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REVIEW ARTICLE

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

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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

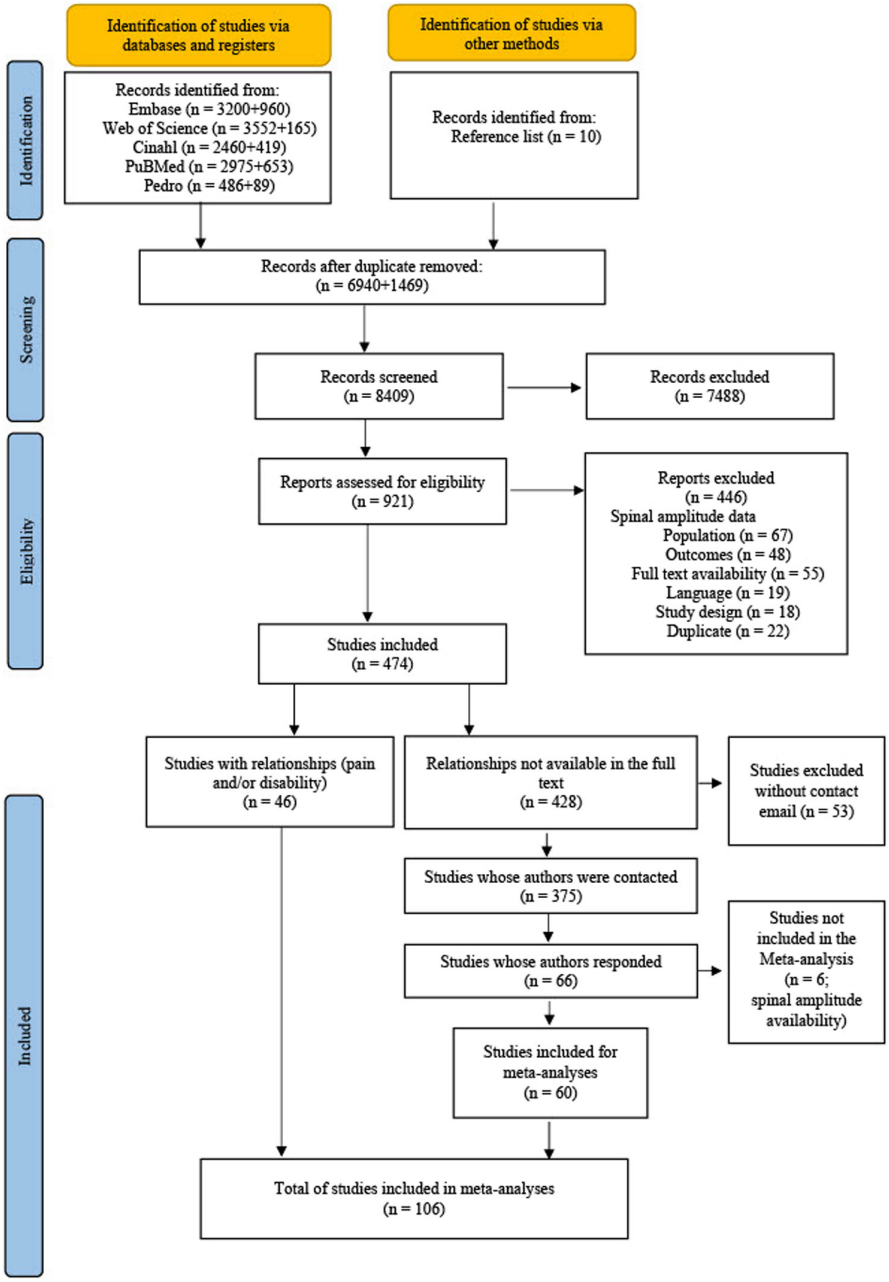

FIGURE 1 Flowchart diagram of included studies in the meta-analysis. In the identification phase, number of studies identified in the first and updated literature search are presented.

