REVIEW ARTICLE

EJP
European Journal of Pain

The relationships between spinal amplitude of movement, pain and disability in low back pain: A systematic review and meta-analysis

J. Nzamba[1] | S. Van Damme[2] | J. Favre[3] | G. Christe[3,4]

[1]Division of Physiotherapy, School of Health Professions, Bern University of Applied Sciences, Bern, Switzerland

[2]Department of Experimental-Clinical and Health Psychology, Ghent University, Ghent, Belgium

[3]Swiss BioMotion Lab, Department of Musculoskeletal Medicine, Lausanne University Hospital and University of Lausanne, Lausanne, Switzerland

[4]Department of Physiotherapy, HESAV School of Health Sciences, HES-SO University of Applied Sciences and Arts Western Switzerland, Lausanne, Switzerland

Correspondence
G. Christe, HESAV School of Health Sciences, Av. Beaumont 21, 1010 Lausanne, Switzerland.
Email: guillaume.christe@hesav.ch

Abstract

Background and Objectives: The role of spinal movement alterations in low back pain (LBP) remains unclear. This systematic review and meta-analyses examined the relationships between spinal amplitude of movement, disability and pain intensity in patients with LBP.

Databases and Data Treatment: We searched PubMed, CINAHL, Embase, Pedro and Web of Science for relevant articles until 14th March 2023. Risk of bias was assessed with the Quality in Prognostic Studies Tool. We analysed the relationships between amplitude of movement, disability and pain intensity with standard correlational meta-analyses and meta-analytic structural equation modelling (MASEM) in cross-sectional and longitudinal data.

Results: A total of 106 studies (9001 participants) were included. In cross-sectional data, larger amplitude of movement was associated with lower disability (pooled coefficient: −0.25, 95% confidence interval: [−0.29 to −0.21]; 69/5899 studies/participants) and pain intensity (−0.13, [−0.17 to −0.09]; 74/5806). An increase in amplitude of movement was associated with a decrease in disability (−0.23, [−0.31 to −0.15]; 33/2437) and pain intensity (−0.25, [−0.33 to −0.17]; 38/2172) in longitudinal data. MASEM revealed similar results and, in addition, showed that amplitude of movement had a very small influence on the pain intensity–disability relationship.

Conclusions: These results showed a significant but small association between amplitude of movement and disability or pain intensity. Moreover, they demonstrated a direct association between an increase in amplitude of movement and a decrease in pain intensity or disability, supporting interventions aiming to reduce protective spinal movements in patients with LBP.

Significance: The large meta-analyses performed in this work revealed an association between reductions in spinal amplitude of movement and increased levels of disability and pain intensity in people with LBP. Moreover, it highlighted that LBP recovery is associated with a reduction in protective motor behaviour (increased amplitude of movement), supporting the inclusion of spinal movement in the biopsychosocial understanding and management of LBP.

1 | INTRODUCTION

Low back pain (LBP) is one of the main causes of disability worldwide and represents an important cause of consultation in primary care (Chen et al., 2022; Hartvigsen et al., 2018). Prior research has repeatedly found that patients with LBP show reduced spinal amplitude of movement (spinal amplitude) compared to asymptomatic controls, supporting a protective movement behaviour in patients with LBP (Laird et al., 2014; Papi et al., 2018). Nevertheless, prior research could not elucidate to what extent reduced spinal amplitude contributes to disability and pain intensity in patients with LBP, calling for a better understanding of the relationships between spinal amplitude, disability and pain intensity.

LBP is considered to be a multidimensional condition in which disability and pain are influenced by multiple factors (Hartvigsen et al., 2018). In addition, while spinal movement alterations are a major treatment target in LBP rehabilitation (Wood et al., 2021; Wun et al., 2021), it is not known if improving spinal amplitude is associated with improvements in disability and pain intensity. Therefore, having a better understanding of the cross-sectional and longitudinal relationships between spinal movement alterations, disability and pain intensity are critical to inform rehabilitation principles. Hereafter, we describe the various limitations in previous research that may explain the current uncertainties.

While systematic reviews on relationships between spinal movement alterations, disability and pain intensity have already been completed in LBP, they did not include a meta-analysis (Wernli, Tan, et al., 2020), or when a meta-analysis was performed it only included a limited number of studies and participants (Shanbehzadeh et al., 2022; Steiger et al., 2012). Including meta-analyses with large population is particularly important in this regard, as they may provide a clearer and more confident synthesis of the evidence in literature. Furthermore, so far, systematic reviews tested the associations between spinal amplitude and disability or pain intensity in isolation, while disability and pain intensity are related (Zale et al., 2013). Therefore, testing the associations between all these factors together, with meta-analytic structural equation modelling (MASEM) in a large number of studies (Cheung, 2015), is necessary to advance our understanding of the role of spinal amplitude in LBP. Moreover, pain intensity is known to importantly influence disability (Lee et al., 2015). In fact, it has been postulated that a change in spinal amplitude may be a mechanism by which pain is reduced, which ultimately reduces disability (Hodges & Smeets, 2015). Therefore, these analyses can also reveal if spinal amplitude mediates the relationship between pain and disability. Other factors such as self-efficacy or fear have already been shown to mediate the pain intensity–disability relationship (Lee et al., 2015).

The primary objective of this systematic review was to evaluate the relationships between spinal amplitude, disability and pain intensity. These relationships were tested separately in cross-sectional and longitudinal data, as they provide different information. The underlying hypotheses were that in individuals with LBP, (i) larger spinal amplitude would be associated with lower level of disability and pain intensity (with cross-sectional data), (ii) an increase in spinal amplitude would be associated with a decrease in disability and pain intensity (with longitudinal data) and (iii) spinal amplitude would mediate the pain intensity–disability relationship.

2 | METHODS

This review has been registered in PROSPERO (CRD42020221099) and follows the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) principles for its presentation (Moher et al., 2009).

2.1 | Eligibility criteria

To be eligible in this systematic review and meta-analysis, the studies had to fulfil the following criteria:

1. Language: studies written in English or French.
2. Population: studies involving adults presenting non-specific acute, subacute or chronic LBP with or without leg pain.
3. Study design: any study of cross-sectional and longitudinal design involving at least 10 participants with measurements of spinal amplitude and disability and/or pain intensity.
4. Spinal amplitude: collected during a dynamic task such as maximal range of motion (ROM) tests (e.g. maximal bending, fingertip-to-floor [FTF]) or functional activities (e.g. lifting a box). The amplitudes had to be expressed in degrees (e.g. lumbar flexion angle) or in centimetres (e.g., FTF or Schober tests) and measured in the sagittal, frontal or transverse plane. The amplitude had to be measured at the lumbar region alone or in combination with other regions (e.g. lumbar + thoracic spine or hips + lumbar spine + thoracic spine). Because of the influence of the hamstring flexibility on the measures, studies using sit-and-reach tests were excluded (Mayorga-Vega et al., 2014).
5. Disability: evaluated with questionnaires. Studies testing physical function through physical tests were

excluded, as evaluation of spinal amplitude of movement is often included in these tests.

6. Pain intensity: evaluated numerically (e.g. numeric or visual scale).
7. Relationships between spinal amplitude and pain intensity or disability: either reported in the publication or available after contacting the authors. If spinal amplitude and pain intensity or disability were measured, but relationships were not reported, the authors of the study were contacted to obtain the raw data. They were contacted three times before excluding the study.

2.2 | Study selection

PubMED, CINAHL, Embase, Pedro and Web of Science were searched for relevant articles, from the start until September 2020. An updated search was conducted on 14th March 2023. Specific search strategies are presented in Appendix S1. Using the Rayyan program (http://rayyan.qcri.org), the retrieved studies were examined in two stages. First, titles and abstracts were screened based on the inclusion and exclusion criteria described above independently by two reviewers. Differences were debated, and disagreements were solved with the help of a third reviewer. Then, two reviewers examined the full text of the previously selected studies based on the same criteria, with the help of a third reviewer if needed. Deduplication was performed to ensure that similar data set was not included in the meta-analyses.

2.3 | Risk of bias

The Quality in Prognostic Studies Tool (QUIPS; Hayden et al., 2006, 2013) was used to analyse the risk of bias in the included studies. Six domains of risk of bias that can influence the results of this systematic review and meta-analysis were evaluated and scored with this tool following previous comparable works (Appendix S2; Christe, Crombez, et al., 2021; Hayden et al., 2006). The analysis was performed by two reviewers separately.

2.4 | Data extraction and coding

Data extraction was conducted by two reviewers independently using a pre-tested spreadsheet. A third person checked the extracted data. Data extracted included the study population (coded as acute (including subacute) or chronic LBP) and gender distribution (% female). Acute LBP was defined as pain of <3 months, while chronic LBP more than 3 months. Data were extracted separately for all groups if the study included more than one group (e.g. one group with acute LBP and one group with chronic LBP [Grotle et al., 2004]).

For spinal amplitude, values of spinal amplitude and instrumentation (coded as marker-based measurement, inclinometer, Schober test, Finger-to-floor [FTF] test or isokinetic) were extracted. Information about the activity was also recorded: type of activity (coded as maximal ROM tests or functional activity), plane of motion (coded as sagittal, frontal or transverse), direction of movement (coded as flexion or extension for the sagittal plane; lateral flexion for the frontal plane; rotation for the transverse plane) and region of measurement (coded as lumbar, trunk or global).

For disability, values of disability and information concerning the measurement instrument were extracted. For pain intensity, values of pain intensity, measurement instrument and recall period (coded as during activity, current or during the last 24 h, during the last week or during more than 1 week) were extracted.

Finally, relationships between: (1) spinal amplitude and disability, (2) spinal amplitude and pain intensity (3) pain intensity and disability were extracted. If these data were not reported, they were calculated based on the raw data provided by the authors. The type of relationship (coded as Pearson, Spearman or Standardized beta coefficient) and the nature of the data (coded as cross-sectional or longitudinal data) were also extracted. When necessary, the opposite relationships (obtained by multiplying by the coefficients by −1) were considered to be consistent among studies. This way, for all studies, negative coefficients indicate associations between larger spinal amplitude and lower pain intensity or disability (cross-sectional data) or between increased spinal amplitude and decreased pain intensity or disability (longitudinal data).

2.5 | Data synthesis and meta-analysis

In case of multiple measures for one characteristic (e.g. spinal amplitude) in a study, the relationships were calculated for each measure, and then the coefficients averaged to have only one data point for the relationship of interest (Hunter & Schmidt, 2004). If possible, an a priori selection of the measures was performed to avoid the bias of averaging multiple data (Hunter & Schmidt, 2004). Specifically, spinal amplitude measures were selected in this order: (1) measurement of the lumbar region, (2) measurement of the trunk region, (3) global measurement. Based on current recommendations on core outcomes for LBP, disability measures were selected in this order: for: (1) Oswestry Disability Index (ODI), (2) Roland Morris Disability Questionnaire (RMDS), (3) other; and pain intensity

measures in the following order: (1) Numeric Pain Rating Scale (NPRS), (2) Visual Analog Scale (VAS), (3) other (Chiarotto et al., 2019).

Meta-analyses were performed separately for the relationships between spinal amplitude and disability and the relationships between spinal amplitude and pain intensity. As studies reported different measurements, the random-effects model with inversed-variance method was used to perform the meta-analyses (Ahn & Kang, 2018; Borenstein et al., 2021). Fisher's Z transformation was used to avoid edge effects in the meta calculations (Quintana, 2015; Welz et al., 2022). Pooled coefficients of the included studies and their corresponding 95% confidence intervals (CI) as well as the overall weighted estimate were illustrated in forest plots (Quintana, 2015). Their interpretation was based on the criterion described by Cohen (Cohen, 1988), with 0.10 to 0.29, 0.30 to 0.49 and >0.50 considered small, moderate and large associations, respectively. Statistical heterogeneity was tested with Q and I^2 statistics. I^2 values of 25%, 50% and 75% were interpreted as low, moderate and substantial between-study variations, respectively (Higgins et al., 2022). Additionally, Baujat Plots were used to determine the sources of heterogeneity and influential cases (Quintana, 2015).

