (IRP). Pain-related fear was assessed with general and task-specific measures. Lower and upper lumbar angular amplitude and velocity as well as paraspinal muscle activity were recorded during five daily-life tasks to evaluate spinal biomechanics. Relationships were tested with multivariable linear regression analyses.

Results: The large decreases in pain-related fear and catastrophizing following the IRP were scarcely and inconsistently associated with changes in spinal biomechanics (<3% of the models reported a statistically significant association). Results remained comparable for activities inducing more or less fear, for specific or general measures of pain-related fear, and for analyses performed on the entire population or limited to subgroups of patients with higher levels of task-specific fear. In contrast, reductions in task-specific pain-related fear were significantly associated with decreases in movement-evoked pain in all tasks (r = 0.26–0.62, $p \leq 0.02$).

Conclusion: This study does not support an association between pain-related fear and spinal movement avoidance. However, it provides evidence supporting a direct relationship between decreased pain-related fear and decreased movement-evoked pain, possibly explaining some mechanisms of the rehabilitation programs.

KEYWORDS
low back pain, physical therapy, rehabilitation

INTRODUCTION

Treatments for chronic low back pain (CLBP) remain limited,[1] calling for a better understanding of this major cause of disability worldwide.[2] The fear-avoidance model (FAM) is a well-established theory about the processes leading to disability in CLBP. It suggests a mechanism where catastrophic beliefs and pain-related fear may lead

to avoidance behaviors and disability.[3] While the relationship between these psychological factors and disability has been well documented in patients with CLBP,[4,5] empirical evidence supporting a causal link between psychological factors and avoidance is missing.[6,7] Further investigation is strongly warranted as this link could be a centerpiece to our understanding of CLBP and the improvement of rehabilitation strategies. Longitudinal studies are particularly needed to determine if reducing pain-related fear or catastrophizing is associated with improvement in spinal biomechanics. Furthermore, including measures of movement-evoked pain (ie, pain during movement) in these analyses is critical, as it may strongly improve our understanding of the complex relationship between psychological factors, pain intensity, and spinal movement.[8,9]

In patients with CLBP, avoidance can be expressed by protective movement behaviors during daily activities rather than by total avoidance of these activities.[4] Avoidance may therefore be objectified using biomechanical measures. Specifically, patients have frequently been reported to move with reduced spinal amplitude and velocity of movement[10,11] and higher trunk muscles activity.[12,13] Reviewing CLBP literature about these biomechanical measures and about catastrophizing and pain-related fear stresses two important methodological considerations.[6,14] First, it is recommended to measure spinal biomechanics during daily-life tasks and using multi-segment biomechanical models.[15–17] Second, when analyzing the association between pain-related fear and spinal biomechanics, it is suggested to measure task-specific pain-related fear during daily-life tasks considered harmful by the patient (ie, bending and lifting),[6,18,19] because this association is thought to be context-dependent.[20] Following the aforementioned recommendations appears important, as proceeding differently has been pointed out in the past as a major limitation in the effort to relate psychological factors and avoidance.[6]

This study aimed to evaluate the relationship between catastrophizing or pain-related fear and spinal biomechanics in patients treated for CLBP. Specifically, a decrease in catastrophizing or pain-related fear was hypothesized to be associated with an increase in spinal angular amplitude and velocity and a decrease in lumbar paraspinal muscle activity during feared tasks (bending, lifting, and picking-up), but not during less feared tasks (sit-to-stand and stepping-up).

METHODS

Design

This registered prospective longitudinal cohort study (clinicaltrials.org NCT03499613) is reported according to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) criteria.[21]

Population

Patients following a 3-week interdisciplinary rehabilitation program (IRP) at the local university hospital were invited to participate in the study from April 2018 to September 2020, if they met the following inclusion/exclusion criteria. The study included women and men from 18 to 65 years of age with a diagnostic of non-specific CLBP with or without leg pain. Participants needed to be sufficiently fluent in French to understand instructions for the tests, the information sheet, the consent form, and the questionnaires. Exclusion criteria were pregnancy, signs of specific low back pain, important spinal deformities, previous back surgery limiting spinal mobility (eg, fusion), other concomitant pain or condition that could compromise the evaluation of spinal kinematics, or a body mass index (BMI) above 32. The BMI cut-off was selected to limit experimental errors without compromising external validity.[22] The research was approved by the local Ethics Committee (CER-VD 2018-00188) and all participants signed an informed consent form before enrolment in the study.