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

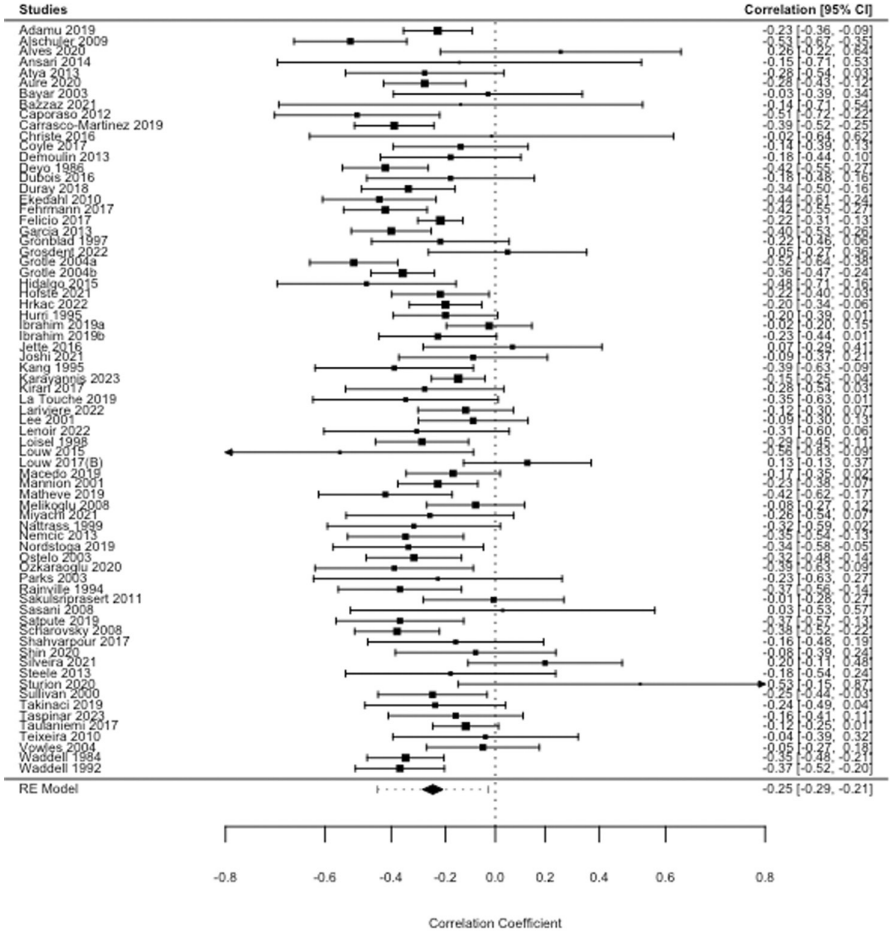

FIGURE 2 Forest plot of the associations between spinal amplitude and disability for cross-sectional data. Negative coefficient means that a larger spinal amplitude is associated with a lower disability. The black squares represent the coefficients and the horizonal lines their 95% confidence intervals (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],

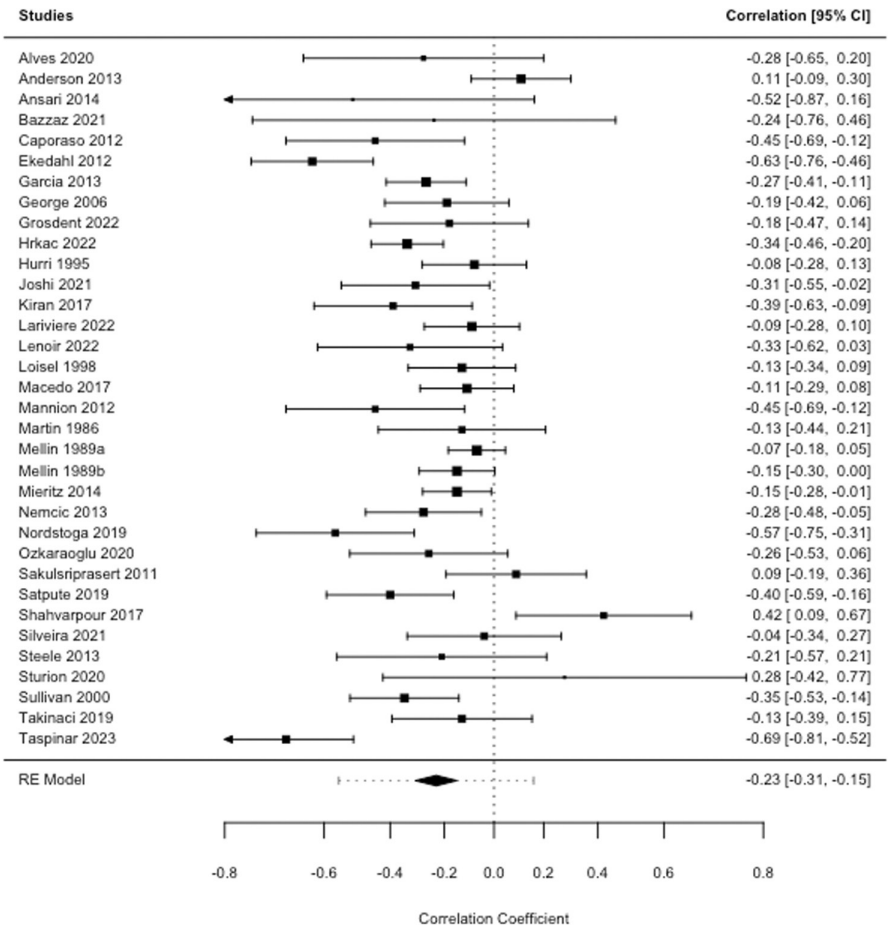

FIGURE 3 Forest plot of the associations between change in spinal movement and change in disability. Negative coefficient means that an increase in spinal amplitude is associated with a decrease in disability. The black squares represent the coefficients and the horizonal lines the 95% confidence interval (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.