Subgroup and moderation analyses were conducted to evaluate the effect of the population (acute or chronic LBP) and the direction of movement (flexion, extension, lateral flexion or rotation). Sensitivity analyses were done by excluding studies showing a high risk of bias based on the QUIPS. One analysis was performed by excluding any study having at least one item of the QUIPS with high risk of bias. Sensitivity analyses were also performed independently for each QUIPS item. Publication bias was analysed using Egger's regression (<25 studies) or rank correlation (>25 studies) and illustrated with funnel plots (Quintana, 2015).

In addition to the individual meta-analyses above, meta-analytic structural equation modelling (MASEM) was conducted to evaluate the relationships between spinal amplitude and disability and pain intensity together. All analyses were conducted using R software, specifically with the packages: 'metafor', 'robumeta' and 'metaSEM'.

3 | RESULTS

3.1 | Study selection

Figure 1 depicts the study selection procedure as a PRISMA flowchart diagram. The relationships were available in 46 studies. In addition, we contacted 375 study authors to request data, which allowed the inclusion of 60 additional studies.

3.2 | Study characteristics

For this systematic review, 106 studies totaling 9001 participants were included. Forty-one studies (39%) had a cross-sectional design, while 65 (61%) had a longitudinal design. Cross-sectional meta-analyses were based on cross-sectional studies or baseline data of longitudinal studies, totaling 94 studies (8053 participants). Longitudinal meta-analyses were based on 45 studies (2840 participants). Seventy-one percent of the included studies involved patients with chronic LBP, 10% included patients with acute and subacute LBP and 19% included patients with any duration of LBP. Appendix S3 presents the characteristics of the included studies.

3.3 | Risk of bias

The evaluation of risk of bias is available in Appendix S4. Study participation was rated with low, moderate and high risk of bias in 26%, 63% and 10% of the studies, respectively. The most frequent risk of bias was unclear description of study population (moderate) or the presence of participants with previous spinal surgery (high risk). In studies presenting longitudinal data, 28% of the studies had moderate risk of bias regarding attrition and 20% of the studies had high risk of bias. The prognostic factor measurement (spinal amplitude) was rated as low risk in 55% of the studies that measured lumbar movement. Moderate (trunk measurement) and high (global measurement, including the hips) risks of bias were found in 18% and 27% of studies, respectively. The outcome measurement (pain or disability instrument) was rated with low risk of bias in 95% of the studies. Study confounding was rated as low risk of bias in 39% of the studies, with these studies considering the three relationships between spinal amplitude, pain and disability. Finally, statistical analysis was rated with low, moderate and high risk of bias in 60%, 37% and 3% of the studies, respectively. The major risk of bias in the main analyses was due to the averaging of multiple coefficients in some studies (moderate risk).

3.4 | Main analyses

Relationships based on cross-sectional data between spinal amplitude and disability were available for 69 studies and 5899 participants (Adamu et al., 2019; Alschuler et al., 2009; Alves et al., 2020; Ansari et al., 2014; Atya, 2013; Aure & Kvåle, 2022; Bayar et al., 2003; Bazzaz-Yamchi et al., 2021; Caporaso et al., 2012; Carrasco-Martínez et al., 2019; Christe et al., 2016; Coyle et al., 2017; de Brito
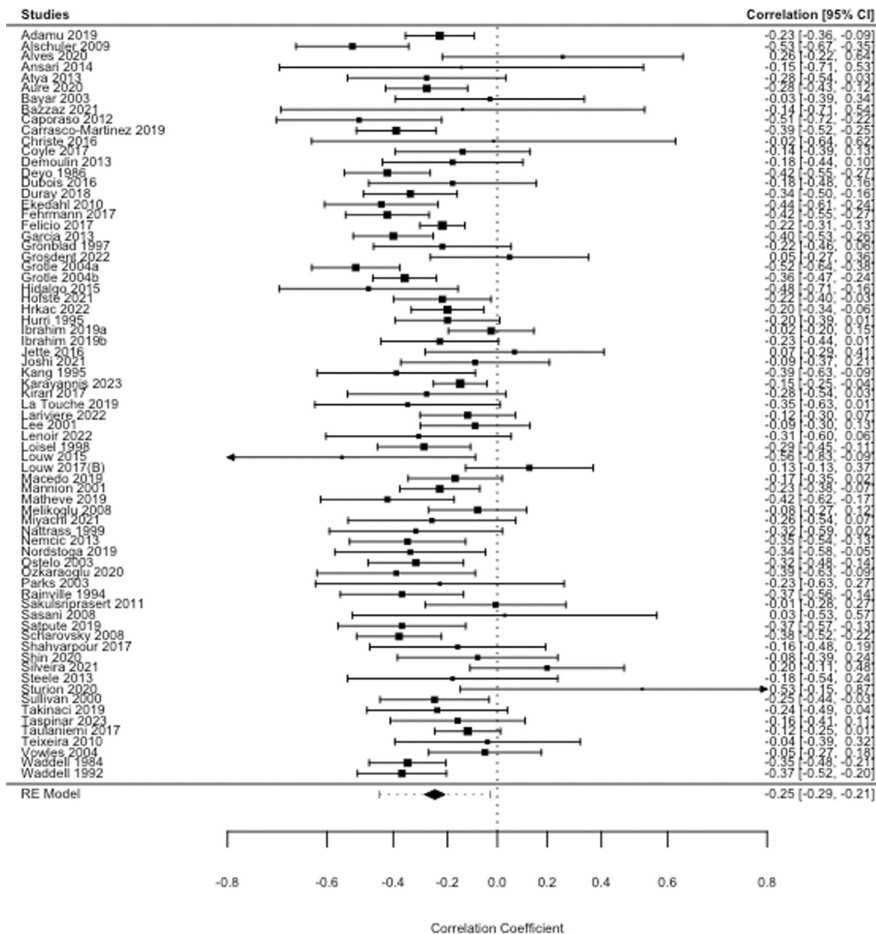
FIGURE 1 Flowchart diagram of included studies in the meta-analysis. In the identification phase, number of studies identified in the first and updated literature search are presented.
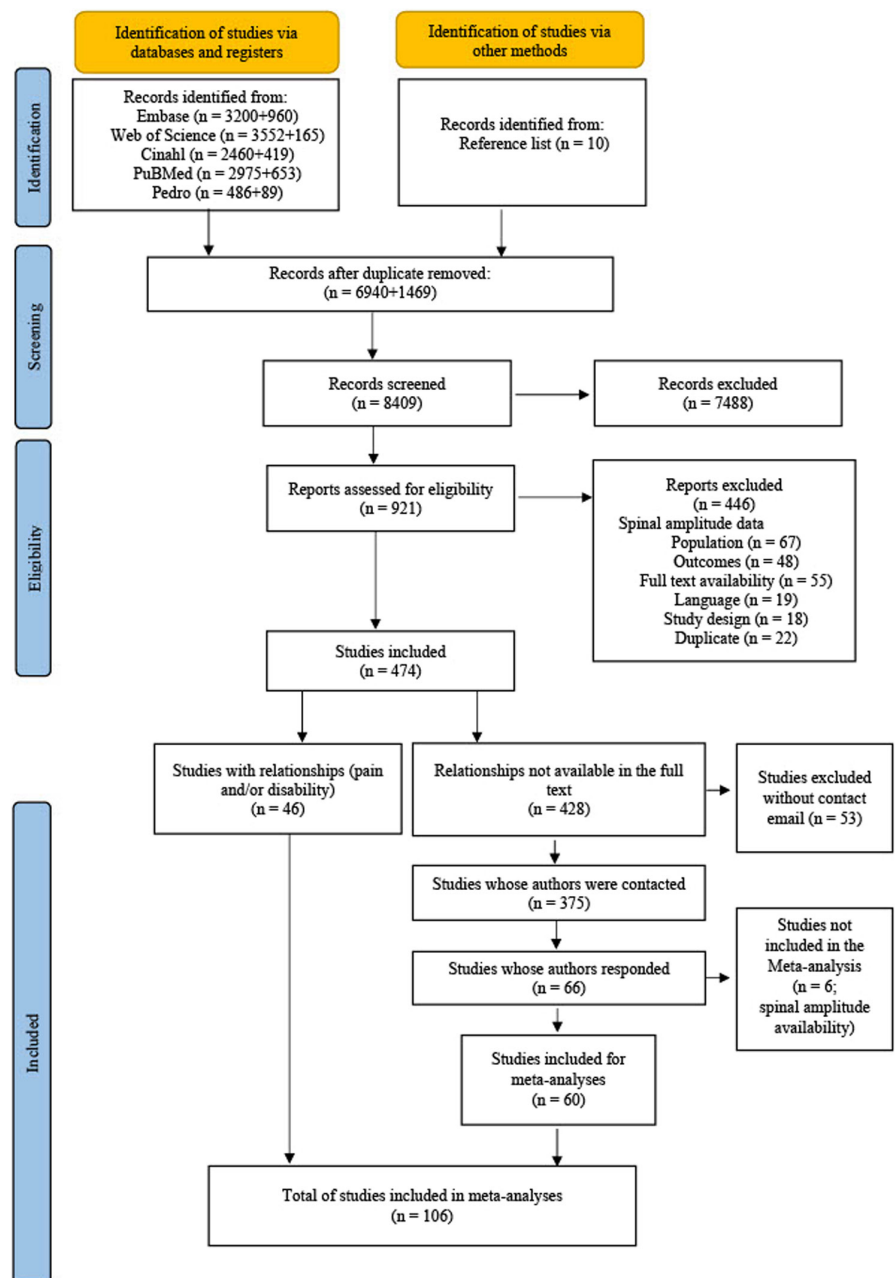
Macedo et al., 2019; Demoulin et al., 2013; Deyo, 1986; Dubois et al., 2016; Duray et al., 2018; Ekedahl et al., 2010; Fehrmann et al., 2017; Felicio et al., 2017; Garcia et al., 2013; Grönblad et al., 1997; Grosdent et al., 2023; Grotle et al., 2004; Hidalgo et al., 2015; Hofste et al., 2021; Hrkać et al., 2022; Hurri et al., 1995; Ibrahim et al., 2019; Jette et al., 2016; Joshi et al., 2021; Kang et al., 1995; Karayannis et al., 2023; Kiran et al., 2017; La Touche et al., 2019; Larivière et al., 2022; Lee et al., 2001; Lenoir dit Caron et al., 2022; Loisel et al., 1998; Louw et al., 2015; Louw, Farrell, et al., 2017; Mannion et al., 2001; Matheve et al., 2019; Melikoglu et al., 2009; Miyachi et al., 2021; Nattrass et al., 1999; Nemcić et al., 2013; Nordstoga et al., 2019; Ostelo et al., 2003; Ozkaraoglu et al., 2020; Parks et al., 2003;

Rainville et al., 1994; Sakulsriprasert et al., 2011; Sasani et al., 2008; Satpute et al., 2019; Scharovsky et al., 2008; Shahvarpour et al., 2017; Shin, 2020; Silveira et al., 2021; Steele et al., 2013; Sturion et al., 2020; Sullivan et al., 2000; Takinacı et al., 2019; Taşpınar et al., 2023; Taulaniemi et al., 2017; Teixeira da Cunha-Filho et al., 2010; Vowles et al., 2004; Waddell et al., 1992; Waddell & Main, 1984). The meta-analysis yielded a pooled coefficient of -0.25 [95% confidence interval (CI): -0.29 to -0.21], indicating that larger spinal amplitude was associated with lower disability (Figure 2). Heterogeneity was moderate ($I^2 = 50.4\%$, Qstatistic: $p < 0.001$).