Setting

The IRP is an intensive 3-week rehabilitation program intended for CLBP patients who failed previous treatments and have difficulties maintaining their professional activity. Patients come daily for individual and group treatments, totalizing about 100 hours of intervention. The IRP team includes physiatrists, physiotherapists, occupational therapists, and psychologists. The IRP aims to improve physical function (eg, cardio-vascular endurance, proprioception, mobility, and strength), improve confidence in performing movements and activities, decrease unhelpful beliefs and kinesiophobia, and discuss the psychological implications of CLBP.[23] In agreement with international studies on comparable interventions, this program was shown to induce a positive change in pain-related fear, LBP beliefs, pain intensity, and spinal mobility.[24–27] Therefore, this setting is relevant to study the relationship between changes in pain-related fear or catastrophizing and changes in spinal biomechanics.

Measurement procedures

Participants were assessed on two occasions, before (baseline) and after (post-treatment) the IRP, by the same experienced physiotherapist (GC) who was not involved in the IRP. The experimental procedures were similar for the two sessions. First, two pairs of electrodes (Myon, Schwarzenberg, CH) were placed on the erector spinae fibers, 3 cm left and right to L3 spinous process, after skin shaving and cleaning.[28,29] Next, for calibration purposes, participants performed one submaximal

voluntary contraction in crook lying as detailed by Dankaerts et al.[30] Then, reflective markers were attached to the back and pelvis of the participants following a previously described protocol.[15,16,31] The marker-to-marker distances as well as the distance between the pelvis markers and the floor were documented at baseline to ensure consistency with post-treatment measures and reduce errors of placement. Marker positions were then recorded during a standing reference pose using a camera-based motion capture system (Vicon, Oxford Metrics) to initialize the biomechanical model.[15,16,31] Finally, muscle activities and marker trajectories were collected synchronously at 1200 and 120 Hz, respectively, during five functional tasks in this order: standing flexion, sit-to-stand, stepping-up on a 36 cm high step, picking-up a sponge from the floor and lifting 4.5 kg box from the floor. Each task was practiced one to three times and then recorded three times, except for picking-up which was recorded 10 times. Standardized instructions were given before each task with a video recording (see Ref.[10] for details). Participants also completed questionnaires during the two measurement sessions.

Measures

Psychological factors

Pain-related fear was measured in two different ways. First, the Tampa Scale of Kinesiophobia (TSK) was used as a general measure of pain-related fear. This common questionnaire assessing pain-related fear beliefs and kinesiophobia has good psychometric proprieties.[32,33] Pain-related fear was also assessed with a task-specific measure (SFear).[10,34] Participants rated on a 0–10 scale how much they thought the subsequent task would be harmful to the back (0: not harmful; 10: extremely harmful). Sfear was assessed before each task after having watched its instruction video.

Catastrophizing was measured with the validated French version of the Pain Catastrophizing Scale (PCS), which demonstrated good psychometric proprieties.[35–37] The TSK and PCS were completed at the beginning of the session, before the tasks measurements.

Spinal biomechanical factors

Because it is unknown which spinal biomechanical measures are the most relevant to assess the relationship between psychological and biomechanical factors,[6,38] we included a panel of measures related to the protective movement behavior in patients with CLBP. Specifically, following prior publications,[10,15,16,31] sagittal-plane angular amplitude and velocity at the lower and upper lumbar spine (LLS and ULS, respectively), as well as erector spinae maximal activity were used to quantify spinal biomechanics. To calculate the angular amplitudes and velocities, a previously defined multi-segment model was used (see Refs[15,16,31] for details). Briefly, the orientation of anatomical frames embedded in each segment was calculated based on marker trajectories. The joint angle curves at the lower lumbar (LLSa) and the upper lumbar (ULSa) joints were then derived from these orientations. Angles were low-pass filtered using a 15 Hz Butterworth filter. Angular velocity curves (LLSv and ULSv) were obtained by numerical differentiation of the angle curves.