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

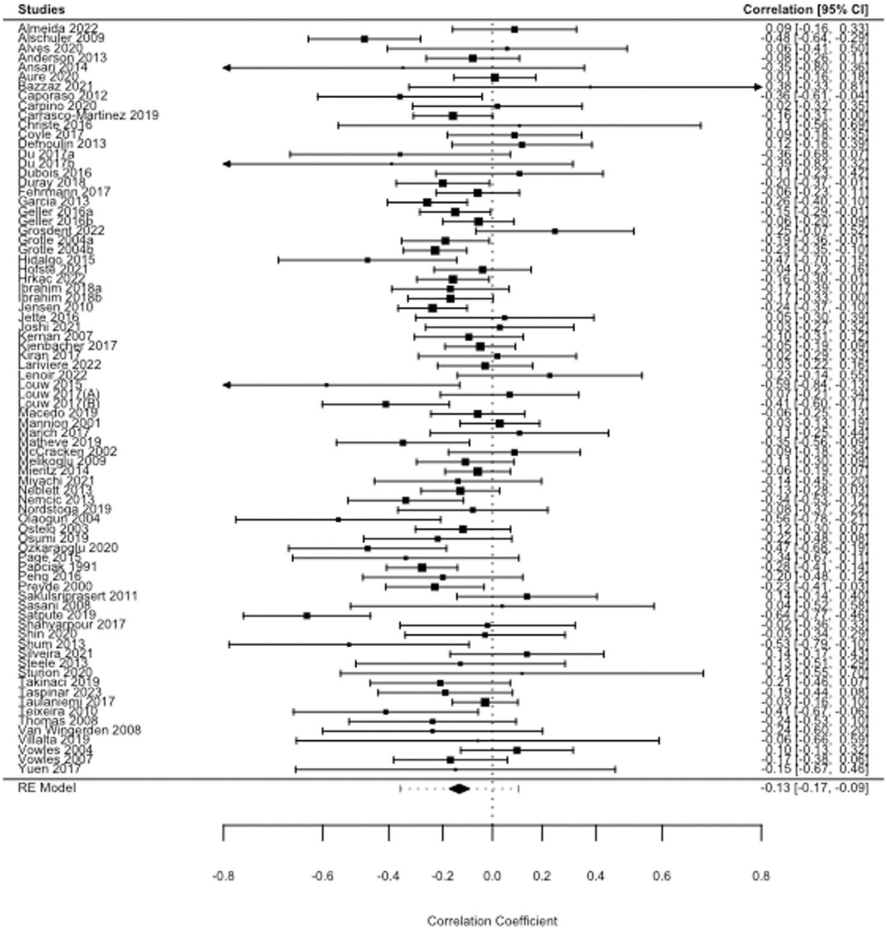

FIGURE 4 Forest plot of the associations between spinal amplitude and pain intensity for cross-sectional data. Negative coefficient means that a larger spinal amplitude is associated with a lower pain intensity. The black squares represent the coefficients and the horizonal lines the 95% confidence intervals (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