For the relationship between change in spinal amplitude and change in disability, based on longitudinal data, 33 studies with 2437 participants were included in the

Studies — Correlation [95% CI]

Studies	Correlation [95% CI]
Adamu 2019	-0.23 [-0.36, -0.09]
Alschuler 2009	-0.53 [-0.67, -0.35]
Alves 2020	-0.15 [-0.22, 0.64]
Ansari 2014	-0.28 [-0.54, 0.03]
Atya 2013	-0.28 [-0.43, -0.12]
Aure 2020	-0.03 [-0.39, 0.34]
Bayar 2003	-0.14 [-0.71, 0.52]
Bazzaz 2021	-0.57 [-0.77, -0.24]
Caporaso 2012	-0.39 [-0.52, -0.25]
Carrasco-Martínez 2019	-0.02 [-0.65, 0.62]
Christe 2016	-0.14 [-0.93, 0.91]
Coyle 2017	-0.18 [-0.44, 0.10]
Demoulin 2013	-0.42 [-0.55, -0.27]
Deyo 1986	-0.18 [-0.48, 0.16]
Dubois 2016	-0.34 [-0.50, -0.16]
Duray 2018	-0.40 [-0.63, -0.24]
Ekedahl 2010	-0.42 [-0.55, -0.27]
Fehrmann 2017	-0.22 [-0.31, -0.13]
Felicio 2017	-0.22 [-0.40, -0.03]
Garcia 2013	-0.05 [-0.27, 0.08]
Gronblad 1997	-0.52 [-0.64, -0.38]
Grosdent 2022	-0.36 [-0.47, -0.24]
Grotle 2004a	-0.22 [-0.40, -0.03]
Grotle 2004b	-0.20 [-0.34, -0.06]
Hidalgo 2015	-0.20 [-0.39, 0.01]
Hofste 2021	-0.23 [-0.44, 0.01]
Hrkac 2022	0.07 [-0.29, 0.41]
Hurri 1995	-0.39 [-0.63, -0.09]
Ibrahim 2019a	-0.15 [-0.25, -0.04]
Ibrahim 2019b	-0.28 [-0.54, 0.01]
Jette 2016	-0.35 [-0.63, 0.01]
Joshi 2021	-0.09 [-0.30, 0.13]
Kang 1995	-0.31 [-0.60, 0.06]
Karayannis 2023	-0.58 [-0.85, 0.01]
Kiran 2017	0.13 [-0.13, 0.37]
La Touche 2019	-0.17 [-0.35, 0.02]
Lariviere 2022	-0.17 [-0.35, 0.02]
Lee 2001	-0.42 [-0.62, 0.17]
Lenoir 2022	-0.08 [-0.27, 0.12]
Loisel 1998	-0.26 [-0.54, 0.07]
Louw 2015	-0.35 [-0.59, 0.05]
Louw 2017(B)	-0.32 [-0.48, -0.14]
Macedo 2019	-0.34 [-0.58, -0.05]
Mannion 2001	-0.32 [-0.48, -0.14]
Matheve 2019	-0.23 [-0.63, 0.27]
Melikoglu 2008	-0.37 [-0.55, -0.14]
Miyachi 2021	-0.01 [-0.28, 0.24]
Nattrass 1999	0.03 [-0.53, 0.57]
Nemcic 2013	-0.38 [-0.52, -0.22]
Nordstoga 2019	-0.16 [-0.48, 0.19]
Ostelo 2003	-0.08 [-0.39, 0.24]
Ozkaraoglu 2020	-0.18 [-0.54, 0.24]
Parks 2003	0.53 [-0.15, 0.87]
Rainville 1994	-0.25 [-0.44, -0.03]
Sakulsriprasert 2011	-0.24 [-0.49, 0.04]
Sasani 2008	-0.16 [-0.41, 0.11]
Satpute 2019	-0.12 [-0.25, 0.01]
Scharovsky 2008	-0.04 [-0.39, 0.32]
Shahvarpour 2017	-0.05 [-0.18, 0.24]
Shin 2020	-0.37 [-0.52, -0.20]
Silveira 2021	
Steele 2013	
Sturion 2020	
Sullivan 2000	
Takinaci 2019	
Taspinar 2023	
Taulaniemi 2017	
Teixeira 2010	
Vowles 2004	
Waddell 1984	
Waddell 1992	
RE Model	-0.25 [-0.29, -0.21]

Correlation Coefficient
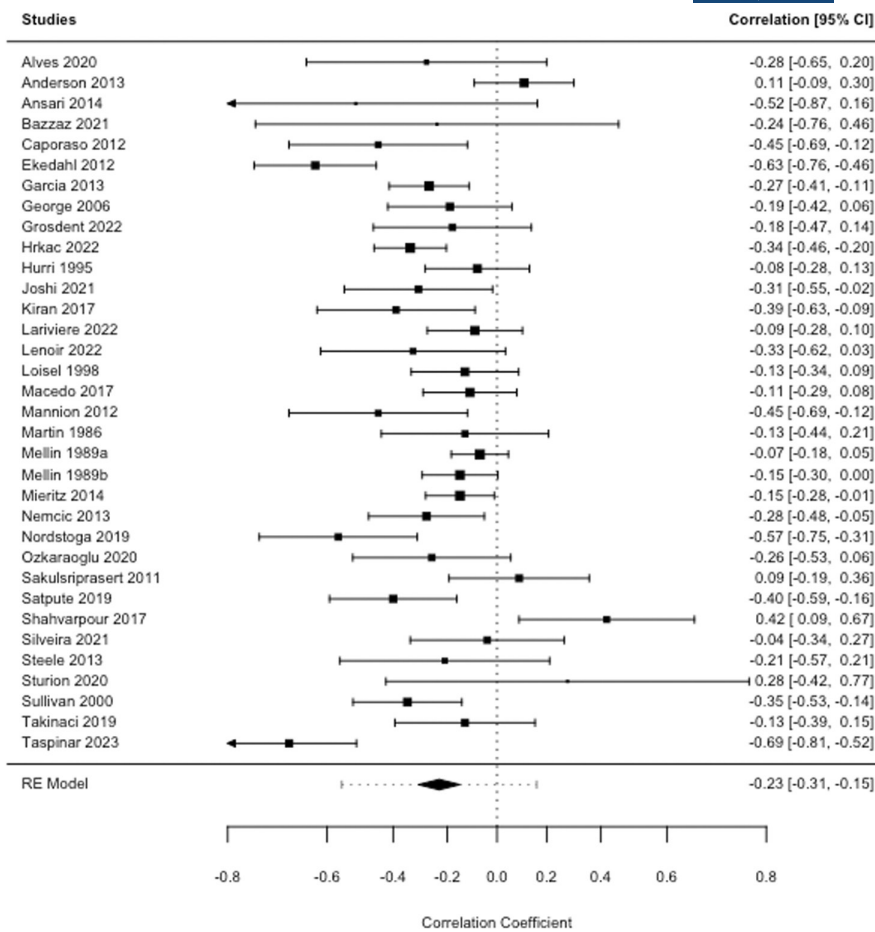-0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8

FIGURE 2 Forest plot of the associations between spinal amplitude and disability for cross-sectional data. Negative coefficient means that a larger spinal amplitude is associated with a lower disability. The black squares represent the coefficients and the horizonal lines their 95% confidence intervals (95% CI). The actual numbers are reported in the right side of the plot. The size of the squares is proportional to the studies' contribution (weights) to the pooled effect estimate. The diamond represents the predicted pooled effect. The width of the diamond indicates the 95% CI and the dashed line prediction interval. RE, random effect. a & b: different populations in a same study.

meta-analysis (Alves et al., 2020; Anderson et al., 2013; Ansari et al., 2014; Bazzaz-Yamchi et al., 2021; Caporaso et al., 2012; de Brito Macedo et al., 2019; Ekedahl et al., 2012; Garcia et al., 2013; George et al., 2006; Grosdent et al., 2023; Hrkać et al., 2022; Hurri et al., 1995; Joshi et al., 2021; Kiran et al., 2017; Larivière et al., 2022; Lenoir dit Caron et al., 2022; Loisel et al., 1998; Mannion et al., 2012; Martin et al., 1986; Mellin et al., 1989; Mieritz et al., 2014; Nemcić et al., 2013; Nordstoga et al., 2019; Ozkaraoglu et al., 2020; Sakulsriprasert et al., 2011; Satpute et al., 2019; Shahvarpour et al., 2017; Silveira et al., 2021; Steele et al., 2013; Sturion et al., 2020; Sullivan et al., 2000; Takinacı et al., 2019; Taşpınar et al., 2023; Vowles et al., 2007). The pooled coefficient was −0.23 [95%CI −0.31 to −0.15], indicating that an increase in spinal amplitude was associated with a decrease in disability (Figure 3). Heterogeneity was substantial ($I^2 = 72.5\%$, Qstatistic: $p < 0.001$).

Relationships based on cross-sectional data between spinal amplitude and pain intensity were available for 74 studies with 5806 participants (Alschuler et al., 2009; Alves et al., 2020; Anderson et al., 2013; Ansari et al., 2014; Aure & Kvåle, 2022; Bazzaz-Yamchi et al., 2021; Caporaso et al., 2012; Carpino et al., 2020; Carrasco-Martínez et al., 2019; Christe et al., 2016; Coyle et al., 2017; de Brito

Macedo et al., 2019; Demoulin et al., 2013; Du et al., 2017; Dubois et al., 2016; Duray et al., 2018; Fehrmann et al., 2017; Garcia et al., 2013; Geller et al., 2016; Grosdent et al., 2023; Grotle et al., 2004; Hidalgo et al., 2015; Hofste et al., 2021; Hrkać et al., 2022; Ibrahim et al., 2019; Jensen et al., 2010; Jette et al., 2016; Joshi et al., 2021; Kernan & Rainville, 2007; Kienbacher et al., 2017; Kiran et al., 2017; Larivière et al., 2022; Lenoir dit Caron et al., 2022; Louw et al., 2015; Louw, Farrell, et al., 2017; Louw, Zimney, et al., 2017; Mannion et al., 2001; Marich et al., 2017; Matheve et al., 2019; McCracken et al., 2002; Melikoglu et al., 2009; Mieritz et al., 2014; Miyachi et al., 2021; Neblett et al., 2013; Nemcić et al., 2013; Nordstoga et al., 2019; Olaogun et al., 2004; Ostelo et al., 2003; Osumi et al., 2019; Ozkaraoglu et al., 2020; Pagé et al., 2015; Papciak & Feuerstein, 1991; Peng et al., 2016; Preyde, 2000; Sakulsriprasert et al., 2011; Sasani et al., 2008; Satpute et al., 2019; Shahvarpour et al., 2017; Shin, 2020; Shum et al., 2013; Silveira et al., 2021; Steele et al., 2013; Sturion et al., 2020; Takinacı et al., 2019; Taşpınar et al., 2023; Taulaniemi et al., 2017; Teixeira da Cunha-Filho et al., 2010; Thomas & France, 2008; van Wingerden et al., 2008; Villalta Santos et al., 2019; Vowles et al., 2004, 2007; Yuen et al., 2017). The meta-analysis resulted in a pooled coefficient of −0.13 [95%CI −0.20 to −0.12],

FIGURE 3 Forest plot of the associations between change in spinal movement and change in disability. Negative coefficient means that an increase in spinal amplitude is associated with a decrease in disability. The black squares represent the coefficients and the horizonal lines the 95% confidence interval (95% CI). The actual numbers are reported in the right side of the plot. The size of the squares is proportional to the studies' contribution (weights) to the pooled effect estimate. The diamond represents the predicted pooled effect. The width of the diamond indicates the 95% CI and the dashed line prediction interval. RE: random effect. a & b: different populations in the same study.