Electromyography recordings from the erector spinae were band-pass filtered using a Butterworth filter with cut-off frequencies at 20 and 450 Hz and rectified. The signals were normalized independently for each muscle using the minimal amplitude recorded during the measurement session as 0% and the value recorded during the maximal voluntary contraction as 100%. The submaximal contraction was chosen for the normalization because its reliability was shown to be superior to the maximal contraction in CLBP patients.[30]

To extract the biomechanical measures from the angular amplitude, angular velocity, and muscle activity curves, the curves were time-normalized to 0%–100% for each repetition of each task. The beginning and the end of the movement were determined visually using strict criteria based on markers trajectories.[15,16] Discrete features were then used to characterize spinal biomechanics, following CLBP movement behavior literature.[10,15,16,31] Specifically, the maximum flexion angle at the LLS ($LLSa_{flexion}$) and ULS ($ULSa_{flexion}$); the maximum flexion angular velocity at the LLS ($LLSv_{flexion}$) and ULS ($ULSv_{flexion}$); and the maximum erector spinae muscle activity during the first half of the movements (EMG_{peak1}) were considered in this study. $ULSv_{flexion}$ was only present in standing flexion, pick-up, and lifting.[10] For EMG_{peak1}, the maximal value observed with the left and right erector spinae muscles was kept for analysis. The measures were averaged over the repetitions to have only one value per participant and task. Reliability (ICC 2.1) at 1-week in patients with CLBP was shown to be above 0.6 for the angular amplitude and muscle activity measures but between 0.3 and 0.6 for the angular velocity measures.[39]

Finally, the duration (in seconds) to perform each movement (DURATION) was used as a general measure of movement. This measure was not considered for the flexion movement, as it included a pause at the end of bending, before coming back to standing.

Confounding factor

Movement-evoked pain (MEP) is described as the measure of pain intensity during movement and was included as a confounding factor. It is closely related to patients' complaints and was reported to be preferable over a static measure of pain intensity to assess

the relationship between pain intensity, spinal biomechanics, and psychological factors.[8,40,41] Patients were asked to rate their pain intensity during movement immediately after each task using the Numeric Pain Rating Scale (NPRS), as previously recommended.[40,41] The NPRS has been shown to be reliable and valid to measure pain intensity.[42,43]

General description of the study population

Disability was measured with the French version of the Oswestry Disability Index (ODI),[44,45] and mean pain intensity during the previous week using the NPRS.[43] These two measures are recommended as core outcome measures for CLBP studies.[46]

Statistical analysis

The changes between baseline and post-treatment were calculated for all measures of interest. To facilitate reading they are reported with a delta sign ahead (eg, TSK change = ΔTSK). Paired *t*-tests were performed to determine if the changes were statistically significant.

To assess the relationships, linear regression models were conducted separately for each biomechanical measure and functional task. The independent variables were changes in pain-related fear (specific or general measures) or catastrophizing. The dependent variable was the change in one spinal biomechanical measure and the change in movement-evoked pain was included as a confounding variable. Predictor variables' standardized Beta coefficients (β), 95% confidence interval (95% CI), and significance level were reported. Assumptions for linear regressions were verified before performing the tests and extreme outliers were discarded from analyses.[47] Pearson correlations were also calculated between changes in psychological, pain intensity, and spinal biomechanical measures. Finally, pre-planned sensitivity analyses were performed to test the relationships between pain-related fear or catastrophizing and spinal biomechanics only in patients who reported high levels of pain-related fear for flexion, lifting, and picking-up. For this purpose, the analyses were repeated with subgroups of patients rating the movement as harmful to the back (SFear ≥ 5/10). Subgroup analyses were not conducted for stepping-up and sit-to-stand, due to the small number of participants with high levels of pain-related fear for these tasks. Statistical analysis was performed with SPSS (Version 25, IBM), using a significance level at $\alpha = 0.05$. This study included diverse psychological and biomechanical measures to increase confidence in the overall findings. In accordance with this study objective, no correction for multiple analyses was applied, but results were interpreted critically, particularly isolated statistically significant relationships.

Sample size

In the absence of relevant data in the literature, the general guideline of 30 participants per independent and confounding variables in the linear regression models was used, leading to a minimal sample size of 60.[48] We aimed to include 75 participants, accounting for 20% of data corruption or dropout.

RESULTS

In total, 125 patients were assessed for eligibility and 71 individuals were included in the study (Figure 1). The recruitment was stopped before including the four last participants because the IRP got canceled due to the COVID pandemic and the minimal sample size was reached. Data at baseline and post-treatment were available for 62 participants (23 women, mean ± SD age = 40.9 ± 10.6 years old, BMI = 25.4 ± 3.3 kg/m^2, LBP duration = 77.0 ± 75.3 months). Mean pain intensity during the previous week, ODI, TSK, and PCS at baseline were 5.7 ± 2.1, 35.0 ± 10.5, 44.5 ± 7.9, and 25.1 ± 11.6, respectively.

TSK, SFear, and PCS scores demonstrated a statistically significant decrease between baseline and post-treatment (Table 1). MEP and DURATION also significantly decreased for all tasks. Angular amplitude and muscle activity measures did not show a statistically significant change following the IRP, except EMG_{peak1} which increased significantly during picking-up. Angular velocity increased significantly at the LLS ($LLSv_{flexion}$) during flexion and at the ULS ($ULSv_{flexion}$) during flexion, lifting, and picking-up.

There was no statistically significant association between changes in psychological factors and spinal biomechanics in all but two (98%) multivariable linear regression models (Figure 2 and Table S1). Consistently, there was no statistically significant relationship in 95% of univariate analyses (Table S2).

The changes in MEP (ΔMEP) were statistically significantly correlated with the changes in task-specific measures of pain-related fear, during all tasks (ΔSFear, $r = 0.26–0.62$, $p \leq 0.02$, median $r = 0.46$) (Table 2). A significant correlation between ΔMEP and ΔDURATION was also present during all tasks ($r = 0.28–0.37$, $p \leq 0.03$). However, there was no statistically significant correlation with changes in spinal angular amplitude, angular velocity, or muscle activity, except for $\Delta LLSa_{flexion}$ and $\Delta ULSa_{flexion}$ during stepping-up (9% of the tested correlations). There was no statistically significant correlation between ΔMEP and the general measures of pain-related fear (ΔTSK) or catastrophizing (ΔPCS), except for ΔTSK during flexion ($r = 0.28$, $p = 0.01$).

There were 29 participants with Sfear ≥5 during flexion, 44 during lifting, and 43 during picking-up. In