Studies	Correlation [95% CI]
Alves 2020	-0.28 [-0.65, 0.20]
Anderson 2013	0.11 [-0.09, 0.30]
Ansari 2014	-0.52 [-0.87, 0.16]
Bazzaz 2021	-0.24 [-0.76, 0.46]
Caporaso 2012	-0.45 [-0.69, -0.12]
Ekedahl 2012	-0.63 [-0.76, -0.46]
Garcia 2013	-0.27 [-0.41, -0.11]
George 2006	-0.19 [-0.42, 0.06]
Grosdent 2022	-0.18 [-0.47, 0.14]
Hrkac 2022	-0.34 [-0.46, -0.20]
Hurri 1995	-0.08 [-0.28, 0.13]
Joshi 2021	-0.31 [-0.55, -0.02]
Kiran 2017	-0.39 [-0.63, -0.09]
Lariviere 2022	-0.09 [-0.28, 0.10]
Lenoir 2022	-0.33 [-0.62, 0.03]
Loisel 1998	-0.13 [-0.34, 0.09]
Macedo 2017	-0.11 [-0.29, 0.08]
Mannion 2012	-0.45 [-0.69, -0.12]
Martin 1986	-0.13 [-0.44, 0.21]
Mellin 1989a	-0.07 [-0.18, 0.05]
Mellin 1989b	-0.15 [-0.30, 0.00]
Mieritz 2014	-0.15 [-0.28, -0.01]
Nemcic 2013	-0.28 [-0.48, -0.05]
Nordstoga 2019	-0.57 [-0.75, -0.31]
Ozkaraoglu 2020	-0.26 [-0.53, 0.06]
Sakulsriprasert 2011	0.09 [-0.19, 0.36]
Satpute 2019	-0.40 [-0.59, -0.16]
Shahvarpour 2017	0.42 [0.09, 0.67]
Silveira 2021	-0.04 [-0.34, 0.27]
Steele 2013	-0.21 [-0.57, 0.21]
Sturion 2020	0.28 [-0.42, 0.77]
Sullivan 2000	-0.35 [-0.53, -0.14]
Takinaci 2019	-0.13 [-0.39, 0.15]
Taspinar 2023	-0.69 [-0.81, -0.52]
RE Model	-0.23 [-0.31, -0.15]

suggesting that a larger spinal amplitude was associated with a lower pain intensity (Figure 4). Heterogeneity was moderate ($I^2 = 51.0\%$, Qstatistic: $p < 0.001$).

Thirty-eight studies, totaling 2172 participants, were included in the meta-analysis about the longitudinal relationship between the change in spinal amplitude and the change in pain intensity (Alves et al., 2020; Anderson et al., 2013; Ansari et al., 2014; Bazzaz-Yamchi et al., 2021; Beladev & Masharawi, 2011; Boucher et al., 2018; Christe et al., 2022; de Brito Macedo et al., 2019; Elnaggar et al., 1991; Ferguson, 1998; Garcia et al., 2013; George et al., 2006; Grosdent et al., 2023; Hrkać et al., 2022; Joshi et al., 2021; Kim et al., 2015; Kiran et al., 2017; Larivière et al., 2022; Lenoir dit Caron et al., 2022; Louw et al., 2015; Louw, Farrell, et al., 2017; Louw, Zimney, et al., 2017; Martin et al., 1986; Masharawi & Nadaf, 2013; McCracken et al., 2002; Mieritz et al., 2014; Nemcić et al., 2013; Nordstoga et al., 2019; Ozkaraoglu et al., 2020; Sakulsriprasert et al., 2011; Satpute et al., 2019; Shahvarpour et al., 2017; Silveira et al., 2021; Steele et al., 2013; Sturion et al., 2020; Takinacı et al., 2019; Taşpınar et al., 2023). The pooled coefficient was −0.25 [95% CI: −0.33 to −0.17] indicating that an increase in spinal amplitude was associated with a decrease in pain intensity (Figure 5). Heterogeneity was moderate ($I^2 = 69.8\%$, Qstatistic: $p < 0.0001$).

3.5 | Moderation, subgroup and sensitivity analyses

Moderation analyses showed that the population (having chronic LBP or acute LBP), the direction of movement (flexion or extension or lateral flexion or rotation) and the type of movement (functional or not) were not significant moderators of any of the relationships tested in the main meta-analyses. The subgroup analyses are presented in Table 1. Excluding influential studies yielded similar effect sizes and a reduction of the heterogeneity (Table 1). In addition, excluding studies with high risk of bias for each domain did not substantially influence the results of the meta-analyses in sensitivity analyses (Appendix S5). No publication bias was detected ($p > 0.5$).

3.6 | Meta-analytic structural equation modelling

The results of MASEM analysis based on cross-sectional data of 95 studies with 8053 participants are shown in Figure 6a. Analysis of longitudinal data was conducted on 45 studies including 2840 participants (Figure 6b). In both analyses, the mediated effect of spinal amplitude on
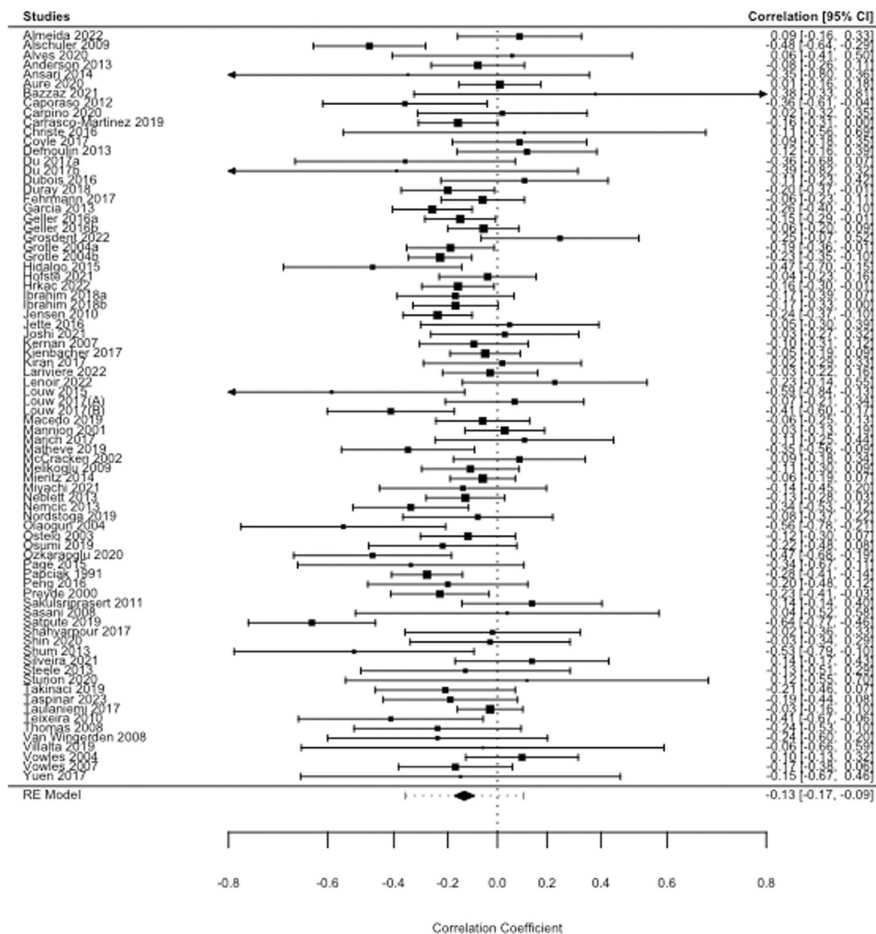
FIGURE 4 Forest plot of the associations between spinal amplitude and pain intensity for cross-sectional data. Negative coefficient means that a larger spinal amplitude is associated with a lower pain intensity. The black squares represent the coefficients and the horizonal lines the 95% confidence intervals (95% CI). The actual numbers are reported in the right side of the plot. The size of the squares is proportional to the studies' contribution (weights) to the pooled effect estimate. The diamond represents the predicted pooled effect. The width of the diamond indicates the 95% CI and the dashed line prediction interval. RE: random effect. a & b: different populations in the same study.

the relationship between pain intensity and disability was very small (indirect effect = 0.03).

4 | DISCUSSION

4.1 | Main findings

This systematic review and meta-analysis supported the hypotheses that (i) larger spinal amplitude is associated with lower levels of disability and pain intensity and (ii) an increase in spinal amplitude is associated with reductions in disability and pain intensity. The reported associations were also present in MASEM analyses, supporting a small association between amplitude of movement and both pain intensity and disability. Furthermore, the MASEM analyses showed that amplitude of movement has a very small influence on the relationship between pain intensity and disability.

4.2 | Cross-sectional data

The results based on cross-sectional data were robust, with a large number of studies, small confidence intervals and were similar in the standard and MASEM meta-analyses. This first meta-analysis to test these relationships in multivariable analyses showed that lower amplitude of movement is a significant but small contributor of larger disability and pain intensity in patients with LBP. Compared with previous meta-analyses (Christe, Crombez, et al., 2021; Shanbehzadeh et al., 2022), this work included a larger number of studies (55 compared to 15 for disability and 60 studies compared to 34 for pain intensity), leading to more robust results.

While we found significant associations, the effect sizes were small. Regarding the spinal movement–disability relationship, other studies have analysed the relationships between disability and other physical variables, such as trunk muscle strength, proprioception or functional limitations, and also reported small associations (Bozorgmehr et al., 2018; Caporaso et al., 2012; Lin et al., 2019; Smeets et al., 2006). Consequently, together, these findings support that physical impairments have only a small association with disability in patients with LBP. Regarding the association with pain intensity, our findings do not support common beliefs that pain intensity has a large influence on spinal movement (Hodges & Smeets, 2015; Van Dieën et al., 2019). It is important to stress that in view of the large number of studies included in the present

FIGURE 5 Forest plot of the associations between change in spinal amplitude and change in pain intensity. Negative correlation coefficient means that increase in spinal amplitude is associated with decrease in pain intensity. The black squares represent the correlation coefficients and the horizonal line the 95% confidence intervals (95% CI). The actual numbers are reported in the right side of the plot. The size of the squares is proportional to the studies' contribution (weights) to the pooled effect estimate. Diamond represents the predicted pooled effect and the dashed line indicates prediction interval. RE, random effect.

4.3 | Longitudinal data

This work also showed small associations between an increase in amplitude of movement and a decrease in disability and pain intensity. The meta-analyses are the largest quantitative synthesis of the literature so far and the first to demonstrate significant relationships between these factors. While the included studies covered a wide range of interventions, the findings were consistent in the direction of larger amplitude of movement associated with clinical improvements. As spinal flexion was by far the most measured movement, the results support that increasing spinal flexion is associated with reduction in disability and pain intensity. Therefore, these findings support interventions aiming at changing movement behaviour towards less protective spinal movement and larger amplitude compared to interventions aiming at reducing spinal movement to protect the spine (e.g. moving more in the hips and knees and less in the spine). This has important implications for LBP management, as spinal flexion is still

meta-analyses, it is unlikely that new cross-sectional studies using non-individualized measures during maximal ROM tests would lead to different conclusions.

often considered to be dangerous for the back by patients and healthcare professionals (Bunzli et al., 2015; Christe, Nzamba, et al., 2021; Christe, Pizzolato, et al., 2021).

Analysing the three factors together in MASEM analyses showed a smaller effect size between spinal amplitude and disability compared to between spinal amplitude and pain intensity. These findings also highlight the importance of decreasing pain intensity to reduce disability. In fact, increasing spinal amplitude may be an effective way to reduce pain intensity and indirectly improve disability through a reduction of pain intensity. However, this work also stressed the fact that rehabilitation should target multidimensional factors, as increasing amplitude of movement alone will certainly not have a large impact on disability. As spinal amplitude is associated with psychological factors (Christe, Crombez, et al., 2021), interventions could notably improve spinal movement through reductions of unhelpful beliefs and pain-related fear, which could at the same time decrease pain intensity (Christe et al., 2022). Similarly, reducing protective behaviours could reduce unhelpful beliefs and pain-related fear (Caneiro et al., 2022; Wernli et al., 2022). Altogether, these findings support a biopsychosocial management of LBP, combining exercises and psychological interventions (Ho et al., 2022).

TABLE 1 Subgroup analyses. The influential cases removed were: [1]: Alschuler et al., 2009; Satpute et al., 2019; [2]: Kim et al., 2015; Taşpınar et al., 2023; [3]: Alschuler et al., 2009; Grotle et al., 2004; Louw, Farrell, et al., 2017; Louw, Zimney, et al., 2017; Silveira et al., 2021; [4]: Ekedahl et al., 2012; Shahvarpour et al., 2017; Taşpınar et al., 2017; Taşpınar et al., 2023. For easiness of reading, the results of the main analyses with all data are repeated in this table (for details, see Figures 2–5). N (p): number of studies (number of participants).

	Cross-sectional data					Longitudinal data				
	n (p)	r	95%CI to	I^2	Q (p_{value})	n (p)	r	95%CI to	I^2	Q (p_{value})
Pain										
Main analysis with all data	74 (5806)	−0.13	−0.17 to −0.09	51.0	<0.001	38 (2172)	−0.25	−0.33 to −0.17	69.8	<0.001
Subgroup analyses										
Suppression of influential cases	72 (5670)[1]	−0.12	−0.15 to −0.09	31.1	0.001	36 (2044)[2]	−0.21	−0.28 to −0.15	51.35	0.001
Only in CLBP	55 (3679)	−0.13	−0.18 to −0.08	45.1	0.0003	25 (1413)	−0.26	−0.35 to −0.17	65.7	<0.001
Only in ALBP	7 (459)	−0.18	−0.28 to −0.07	9	0.16	3 (141)	−0.21	−0.53 to 0.18	79.3	0.006
Only in flexion	63 (4623)	−0.14	−0.19 to −0.1	58.3	<0.001	31 (1774)	−0.24	−0.34 to −0.14	76.1	<0.001
Only in extension	21 (1131)	−0.09	−0.19 to 0.01	61.6	0.0004	8 (463)	−0.3	−0.46 to −0.13	67.6	0.006
Only in lateral flexion	16 (1329)	−0.06	−0.13 to 0.003	20.6	0.1	9 (598)	−0.13	−0.31 to 0.07	79.0	<0.001
Only in rotation	3 (187)	−0.07	−0.27 to 0.13	50.6	0.13	1 (28)				
Only functional activity	4 (132)	−0.08	−0.33 to 0.17	48.9	0.129	1 (62)				
Only lumbar measure	43 (2838)	−0.12	−0.18 to −0.06	47.5	0.002	21 (1078)	−0.23	−0.32 to −0.13	59.1	0.0004
Only current pain	25 (1622)	−0.17	−0.24 to −0.1	44.3	0.006	10 (487)	−0.23	−0.38 to −0.06	67.4	0.0003
Disability										
Main Analysis with all data	69 (5899)	−0.25	−0.29 to −0.21	50.4	<0.001	33 (2437)	−0.23	−0.31 to −0.15	72.5	<0.001
Subgroup analyses										
Suppression of influential cases	65 (5598)[3]	−0.25	−0.28 to −0.22	34.9	0.004	30 (2285)[4]	−0.2	−0.26 to −0.14	43.5	0.008
Only in CLBP	50 (3843)	−0.25	−0.29 to −0.20	47.8	0.0002	21 (1590)	−0.21	−0.28 to −0.14	43.3	0.024
Only in ALBP	7 (1016)	−0.32	−0.43 to −0.2	71.8	0.002	4 (261)	−0.24	−0.53 to 0.1	86.8	<0.001
Only in flexion	61 (4784)	−0.25	−0.30 to −0.20	64.5	<0.001	30 (2147)	−0.19	−0.29 to −0.08	82.5	<0.001
Only in extension	20 (968)	−0.21	−0.29 to −0.13	31.6	0.09	10 (933)	−0.14	−0.26 to 0.01	67.4	0.0002
Only in lateral flexion	18 (1420)	−0.16	−0.24 to −0.08	50.9	0.011	9 (998)	−0.12	−0.27 to 0.03	78.7	<0.001
Only in rotation	7 (366)	−0.26	−0.4 to −0.1	54.9	0.03	3 (544)	0.07	−0.24 to 0.37	91.8	<0.001
Only functional activity	2 (65)	−0.36	−0.6 to −0.06	13.4	0.283	-				
Only lumbar measure	36 (2070)	−0.23	−0.28 to −0.19	18.5	0.1566	17 (999)	−0.14	−0.25 to −0.04	57.9	0.003

(a)

0.03 [0.02 to 0.03] (indirect effect)

Spinal amplitude

-0.13 [-0.17 to -0.10]   -0.18 [-0.23 to -0.15]

Pain intensity   0.39 [0.34 to 0.44] (direct effect)   Disability

0.42 [0.37 to 0.47] (total effect)

(b)

0.03 [0.01 to 0.05] (indirect effect)

Spinal amplitude

-0.23 [-0.30 to -0.17]   -0.13 [-0.21 to -0.05]

Pain intensity   0.40 [0.31 to 0.48] (direct effect)   Disability

0.43 [0.35 to 0.51] (total effect)
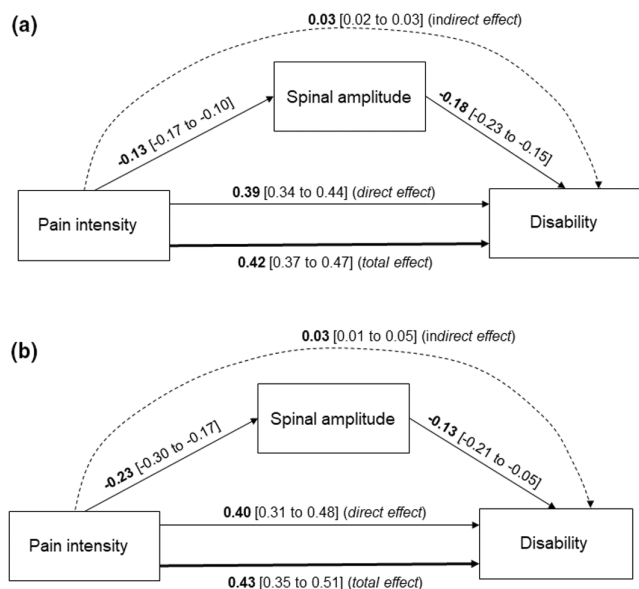
FIGURE 6   Results of MASEM analyses. (a) cross-sectional data; (b) longitudinal data.

4.4 | Implications for the role of spinal movement in LBP

In the context of a multidimensional condition such as LBP, it is questionable if the small effect sizes found in this review are clinically relevant. In comparison with psychological factors that are well-known contributors of disability and pain intensity in patients with LBP (Hartvigsen et al., 2018), the effect sizes in the present meta-analyses were about two times smaller. As an example, pain-related fear and catastrophizing were associated with disability and with pain intensity in patients with LBP with effect sizes of 0.42 and 0.47 (Martinez-Calderon et al., 2019; Zale et al., 2013) and 0.24 and 0.35 (Kroska, 2016; Martinez-Calderon et al., 2019), respectively. The current study therefore confirmed that spinal amplitude, like other physical factors (Steiger et al., 2012), is associated with disability and pain intensity to a smaller extent than some psychological factors. Nevertheless, it is important to acknowledge that amplitude of movement measures only provide information on the maximal amplitude of movement during a particular task, but do not explain *how* the individuals move. In fact, motor behaviour is considered a highly complex and individual phenomenon, and spinal amplitude is only one simple measure of it (Hodges & Smeets, 2015). Therefore, future studies analysing other features of spinal movement, such as the patterns of movement (Papi et al., 2020), and measuring movement in relevant functional task for the individual (Wernli, O'Sullivan, et al., 2020), might find larger effect sizes. This may contribute to support the inclusion of spinal

movement as a more important factor in the multidimensional understanding of LBP and provide clues for more specific therapeutic interventions.

4.5 | Strength and limitations of the study

The main strengths of this study were the extensive literature search and the inclusion of non-published associations that yielded many studies and robust results. To the best of our knowledge, this is the largest systematic review with meta-analyses on this topic and the first to assess the relationships between spinal movement, disability and pain intensity together in MASEM analyses. Including both cross-sectional and longitudinal data also brought different views, but similar answers, on this topic. Moreover, results from the subgroup analyses supported the main analyses, by showing no significant differences between participants with chronic or acute LBP or between different directions of movement. Finally, excluding the influential cases from the analyses led to comparable effect sizes and lower heterogeneity. Altogether, these arguments support the robustness of our results.

One of the main limitations of this study is related to the data analysis. Indeed, since selecting spinal amplitude measures on an a priori basis was not possible, for some studies we had to average multiple coefficients obtained with different measures before performing the meta-analyses. Although this is a recommended procedure, an effect on the precision of the calculation of the pooled coefficient cannot be excluded (Hunter & Schmidt, 2004). Nevertheless, because the subgroup analyses for flexion and extension movements that did not require averaging coefficients demonstrated similar effect sizes as the main analyses, we can assume that the averaging effect remained limited. The second main limitation regards the measurement of spinal movement. In the included studies, there was an important proportion of studies measuring maximal amplitude of motion (especially maximal flexion) in analytical movements. Yet, it has been argued that functional activities would better capture spinal movement alterations and should be preferred to measure spinal movement in LBP (Christe, Aussems, et al., 2021; Wernli, O'Sullivan, et al., 2020). Furthermore, as spinal movement assessment was often not individualized based on patients' complaints and difficulties, the movement measures in literature might not always be the most appropriate to capture the alterations with LBP. These limitations regarding movement measurement could have reduced the size of the associations. This possibility has the support of a recent study, albeit with a small sample size, reporting that assessing spinal movement based on

the individual most problematic activity yielded to larger associations with pain and disability (Wernli, O'Sullivan, et al., 2020). While the present review could not change the movement measures in prior studies, it supports the idea that future research should consider individual measurements of spinal movement during functional movements as this could widen our understanding. Third, in longitudinal analyses, participants could receive any type of intervention. Having interventions aiming to increase spinal amplitude with large effect on pain and disability might produce larger effect sizes. Finally, while the observations did not differ between patients with chronic or acute LBP, the small number of studies with acute LBP precludes a definite conclusion on this question.

5 | CONCLUSION

This systematic review and meta-analysis demonstrated that larger spinal amplitude is weakly associated with lower pain intensity and disability in patients with LBP. It also showed that increasing the amplitude of movement is weakly associated with reductions in pain intensity and disability. Furthermore, the results supported the important role of reducing pain intensity to decrease disability, which may be achieved by increasing the amplitude of movement. Therefore, this work supports the consideration of movement measures in LBP research as well as multidimensional therapeutic interventions aiming at increasing the amplitude of movement.

AUTHOR CONTRIBUTIONS
G. Christe planned the study and wrote the protocol, with the contribution of S. Van Damme and J. Favre. J. Nzamba and G. Christe participated to the study selection process and data analysis. J. Nzamba wrote the first draft of the manuscript. All authors discussed the results and commented on the manuscript.

CONFLICT OF INTEREST STATEMENT
The authors have no conflict of interest to declare.

ORCID
G. Christe https://orcid.org/0000-0003-4337-2245

REFERENCES

Adamu, A. S., Ibrahim, A. A., Ahmad, R. Y., Akindele, M. O., Kaka, B., & Mukhtar, N. B. (2019). Cross-cultural adaptation and validation of the Hausa version of the Oswestry disability index 2.1a for patients with low back pain. *Spine*, *44*, E1092–E1102.

Ahn, E., & Kang, H. (2018). Introduction to systematic review and meta-analysis. *Korean Journal of Anesthesiology*, *71*, 103–112.

Alschuler, K. N., Neblett, R., Wiggert, E., Haig, A. J., & Geisser, M. E. (2009). Flexion-relaxation and clinical features associated with chronic low back pain: A comparison of different methods of quantifying flexion-relaxation. *The Clinical Journal of Pain*, *25*, 760–766.

Alves, M. C., de Souza Neto, R. J., Barbosa, R. I., Marcolino, A. M., & Kuriki, H. U. (2020). Effects of a Pilates protocol in individuals with non-specific low back pain compared with healthy individuals: Clinical and electromyographic analysis. *Clinical Biomechanics*, *72*, 172–178.

Anderson, B., Lygren, H., Magnussen, L. H., Eide, G. E., & Strand, L. I. (2013). What functional aspects explain Patients' impression of change after rehabilitation for long-lasting low back pain?: Functional aspects of PGIC in LBP. *Physiotherapy Research International*, *18*, 167–177.

Ansari, N. N., Naghdi, S., Naseri, N., Entezary, E., Irani, S., Jalaie, S., & Hasson, S. (2014). Effect of therapeutic infra-red in patients with non-specific low back pain: A pilot study. *Journal of Bodywork and Movement Therapies*, *18*, 75–81.

Atya, A. M. (2013). The validity of spinal mobility for prediction of functional disability in male patients with low back pain. *Journal of Advanced Research*, *4*, 43–49.

Aure, O., & Kvåle, A. (2022). Do pain, function, range of motion, fear and distress differ according to symptom duration and work status in patients with low back pain? A cross-sectional study. *European Journal of Physiotherapy*, *24*, 111–118.