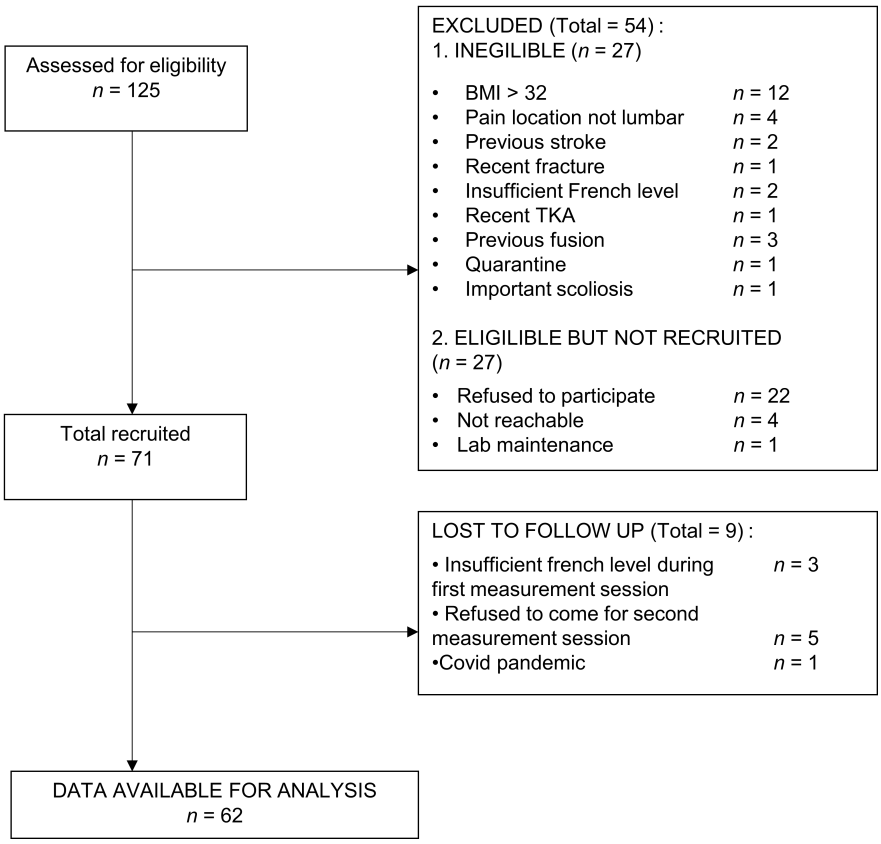

FIGURE 1 Flow diagram.

these subgroup analyses, only 3/51 multivariable analyses reported a statistically significant association between psychological factors and spinal biomechanics (Table S3).

DISCUSSION

The hypotheses were not supported, as associations between changes in psychological and spinal biomechanical measures were only scarcely and inconsistently observed (<3% of the analyses reported a statistically significant association). The interpretation favoring an absence of relationship was further reinforced by the fact that large decreases in pain-related fear and catastrophizing occurred after the IRP. Moreover, the lack of association was consistent between feared and non-feared daily-life tasks, as well as with specific and general measures of pain-related fear. The findings were again consistent in subgroup analyses, including only patients with a high level of fear in the movements. In contrast, decreases in task-specific pain-related fear were correlated with reduced movement-evoked pain in all tasks. In summary, the study results suggest that a decrease in pain-related fear for a specific task is not associated with changes in spinal biomechanics but is moderately to largely related to reduced pain intensity during this specific task.

Relationship between psychological and spinal biomechanical factors

This study, with longitudinal multi-segment measures of spinal biomechanics during various feared and non-feared daily-life activities, filled an important gap in our understanding of the relationship between psychological and spinal biomechanical factors. The results largely extend knowledge from a recent meta-analysis showing small effect sizes in cross-sectional studies[6] and from the only longitudinal study on this topic known by the authors that found a weak association between changes in fear-avoidance beliefs and changes in a global measure of spinal angular amplitude and velocity.[49] Altogether, present and prior results indicate that the existence of a large association between psychological and spinal biomechanical factors is very unlikely. This questions the current state of knowledge regarding the plausibility of a causal relationship between pain-related fear or catastrophizing and protective spinal movement behavior. Indeed, for a causal relationship to be plausible, large associations should exist in observational studies.[50,51]

The present study brings important information to appreciate the relationship between pain-related fear and physical measures in patients with CLBP. While unexpected, our findings are not totally disconnected from the literature, as prior studies analyzing the level

TABLE 1 Changes following the 3-week rehabilitation program (IRP)

ΔTSK (range: 17–68)	−14.0 ± 7.3				
ΔPCS (range: 0–52)	−13.9 ± 9.0				
	Flexion	**Lifting**	**Picking-up**	**Stepping-up**	**Sit-to-stand**
ΔSfear (range: 0–10)	**−4.0 ± 3.3**	**−4.8 ± 3.4**	**−5.0 ± 3.1**	**−1.5 ± 1.9**	**−2.1 ± 2.7**
ΔMEP (range: 0–10)	**−1.9 ± 2.6**	**−2.3 ± 2.6**	**−1.8 ± 2.3**	**−1.2 ± 1.6**	**−1.3 ± 1.7**
ΔDURATION (s)		**−0.8 ± 1.0**	**−0.7 ± 0.8**	**−0.4 ± 0.5**	**−0.5 ± 0.6**
$\Delta LLSa_{flexion}$ (°)	−1.9 ± 6.3	−0.6 ± 6.4	−0.9 ± 6.3	−1.2 ± 5.3	−1.2 ± 5.9
$\Delta ULSa_{flexion}$ (°)	−0.2 ± 4.3	−1.1 ± 7.0	−0.1 ± 5.2	0.1 ± 4.9	0.1 ± 4.5
$\Delta LLSv_{flexion}$ (°/s)	**−1.9 ± 4.9**	−2.3 ± 10.3	−1.7 ± 7.6	−1.2 ± 8.8	−1.2 ± 8.8
$\Delta ULSv_{flexion}$ (°/s)	**−5.3 ± 7.6**	**−8.0 ± 13.6**	**−7.9 ± 14.9**		
ΔEMG_{peak1} (%)	0.0 ± 0.2	0.1 ± 0.4	**0.2 ± 0.4**	0.0 ± 0.4	0.0 ± 0.4