Bayar, K., Bayar, B., Yakut, E., & Yakut, Y. (2003). Reliability and construct validity of the Oswestry low back pain disability questionnaire in the elderly with low back pain. *The Pain Clinic*, *15*, 55–59.

Bazzaz-Yamchi, M., Naghdi, S., Nakhostin-Ansari, A., Hadizadeh, M., Ansari, N. N., Moghimi, E., & Hasson, S. (2021). Acute and short-term effects of dry needling in patients with chronic non-specific low back pain and hamstring tightness: A pilot study. *The Scientific World Journal*, *2021*, 1–6.

Beladev, N., & Masharawi, Y. (2011). The effect of group-exercising on females with non-specific chronic low back pain in a sitting position: A pilot study. *BMR*, *24*, 181–188.

Borenstein, M., Hedges, L. V., Higgins, J., & Rothstein, H. R. (2021). *Introduction to meta-analysis*. Wiley.

Boucher, J.-A., Preuss, R., Henry, S. M., Nugent, M., & Larivière, C. (2018). Trunk postural adjustments: Medium-term reliability and correlation with changes of clinical outcomes following an 8-week lumbar stabilization exercise program. *Journal of Electromyography and Kinesiology*, *41*, 66–76.

Bozorgmehr, A., Zahednejad, S., Salehi, R., Ansar, N. N., Abbasi, S., Mohsenifar, H., & Villafañe, J. H. (2018). Relationships between muscular impairments, pain, and disability in patients with chronic nonspecific low back pain: A cross sectional study. *Journal of Exercise Rehabilitation*, *14*, 1041–1047.

Bunzli, S., Smith, A., Schütze, R., & O'Sullivan, P. (2015). Beliefs underlying pain-related fear and how they evolve: A qualitative

investigation in people with chronic back pain and high pain-related fear. *BMJ Open*, 5, e008847.

Caneiro, J. P., Smith, A., Bunzli, S., Linton, S., Moseley, G. L., & O'Sullivan, P. (2022). From fear to safety: A roadmap to recovery from musculoskeletal pain. *Physical Therapy*, 102, pzab271.

Caporaso, F., Pulkovski, N., Sprott, H., & Mannion, A. F. (2012). How well do observed functional limitations explain the variance in Roland Morris scores in patients with chronic non-specific low back pain undergoing physiotherapy? *European Spine Journal*, 21, 187–195.

Carpino, G., Tran, S., Currie, S., Enebo, B., Davidson, B. S., & Howarth, S. J. (2020). Does manual therapy affect functional and biomechanical outcomes of a sit-to-stand task in a population with low back pain? A preliminary analysis. *Chiropractic & Manual Therapies*, 28, 5.

Carrasco-Martínez, F., Ibáñez-Vera, A. J., Martínez-Amat, A., Hita-Contreras, F., & Lomas-Vega, R. (2019). Short-term effectiveness of the flexion-distraction technique in comparison with high-velocity vertebral manipulation in patients suffering from low-back pain. *Complementary Therapies in Medicine*, 44, 61–67.

Chen, S., Chen, M., Wu, X., Lin, S., Tao, C., Cao, H., Shao, Z., & Xiao, G. (2022). Global, regional and national burden of low back pain 1990–2019: A systematic analysis of the global burden of disease study 2019. *Journal of Orthopaedic Translation*, 32, 49–58.

Cheung, M. W.-L. (2015). metaSEM: An R package for meta-analysis using structural equation modeling. *Frontiers in Psychology*, 5, 1–7.

Chiarotto, A., Maxwell, L. J., Ostelo, R. W., Boers, M., Tugwell, P., & Terwee, C. B. (2019). Measurement properties of visual analogue scale, numeric rating scale, and pain severity subscale of the brief pain inventory in patients with low back pain: A systematic review. *The Journal of Pain*, 20, 245–263.

Christe, G., Aussems, C., Jolles, B. M., & Favre, J. (2021). Patients with chronic low back pain have an individual movement signature: A comparison of angular amplitude, angular velocity and muscle activity across multiple functional tasks. *Frontiers in Bioengineering and Biotechnology*, 9, 767974.

Christe, G., Benaim, C., Luthi, F., Jolles, B. M., & Favre, J. (2022). 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 Practice*, 23, 290–300.

Christe, G., Crombez, G., Edd, S., Opsommer, E., Jolles, B. M., & Favre, J. (2021). Relationship between psychological factors and spinal motor behaviour in low back pain: A systematic review and meta-analysis. *Pain*, 162, 672–686.

Christe, G., Nzamba, J., Desarzens, L., Leuba, A., Darlow, B., & Pichonnaz, C. (2021). Physiotherapists' attitudes and beliefs about low back pain influence their clinical decisions and advice. *Musculoskeletal Science and Practice*, 53, 102382.

Christe, G., Pizzolato, V., Meyer, M., Nzamba, J., & Pichonnaz, C. (2021). Unhelpful beliefs and attitudes about low back pain in the general population: A cross-sectional survey. *Musculoskeletal Science and Practice*, 52, 102342.

Christe, G., Redhead, L., Legrand, T., Jolles, B. M., & Favre, J. (2016). Multi-segment analysis of spinal kinematics during sit-to-stand in patients with chronic low back pain. *Journal of Biomechanics*, 49, 2060–2067.

Cohen, J. (1988). Set correlation and contingency tables. *Applied Psychological Measurement*, 12, 425–434.

Coyle, P. C., Velasco, T., Sions, J. M., & Hicks, G. E. (2017). Lumbar mobility and performance-based function: An investigation in older adults with and without chronic low back pain. *Pain Medicine*, 18, 161–168.

Demoulin, C., Huijnen, I. P. J., Somville, P.-R., Grosdent, S., Salamun, I., Crielaard, J.-M., Vanderthommen, M., & Volders, S. (2013). Relationship between different measures of pain-related fear and physical capacity of the spine in patients with chronic low back pain. *The Spine Journal*, 13, 1039–1047.

Deyo, R. A. (1986). Comparative validity of the sickness impact profile and shorter scales for functional assessment in low-back pain. *Spine*, 11, 951–954.

Du, W., Li, H., Chen, W., Sun, X., & Wang, L. (2017). A laboratory study on trunk angle in patients with lumbar disc herniation during bending exercises based on motion sensors. In *2017 IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN), Eindhoven, Netherlands* (pp. 189–192). IEEE. https://doi.org/10.1109/BSN.2017.7936038

Dubois, J.-D., Cantin, V., Piché, M., & Descarreaux, M. (2016). Physiological and psychological predictors of short-term disability in workers with a history of low back pain: A longitudinal study. *PLoS One*, 11, e0165478.

Duray, M., Yagci, N., & Ok, N. (2018). Determination of physical parameters associated with self-efficacy in patients with chronic mechanic low back pain. *BMR*, 31, 743–748.

Ekedahl, H., Jönsson, B., & Frobell, R. B. (2012). Fingertip-to-floor test and straight leg raising test: Validity, responsiveness, and predictive value in patients with acute/subacute low back pain. *Archives of Physical Medicine and Rehabilitation*, 93, 2210–2215.

Ekedahl, K. H., Jönsson, B., & Frobell, R. B. (2010). Validity of the fingertip-to-floor test and straight leg raising test in patients with acute and subacute low back pain: A comparison by sex and radicular pain. *Archives of Physical Medicine and Rehabilitation*, 91, 1243–1247.

Elnaggar, I. M., Nordin, M., Sheikhzadeh, A., Parnianpour, M., & Kahanovitz, N. (1991). Effects of spinal flexion and extension exercises on low-back pain and spinal mobility in chronic mechanical low-back pain patients. *Spine*, 16, 967–972.

Fehrmann, E., Tuechler, K., Kienbacher, T., Mair, P., Spreitzer, J., Fischer, L., Kollmitzer, J., & Ebenbichler, G. (2017). Comparisons in muscle function and training rehabilitation outcomes between avoidance-endurance model subgroups. *The Clinical Journal of Pain*, 33, 912–920.

Felicio, D. C., Pereira, D. S., Diz, J. B. M., de Queiroz, B. Z., da Silva, J. P., Leopoldino, A. A. O., & Pereira, L. S. M. (2017). Anterior trunk mobility does not predict disability in elderly women with acute low back pain: Brazilian Back complaints in the elders (BACE-Brazil) study results. *Spine*, 42, 1552–1558.

Ferguson, S. A. (1998). Quantification of low back pain recovery using biomechanical, symptom, activities of daily living and work status measures. Thesis.

Garcia, A. N., Costa, L. D., da Silva, T. M., Gondo, F. L. B., Cyrillo, F. N., Costa, R. A., & Costa, L. O. P. (2013). Effectiveness of back school versus McKenzie exercises in patients with chronic non-specific low back pain: A randomized controlled trial. *Physical Therapy*, 93, 729–747.

Geller, M., Mibielli, M. A., Nunes, C. P., da Fonseca, A. D., Goldberg, S. W., & Oliveira, L. (2016). Comparison of the

action of diclofenac alone versus diclofenac plus B vitamins on mobility in patients with low back pain. *Journal of Drug Assessment*, *5*, 1–3.

George, S. Z., Fritz, J. M., & McNeil, D. W. (2006). Fear-avoidance beliefs as measured by the fear-avoidance beliefs questionnaire: Change in fear-avoidance beliefs questionnaire is predictive of change in self-report of disability and pain intensity for patients with acute low back pain. *The Clinical Journal of Pain*, *22*, 197–203.

Grönblad, M., Hurri, H., & Kouri, J. P. (1997). Relationships between spinal mobility, physical performance tests, pain intensity and disability assessments in chronic low back pain patients. *Scandinavian Journal of Rehabilitation Medicine*, *29*, 17–24.

Grosdent, S., Grieven, L., Martin, E., Demoulin, C., Kaux, J.-F., & Vanderthommen, M. (2023). Effectiveness of resisted training through translation of the pelvis in chronic low back pain. *BMR*, *36*, 493–502.

Grotle, M., Vøllestad, N. K., Veierød, M. B., & Brox, J. I. (2004). Fear-avoidance beliefs and distress in relation to disability in acute and chronic low back pain. *Pain*, *112*, 343–352.

Hartvigsen, J., Hancock, M. J., Kongsted, A., Louw, Q., Ferreira, M. L., Genevay, S., Hoy, D., Karppinen, J., Pransky, G., Sieper, J., Smeets, R. J., Underwood, M., Buchbinder, R., Hartvigsen, J., Cherkin, D., Foster, N. E., Maher, C. G., Underwood, M., van Tulder, M., ... Woolf, A. (2018). What low back pain is and why we need to pay attention. *The Lancet*, *391*, 2356–2367.

Hayden, J. A., Côté, P., & Bombardier, C. (2006). Evaluation of the quality of prognosis studies in systematic reviews. *Annals of Internal Medicine*, *144*, 427.

Hayden, J. A., van der Windt, D. A., Cartwright, J. L., Côté, P., & Bombardier, C. (2013). Assessing bias in studies of prognostic factors. *Annals of Internal Medicine*, *158*, 280.

Hidalgo, B., Pitance, L., Hall, T., Detrembleur, C., & Nielens, H. (2015). Short-term effects of mulligan mobilization with movement on pain, disability, and kinematic spinal movements in patients with nonspecific low back pain: A randomized placebo-controlled trial. *Journal of Manipulative and Physiological Therapeutics*, *38*, 365–374.

Higgins, J. P., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (2022). Cochrane handbook for systematic reviews of interventions version 6.3 (updated February 2022).

Ho, E. K.-Y., Chen, L., Simic, M., Ashton-James, C. E., Comachio, J., Wang, D. X. M., Hayden, J. A., Ferreira, M. L., & Ferreira, P. H. (2022). Psychological interventions for chronic, non-specific low back pain: Systematic review with network meta-analysis. *BMJ*, *376*, e067718.

Hodges, P. W., & Smeets, R. J. (2015). Interaction between pain, movement, and physical activity: Short-term benefits, long-term consequences, and targets for treatment. *The Clinical Journal of Pain*, *31*, 97–107.

Hofste, A., Soer, R., Groen, G. J., van der Palen, J., Geerdink, F. J. B., Oosterveld, F. G. J., Kiers, H., Wolff, A. P., & Hermens, H. (2021). Functional and morphological lumbar multifidus characteristics in subgroups with low back pain in primary care. *Musculoskeletal Science and Practice*, *55*, 102429.

Hrkać, A., Bilić, D., Černy-Obrdalj, E., Baketarić, I., & Puljak, L. (2022). Comparison of supervised exercise therapy with or without biopsychosocial approach for chronic nonspecific low back pain: A randomized controlled trial. *BMC Musculoskeletal Disorders*, *23*, 966.

Hunter, J. E., & Schmidt, F. L. (2004). *Methods of meta-analysis: Correcting error and bias in research findings*. Sage.

Hurri, H., Hupli, M., & Alaranta, H. (1995). Strength and mobility measurements in assessing the outcome of an intensive back rehabilitation program. *European Journal of Physical Medicine & Rehabilitation*, *5*, 160–164.

Ibrahim, A. A., Akindele, M. O., Kaka, B., & Bello, B. (2019). Translation, cross-cultural adaptation, and psychometric properties of the Hausa version of the fear-avoidance beliefs questionnaire in patients with low back pain. *Scandinavian Journal of Pain*, *19*, 83–92.

Jensen, O. K., Nielsen, C. V., & Stengaard-Pedersen, K. (2010). One-year prognosis in sick-listed low back pain patients with and without radiculopathy. Prognostic factors influencing pain and disability. *The Spine Journal*, *10*, 659–675.

Jette, N., Lim, Y., Lim, H., Mokhtar, S., Gan, K., & Singh, D. (2016). Lumbar kinematics, functional disability and fear avoidance beliefs among adults with nonspecific chronic low back pain. *Sultan Qaboos University Medical Journal*, *16*, e430–e436.

Joshi, S., Yadav, R., & Pawalia, A. (2021). Can a cervical muscle inhibition technique reduce chronic low back pain? *Advances in Rehabilitation*, *35*, 38–46.

Kang, S. W., Lee, W. N., Moon, J. H., & Chun, S. I. (1995). Correlation of spinal mobility with the severity of chronic lower back pain. *Yonsei Medical Journal*, *36*, 37–44.

Karayannis, N. V., Smuck, M., Law, C., Mackey, S. C., Gross, J. J., Darnall, B. D., & Hush, J. (2023). Self-reported physical function is strongly related to pain behavior and pain interference and weakly related to physical capacity in people with chronic low back pain. *Musculoskeletal Science and Practice*, *63*, 102721.

Kernan, T., & Rainville, J. (2007). Observed outcomes associated with a quota-based exercise approach on measures of Kinesiophobia in patients with chronic low back pain. *The Journal of Orthopaedic and Sports Physical Therapy*, *37*, 679–687.

Kienbacher, T., Fehrmann, E., Habenicht, R., Oeffel, C., Kollmitzer, J., Mair, P., & Ebenbichler, G. (2017). Diagnostic value of trunk flexion–extension testing in old chronic low back pain patients. *European Spine Journal*, *26*, 510–517.

Kim, T. H., Kim, E.-H., & Cho, H. (2015). The effects of the CORE programme on pain at rest, movement-induced and secondary pain, active range of motion, and proprioception in female office workers with chronic low back pain: A randomized controlled trial. *Clinical Rehabilitation*, *29*, 653–662.

Kiran, R., Mohanty, P., & Pattnaik, M. (2017). Thoracic mobilisation and periscapular soft tissue manipulations in the management of chronic prolapsed intervertebral disc (PIVD)—An innovative manual therapy approach. *Australasian Medical Journal*, *10*, 838–847.

Kroska, E. B. (2016). A meta-analysis of fear-avoidance and pain intensity: The paradox of chronic pain. *Scandinavian Journal of Pain*, *13*, 43–58.

La Touche, R., Pérez-Fernández, M., Barrera-Marchessi, I., López-de-Uralde-Villanueva, I., Villafañe, J. H., Prieto-Aldana, M., Suso-Martí, L., & Paris-Alemany, A. (2019). Psychological and physical factors related to disability in chronic low back pain. *Journal of Back and Musculoskeletal Rehabilitation*, *32*, 603–611.

Laird, R. A., Gilbert, J., Kent, P., & Keating, J. L. (2014). Comparing lumbo-pelvic kinematics in people with and without back pain: A systematic review and meta-analysis. *BMC Musculoskeletal Disorders*, *15*, 229.

Larivière, C., Rabhi, K., Preuss, R., Coutu, M.-F., Roy, N., & Henry, S. M. (2022). Derivation of clinical prediction rules for identifying patients with non-acute low back pain who respond best to a lumbar stabilization exercise program at post-treatment and six-month follow-up. *PLoS One*, 17, e0265970.

Lee, C. E., Simmonds, M. J., Novy, D. M., & Jones, S. (2001). Self-reports and clinician-measured physical function among patients with low back pain: A comparison. *Archives of Physical Medicine and Rehabilitation*, 82, 227–231.

Lee, H., Hübscher, M., Moseley, G. L., Kamper, S. J., Traeger, A. C., Mansell, G., & McAuley, J. H. (2015). How does pain lead to disability? A systematic review and meta-analysis of mediation studies in people with back and neck pain. *Pain*, 156, 988–997.

Lenoir dit Caron, R., Rouzée, M., Coquart, J., & Gilliaux, M. (2022). Compliance with a personalised home exercise programme in chronic low back pain patients after a multidisciplinary programme: A pilot randomised controlled trial. *Frontiers in Rehabilitation Sciences*, 3, 1050157.

Lin, J., Halaki, M., Rajan, P., & Leaver, A. (2019). Relationship between proprioception and pain and disability in people with non-specific low back pain: A systematic review with meta-analysis. *Spine*, 44, E606–E617.

Loisel, P., Poitras, S., Lemaire, J., Durand, P., Southière, A., & Abenhaim, L. (1998). Is work status of low back pain patients best described by an automated device or by a questionnaire? *Spine*, 23, 1588–1594.

Louw, A., Farrell, K., Landers, M., Barclay, M., Goodman, E., Gillund, J., McCaffrey, S., & Timmerman, L. (2017). The effect of manual therapy and neuroplasticity education on chronic low back pain: A randomized clinical trial. *Journal of Manual & Manipulative Therapy*, 25, 227–234.

Louw, A., Farrell, K., Wettach, L., Uhl, J., Majkowski, K., & Welding, M. (2015). Immediate effects of sensory discrimination for chronic low back pain: A case series. *New Zealand Journal of Physiotherapy*, 43, 60–65.

Louw, A., Zimney, K., Johnson, E. A., Kraemer, C., Fesler, J., & Burcham, T. (2017). De-educate to re-educate: Aging and low back pain. *Aging Clinical and Experimental Research*, 29, 1261–1269.

de Brito Macedo, L., Richards, J., Borges, D. T., Melo, S. A., & Brasileiro, J. S. (2019). Kinesio taping reduces pain and improves disability in low back pain patients: A randomised controlled trial. *Physiotherapy*, 105, 65–75.

Mannion, A. F., Caporaso, F., Pulkovski, N., & Sprott, H. (2012). Spine stabilisation exercises in the treatment of chronic low back pain: A good clinical outcome is not associated with improved abdominal muscle function. *European Spine Journal*, 21, 1301–1310.

Mannion, A. F., Junge, A., Taimela, S., Müntener, M., Lorenzo, K., & Dvorak, J. (2001). Active therapy for chronic low back pain: Part 3. Factors influencing self-rated disability and its change following therapy. *Spine*, 26, 920–929.

Marich, A. V., Hwang, C.-T., Salsich, G. B., Lang, C. E., & Van Dillen, L. R. (2017). Consistency of a lumbar movement pattern across functional activities in people with low back pain. *Clinical Biomechanics*, 44, 45–51.

Martin, P. R., Rose, M. J., Nichols†, P. J. R., Russell, P. L., & Hughes, I. G. (1986). Physiotherapy exercises for low back pain: Process and clinical outcome. *International Rehabilitation Medicine*, 8, 34–38.

Martinez-Calderon, J., Jensen, M. P., Morales-Asencio, J. M., & Luque-Suarez, A. (2019). Pain catastrophizing and function in individuals with chronic musculoskeletal pain: A systematic review and meta-analysis. *The Clinical Journal of Pain*, 35, 279–293.

Masharawi, Y., & Nadaf, N. (2013). The effect of non-weight bearing group-exercising on females with non-specific chronic low back pain: A randomized single blind controlled pilot study. *Journal of Back and Musculoskeletal Rehabilitation*, 26, 353–359.

Matheve, T., De Baets, L., Bogaerts, K., & Timmermans, A. (2019). Lumbar range of motion in chronic low back pain is predicted by task-specific, but not by general measures of pain-related fear. *European Journal of Pain*, 23, 1171–1184.

Mayorga-Vega, D., Merino-Marban, R., & Viciana, J. (2014). Criterion-related validity of sit-and-reach tests for estimating hamstring and lumbar extensibility: A meta-analysis. *Journal of Sports Science and Medicine*, 13, 1–14.

McCracken, L. M., Gross, R. T., & Eccleston, C. (2002). Multimethod assessment of treatment process in chronic low back pain: Comparison of reported pain-related anxiety with directly measured physical capacity. *Behaviour Research and Therapy*, 40, 585–594.

Melikoglu, M. A., Kocabas, H., Sezer, I., Bilgilisoy, M., & Tuncer, T. (2009). Validation of the Turkish version of the Quebec back pain disability scale for patients with low back pain. *Spine*, 34, E219–E224.

Mellin, G., Hurri, H., Härkäpää, K., & Järvikoski, A. (1989). A controlled study on the outcome of inpatient and outpatient treatment of low back pain. Part II. Effects on physical measurements three months after treatment. *Scandinavian Journal of Rehabilitation Medicine*, 21, 91–95.

Mieritz, R. M., Bronfort, G., & Hartvigsen, J. (2014). Regional lumbar motion and patient-rated outcomes: A secondary analysis of data from a randomized clinical trial. *Journal of Manipulative and Physiological Therapeutics*, 37, 628–640.

Miyachi, R., Sano, A., Tanaka, N., Tamai, M., & Miyazaki, J. (2021). Relationships among lumbar hip motion angle, perceptual awareness, and low back pain in young adults. *Journal of Physical Therapy Science*, 33, 880–886.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA Statement. *PLoS Medicine*, 6, e1000097.

Nattrass, C. L., Nitschke, J. E., Disler, P. B., Chou, M. J., & Ooi, K. T. (1999). Lumbar spine range of motion as a measure of physical and functional impairment: An investigation of validity. *Clinical Rehabilitation*, 13, 211–218.

Neblett, R., Brede, E., Mayer, T. G., & Gatchel, R. J. (2013). What is the best surface EMG measure of lumbar flexion-relaxation for distinguishing chronic low back pain patients from pain-free controls? *The Clinical Journal of Pain*, 29, 334–340.

Nemcić, T., Budisin, V., Vrabec-Matković, D., & Grazio, S. (2013). Comparison of the effects of land-based and water-based therapeutic exercises on the range of motion and physical disability in patients with chronic low-back pain: Single-blinded randomized study. *Acta Clinica Croatica*, 52, 321–327.

Nordstoga, A. L., Meisingset, I., Vasseljen, O., Nilsen, T. I. L., & Unsgaard-Tøndel, M. (2019). Longitudinal associations of kinematics and fear-avoidance beliefs with disability, work

ability and pain intensity in persons with low back pain. *Musculoskeletal Science and Practice*, *41*, 49–54.

Olaogun, M. O. B., Adedoyin, R. A., Ikem, I. C., & Anifaloba, O. R. (2004). Reliability of rating low back pain with a visual analogue scale and a semantic differential scale. *Physiotherapy Theory and Practice*, *20*, 135–142.

Ostelo, R. W. J. G., de Vet, H. C. W., Berfelo, M. W., Kerckhoffs, M. R., Vlaeyen, J. W. S., Wolters, P. M. J. C., & van den Brandt, P. A. (2003). Effectiveness of behavioral graded activity after first-time lumbar disc surgery: Short term results of a randomized controlled trial. *European Spine Journal*, *12*, 637–644.