Note: Data are reported as mean ± standard deviation. Statistically significant differences between pre- and post-treatment are reported in bold ($p < 0.05$).

of physical activity,[52–54] walking endurance capacity,[55] maximal oxygen consumption,[54,56] or back muscles strength,[34,53,57–60] also concluded on an absence of a relationship with pain-related fear. Overall, these results question the idea that submaximal performance in patients with CLBP, commonly related to the concepts of physical deconditioning or disuse, is importantly associated with pain-related fear.

Relationship between task-specific pain-related fear and movement-evoked pain

While our study found no conclusive relationship between psychological factors and a protective behavior measured with spinal biomechanical factors, it highlighted a moderate to a large association between reduced task-specific pain-related fear and reduced movement-evoked pain. Interestingly, the reductions in movement-evoked pain occurred independently of the changes in spinal biomechanics. Therefore, the popular hypothesis that altered spinal biomechanics should be corrected to reduce pain during movement is questioned by our results.[61,62] On the other hand, our findings support a direct association between pain-related fear and pain intensity, which may explain some of the mechanisms of IRPs. In support, neurophysiological research showed interferences between pain-related fear and the descending pain modulatory system, through the activation of brain regions such as the amygdala or the periaqueductal gray.[63,64] Moreover, the reduction of pain-related fear has been associated with changes in cognitive/affective brain regions that may participate in pain modulation.[65] While these observations may sound like promising perspectives for the understanding of CLBP, it is important to note that our findings and previous evidence cannot prove the direction of the relationship between pain-related fear and movement-evoked pain, if any.

Our findings also showed that having less movement-evoked pain is associated with improved performance, as shown by the correlations between movement-evoked pain and the duration of the tasks. These findings suggest that movement-evoked pain may be an important factor of limitation in daily activities, as previously hypothesized.[8,40,41] As there was no association between the duration of the task and pain-related fear, these results also provide preliminary evidence of a possible indirect relationship between task-specific pain-related fear and a global measure of performance (here, the time necessary to perform the task), through their associations with movement-evoked pain.

Clinical implications

This study provides novel evidence on the recovery side of the fear-avoidance model, which is much less researched than the part explaining the acquisition and maintenance of chronic pain. Specifically, our results suggest that reductions in pain-related fear and catastrophizing do not directly lead to a reduction in spinal protective movement behavior. In addition, our study does not support that improving spinal angular amplitude or velocity, or moving with lower muscle activity, is needed to reduce pain-related fear or movement-evoked pain. In fact, changing the spinal biomechanical factors measured in this study will unlikely lead to reduced pain-related fear or movement-evoked pain in patients with CLBP. Furthermore, rehabilitation strategies should consider the associations between task-specific pain-related fear and movement-evoked pain. These findings support previous research on fear reduction, stressing the importance of safety learning.[66] To establish safety learning, expectancy violation through experimentation is crucial and can be enhanced by creating new positive experiences. As an example, lifting with less pain could create a new positive experience that contrasts with the belief "it

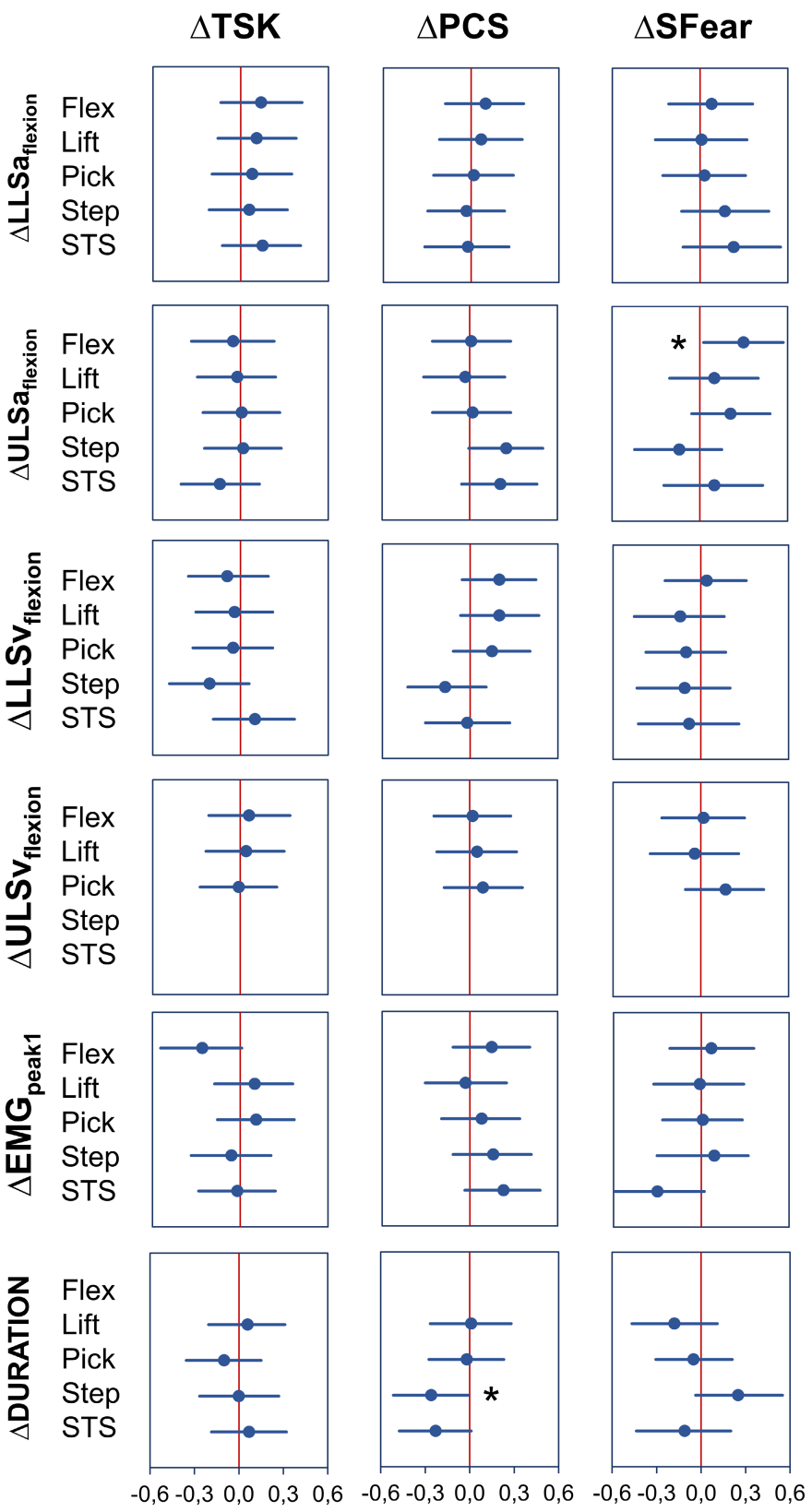

FIGURE 2 Standardized Beta coefficients between changes in psychological and biomechanical measures in each task. Standardized Beta coefficients (blue dots) and their 95% confidence interval (blue lines) for the relationships between ΔTSK, ΔPCS, or ΔSFear and six spinal biomechanical measures during five tasks. ΔMEP was included as a confounding variable in these analyses. Flex: flexion; lift: Lifting; pick: picking-up; step: stepping-up; STS: sit-to-stand. The stars (*) indicate significant associations ($p<0.05$). The actual data are reported in (Table S1).

TABLE 2 Pearson correlation coefficients (*r*) between changes in movement-evoked pain (ΔMEP) and changes in psychological or biomechanical measures in each task

	ΔTSK	ΔPCS	ΔSfear	$\Delta LLSa_{flexion}$	$\Delta ULSa_{flexion}$	$\Delta LLSv_{flexion}$	$\Delta ULSv_{flexion}$	ΔEMG_{peak1}	ΔDURATION
ΔMEP (flexion)	**0.28**	0.06	**0.35**	0.14	−0.14	0.08	0.12	−0.08	
ΔMEP (lifting)	0.11	0.22	**0.48**	0.08	−0.09	0.23	0.12	0.01	**0.31**
ΔMEP (picking-up)	0.15	0.19	**0.26**	0.05	−0.04	0.19	−0.04	0.15	**0.37**
ΔMEP (stepping-up)	0.25	0.25	**0.46**	**0.34**	**−0.3**	0.12		0.11	**0.28**
ΔMEP (sit-to-stand)	0.14	−0.11	**0.62**	−0.03	−0.02	0.11		0.14	**0.35**