Osumi, M., Sumitani, M., Otake, Y., Nishigami, T., Mibu, A., Nishi, Y., Imai, R., Sato, G., Nagakura, Y., & Morioka, S. (2019). Kinesiophobia modulates lumbar movements in people with chronic low back pain: A kinematic analysis of lumbar bending and returning movement. *European Spine Journal*, *28*, 1572–1578.

Ozkaraoglu, D. K., Tarakci, D., & Algun, Z. C. (2020). Comparison of two different electrotherapy methods in low back pain treatment. *Journal of Back and Musculoskeletal Rehabilitation*, *33*, 193–199.

Pagé, I., Marchand, A.-A., Nougarou, F., O'Shaughnessy, J., & Descarreaux, M. (2015). Neuromechanical responses after biofeedback training in participants with chronic low back pain: An experimental cohort study. *Journal of Manipulative and Physiological Therapeutics*, *38*, 449–457.

Papciak, A. S., & Feuerstein, M. (1991). Psychological factors affecting isokinetic trunk strength testing in patients with work-related chronic low back pain. *Journal of Occupational Rehabilitation*, *1*, 95–104.

Papi, E., Bull, A. M. J., & McGregor, A. H. (2018). Is there evidence to use kinematic/kinetic measures clinically in low back pain patients? A systematic review. *Clinical Biomechanics*, *55*, 53–64.

Papi, E., Bull, A. M. J., & McGregor, A. H. (2020). Alteration of movement patterns in low back pain assessed by statistical parametric mapping. *Journal of Biomechanics*, *100*, 109597.

Parks, K. A., Crichton, K. S., Goldford, R. J., & McGill, S. M. (2003). A comparison of lumbar range of motion and functional ability scores in patients with low back pain: Assessment for range of motion validity. *Spine*, *28*, 380–384.

Peng, F., Li, H., Ivanov, K., Zhao, G., Zhou, F., Du, W., & Wang, L. (2016). Quantitative analysis of spine angle range of individuals with low back pain performing dynamic exercises. In *2016 IEEE 13th international conference on wearable and implantable body sensor networks (BSN), San Francisco, CA, USA* (pp. 136–140). IEEE. https://doi.org/10.1109/BSN.2016.7516247

Preyde, M. (2000). Effectiveness of massage therapy for subacute low-back pain: A randomized controlled trial. *CMAJ*, *162*, 1815–1820.

Quintana, D. S. (2015). From pre-registration to publication: A non-technical primer for conducting a meta-analysis to synthesize correlational data. *Frontiers in Psychology*, *6*, 1–9.

Rainville, J., Sobel, J. B., & Hartigan, C. (1994). Comparison of total lumbosacral flexion and true lumbar flexion measured by a dual inclinometer technique. *Spine (Phila Pa 1976)*, *19*, 2698–2701.

Sakulsriprasert, P., Vachalathiti, R., Vongsirinavarat, M., & Pichaisak, W. (2011). Responsiveness of pain, active range of motion, and disability in patients with acute nonspecific low back pain. *Hong Kong Physiotherapy Journal*, *29*, 20–24.

Sasani, M., Aydin, A. L., Oktenoglu, T., Cosar, M., Ataker, Y., Kaner, T., & Ozer, A. F. (2008). The combined use of a posterior dynamic transpedicular stabilization system and a prosthetic disc nucleus device in treating lumbar degenerative disc disease with disc herniations. *SAS Journal*, *2*, 130–136.

Satpute, K., Hall, T., Bisen, R., & Lokhande, P. (2019). The effect of spinal mobilization with leg movement in patients with lumbar radiculopathy—A double-blind randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, *100*, 828–836.

Scharovsky, A., Pueyrredón, M., Craig, D., Rivas, M. E., Converso, G., Pueyrredón, J. H., Salvat, F., & Alzúa, O. (2008). Cross-cultural adaptation and validation of the Argentinean version of the Roland-Morris disability questionnaire. *Spine*, *33*, 1391–1395.

Shahvarpour, A., Henry, S. M., Preuss, R., Mecheri, H., & Larivière, C. (2017). The effect of an 8-week stabilization exercise program on the lumbopelvic rhythm and flexion-relaxation phenomenon. *Clinical Biomechanics*, *48*, 1–8.

Shanbehzadeh, S., ShahAli, S., Ebrahimi Takamjani, I., Vlaeyen, J. W. S., Salehi, R., & Jafari, H. (2022). Association of pain-related threat beliefs and disability with postural control and trunk motion in individuals with low back pain: A systematic review and meta-analysis. *European Spine Journal*, *31*, 1802–1820.

Shin, D. (2020). Correlation between non-specific chronic low back pain and physical factors of lumbar and hip joint in office workers. *Medical Hypotheses*, *144*, 110304.

Shum, G. L., Tsung, B. Y., & Lee, R. Y. (2013). The immediate effect of posteroanterior mobilization on reducing Back pain and the stiffness of the lumbar spine. *Archives of Physical Medicine and Rehabilitation*, *94*, 673–679.

Silveira, A. M., Santos, L. T., Rodrigues, A. Y. B. M., Brum, F. D., Yamada, E. F., & Silva, M. D. (2021). A eletroterapia pode aprimorar o efeito de exercícios cinesiofuncionais no tratamento da dor lombar inespecífica crônica? *Fisioterapia e Pesquisa*, *28*, 284–290.

Smeets, R. J. E. M., Wade, D., Hidding, A., Van Leeuwen, P. J. C. M., Vlaeyen, J. W. S., & Knottnerus, J. A. (2006). The association of physical deconditioning and chronic low back pain: A hypothesis-oriented systematic review. *Disability and Rehabilitation*, *28*, 673–693.

Steele, J., Bruce-Low, S., Smith, D., Jessop, D., & Osborne, N. (2013). A randomized controlled trial of limited range of motion lumbar extension exercise in chronic low back pain. *Spine*, *38*, 1245–1252.

Steiger, F., Wirth, B., de Bruin, E. D., & Mannion, A. F. (2012). Is a positive clinical outcome after exercise therapy for chronic non-specific low back pain contingent upon a corresponding improvement in the targeted aspect(s) of performance? A systematic review. *European Spine Journal*, *21*, 575–598.

Sturion, L. A., Nowotny, A. H., Barillecb, F., Barette, G., Santosa, G. K., Teixeirac, F. A., Fernandes, K. P., & Da Silva, R. (2020). Comparison between high-velocity low-amplitude manipulation and muscle energy technique on pain and trunk neuromuscular postural control in male workers with chronic low back pain: A randomised crossover trial. *The South African Journal of Physiotherapy*, *76*, 1–9.

Sullivan, M. S., Shoaf, L. D., & Riddle, D. L. (2000). The relationship of lumbar flexion to disability in patients with low back pain. *Physical Therapy*, *80*, 240–250.

Takinacı, Z. D., Karagülle, M., İşsever, H., & Karagülle, M. Z. (2019). Clinical efficacy of spa therapy (balneotherapy) for chronic low

back pain: A randomized single-blind trial. *European Journal of Integrative Medicine*, *29*, 100928.

Taşpınar, G., Angın, E., & Oksüz, S. (2023). The effects of Pilates on pain, functionality, quality of life, flexibility and endurance in lumbar disc herniation. *Journal of Comparative Effectiveness Research*, *12*, cer-2022-0144. https://doi.org/10.2217/cer-2022-0144

Taulaniemi, A., Kuusinen, L., Tokola, K., Kankaanpää, M., & Suni, J. (2017). Bio-psychosocial factors are associated with pain intensity, physical functioning, and ability to work in female healthcare personnel with recurrent low back pain. *Journal of Rehabilitation Medicine*, *49*, 667–676.

Teixeira da Cunha-Filho, I., Lima, F. C., Guimarães, F. R., & Leite, H. R. (2010). Use of physical performance tests in a group of Brazilian Portuguese-speaking individuals with low back pain. *Physiotherapy Theory and Practice*, *26*, 49–55.

Thomas, J. S., & France, C. R. (2008). The relationship between pain-related fear and lumbar flexion during natural recovery from low back pain. *European Spine Journal*, *17*, 97–103.

Van Dieën, J. H., Peter Reeves, N., Kawchuk, G., Van Dillen, L. R., & Hodges, P. W. (2019). Motor control changes in low back pain: Divergence in presentations and mechanisms. *Journal of Orthopaedic and Sports Physical Therapy*, *49*, 370–379.

van Wingerden, J.-P., Vleeming, A., & Ronchetti, I. (2008). Differences in standing and forward bending in women with chronic low back or pelvic girdle pain: Indications for physical compensation strategies. *Spine*, *33*, E334–E341.

Villalta Santos, L., Lisboa Córdoba, L., Benite Palma Lopes, J., Santos Oliveira, C., André Collange Grecco, L., Bovi Nunes Andrade, A. C., & Pasin Neto, H. (2019). Active visceral manipulation associated with conventional physiotherapy in people with chronic low back pain and visceral dysfunction: A preliminary, randomized, controlled, double-blind clinical trial. *Journal of Chiropractic Medicine*, *18*, 79–89.

Vowles, K. E., McNeil, D. W., Gross, R. T., McDaniel, M. L., Mouse, A., Bates, M., Gallimore, P., & McCall, C. (2007). Effects of pain acceptance and pain control strategies on physical impairment in individuals with chronic low back pain. *Behavior Therapy*, *38*, 412–425.

Vowles, K. E., Zvolensky, M. J., Gross, R. T., & Sperry, J. A. (2004). Pain-related anxiety in the prediction of chronic low-back pain distress. *Journal of Behavioral Medicine*, *27*, 77–89.

Waddell, G., & Main, C. J. (1984). Assessment of severity in low-back disorders. *Spine*, *9*, 204–208.

Waddell, G., Somerville, D., Henderson, I., & Newton, M. (1992). Objective clinical evaluation of physical impairment in chronic low back pain. *Spine*, *17*, 617–628.

Welz, T., Doebler, P., & Pauly, M. (2022). Fisher transformation based confidence intervals of correlations in fixed- and random-effects meta-analysis. *British Journal of Mathematical and Statistical Psychology*, *75*, 1–22.

Wernli, K., O'Sullivan, P., Smith, A., Campbell, A., & Kent, P. (2020). Movement, posture and low back pain. How do they relate? A replicated single-case design in 12 people with persistent, disabling low back pain. *European Journal of Pain*, *24*, 1831–1849.

Wernli, K., Smith, A., Coll, F., Campbell, A., Kent, P., & O'Sullivan, P. (2022). From protection to non-protection: A mixed methods study investigating movement, posture and recovery from disabling low back pain. *European Journal of Pain*, *26*, 2097–2119.

Wernli, K., Tan, J.-S., O'Sullivan, P., Smith, A., Campbell, A., & Kent, P. (2020). Does movement change when low back pain changes? A systematic review. *The Journal of Orthopaedic and Sports Physical Therapy*, *50*, 664–670.

Wood, L., Foster, N. E., Lewis, M., & Bishop, A. (2021). Exercise interventions for persistent non-specific low back pain—Does matching outcomes to treatment targets make a difference? A systematic review and meta-analysis. *The Journal of Pain*, *22*, 107–126.

Wun, A., Kollias, P., Jeong, H., Rizzo, R. R. N., Cashin, A. G., Bagg, M. K., McAuley, J. H., & Jones, M. D. (2021). Why is exercise prescribed for people with chronic low back pain? A review of the mechanisms of benefit proposed by clinical trialists. *Musculoskeletal Science and Practice*, *51*, 102307.

Yuen, J. W. M., Tsang, W. W. N., Tse, S. H. M., Loo, W. T. Y., Chan, S.-T., Wong, D. L. Y., Chung, H. H. Y., Tam, J. K. K., Choi, T. K. S., & Chiang, V. C. L. (2017). The effects of Gua sha on symptoms and inflammatory biomarkers associated with chronic low back pain: A randomized active-controlled crossover pilot study in elderly. *Complementary Therapies in Medicine*, *32*, 25–32.

Zale, E. L., Lange, K. L., Fields, S. A., & Ditre, J. W. (2013). The relation between pain-related fear and disability: A meta-analysis. *The Journal of Pain*, *14*, 1019–1030.

SUPPORTING INFORMATION

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