Note: Statistically significant relationships are reported in bold ($p<0.05$).

is dangerous to lift for my back," which will ultimately reduce fear by repeating this experience. Similarly, interventions aiming at reducing movement-evoked pain, such as symptom-modification approaches,[67] might consider task-specific pain-related fear in their progression. Future clinical trials with interventions that specifically aim to improve task-specific pain-related fear and movement-evoked pain are needed to confirm these potential clinical implications.

Limitations

The first limitations of this study are related to the rehabilitation program and the study design. The IRP is a multimodal intervention that does not focus on improving the spinal biomechanical measures analyzed in this study. Therefore, it remains possible that changes in spinal biomechanics could have been observed with more specific interventions.[68–70] Nevertheless, the IRP was an optimal setting to study the relationships described in the FAM, as it is the most recommended intervention for highly disabled patients with CLBP[71] and demonstrated large effects on psychological factors. Furthermore, it is possible that changes in spinal biomechanics may require more time to develop, and that multiple follow-ups are needed to detect these changes.[72] Finally, while adequately powered, this study tested a single population. The generalizability of the findings to different settings thus remains to be established. Consequently, further research with interventions of longer duration, targeting specifically spinal biomechanics and psychological factors, and with multiple follow-ups will be necessary to confirm the insights outlined by the present study.

A second limitation is related to the measurement of spinal biomechanics. Although it was quantified using the most relevant discrete measures based on current knowledge, it is possible that considering other measures may provide a different perspective on the association with psychological factors. Furthermore, the participants' performance may have been influenced by the video they watched before performing each task. While using less standardized instructions may affect the variability of the measurements over time, it might provide insights into changes in habitual movement behavior, such as changing from a squat to a stoop lifting or picking-up pattern. Finally, the poor to moderate reliability of angular velocity might have influenced the measurements and thus the association between spinal biomechanics and psychological factors.

Finally, the high number of statistical tests conducted without correction for multiple analyses needs to be discussed. In this study, we purposefully chose to assess the association between psychological and spinal biomechanical factors in a number of daily-life tasks and with diverse measures to increase confidence in the overall findings. This approach was successful as consistent

observations were obtained across tasks and measures, providing a wider and more robust picture of the relationship between psychological and biomechanical factors. Importantly, correcting for multiple analyses would not have changed the overall findings of the study, and the few significant associations may be considered spurious.

CONCLUSION

This study showed that large changes in pain-related fear or catastrophizing were not associated with changes in protective movement behavior measured with spinal biomechanical factors. In contrast, for all the tasks, a decrease in task-specific pain-related fear was associated with a reduction in movement-evoked pain. These findings do not support the plausibility of a causal relationship between pain-related fear and movement avoidance when measured with spinal biomechanical factors. However, they provide preliminary evidence for the need to take into account the moderate to large associations between task-specific pain-related fear and movement-evoked pain in CLBP research and rehabilitation.

ACKNOWLEDGMENTS

We would like to thank Valentina Pizzolato and Benjamin Coty for their important contribution to markers' tracking and data management.

FUNDING INFORMATION

The study was supported by the University of Applied Sciences and Arts Western Switzerland/HES-SO, Faculty of Health Science.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare for this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. Standardized Beta coefficients between changes in psychological and biomechanical measures in each task.

Table S2. Pearson correlation coefficients (*r*) between changes in psychological and biomechanical measures.

Table S3. Standardized Beta coefficients between changes in psychological and biomechanical measures in subgroups of patients with Sfear ≥ 5.

How to cite this article: Christe G, Benaim C, Luthi F, Jolles BM, Favre J. Reduction in pain-related fear is not associated with improvement in spinal biomechanics but with decrease in movement-evoked pain in patients with chronic low back pain. Pain Pract. 2023;23:290–300. https://doi.org/10.1111/papr.13191