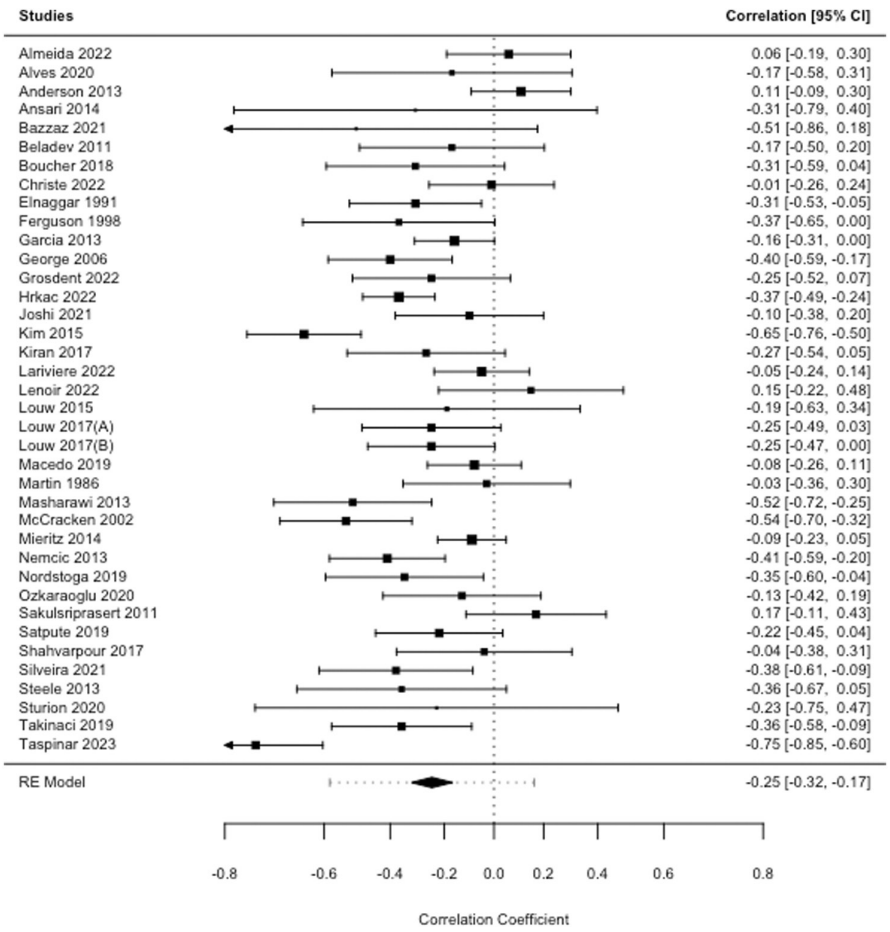

FIGURE 5 Forest plot of the associations between change in spinal amplitude and change in pain intensity. Negative correlation coefficient means that increase in spinal amplitude is associated with decrease in pain intensity. The black squares represent the correlation coefficients and the horizonal 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.

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

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 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., 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**			I^2	***Q* (p_{value})**	***n* (*p*)**	***r***	**95%CI**			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		−0.09	31.1	0.001	36 (2044)[2]	−0.21	−0.28		−0.15	51.35	0.001
	Only in CLBP	55 (3679)	−0.13	−0.18		−0.08	45.1	0.0003	25 (1413)	−0.26	−0.35		−0.17	65.7	<0.001
	Only in ALBP	7 (459)	−0.18	−0.28		−0.07	9	0.16	3 (141)	−0.21	−0.53		0.18	79.3	0.006
	Only in flexion	63 (4623)	−0.14	−0.19		−0.1	58.3	<0.001	31 (1774)	−0.24	−0.34		−0.14	76.1	<0.001
	Only in extension	21 (1131)	−0.09	−0.19		0.01	61.6	0.0004	8 (463)	−0.3	−0.46		−0.13	67.6	0.006
	Only in lateral flexion	16 (1329)	−0.06	−0.13		0.003	20.6	0.1	9 (598)	−0.13	−0.31		0.07	79.0	<0.001
	Only in rotation	3 (187)	−0.07	−0.27		0.13	50.6	0.13	1 (28)						
	Only functional activity	4 (132)	−0.08	−0.33		−0.49	48.9	0.129	1 (62)						
	Only lumbar measure	43 (2838)	−0.12	−0.18		−0.06	47.5	0.002	21 (1078)	−0.23	−0.32		−0.13	59.1	0.0004
	Only current pain	25 (1622)	−0.17	−0.24		−0.1	44.3	0.006	10 (487)	−0.23	−0.38		−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		−0.22	34.9	0.004	30(2285)[4]	−0.2	−0.26		−0.14	43.5	0.008
	Only in CLBP	50 (3843)	−0.25	−0.29		−0.20	47.8	0.0002	21 (1590)	−0.21	−0.28		−0.14	43.3	0.024
	Only in ALBP	7 (1016)	−0.32	−0.43		−0.2	71.8	0.002	4 (261)	−0.24	−0.53		0.1	86.8	<0.001
	Only in flexion	61 (4784)	−0.25	−0.30		−0.20	64.5	<0.001	30 (2147)	−0.19	−0.29		−0.08	82.5	<0.001
	Only in extension	20 (968)	−0.21	−0.29		−0.13	31.6	0.09	10 (933)	−0.14	−0.26		0.01	67.4	0.0002
	Only in lateral flexion	18 (1420)	−0.16	−0.24		−0.08	50.9	0.011	9 (998)	−0.12	−0.27		0.03	78.7	<0.001
	Only in rotation	7 (366)	−0.26	−0.4		−0.1	54.9	0.03	3 (544)	0.07	−0.24		0.37	91.8	<0.001
	Only functional activity	2 (65)	−0.36	−0.6		−0.06	13.4	0.283	-						
	Only lumbar measure	36 (2070)	−0.23	−0.28		−0.19	18.5	0.1566	17 (999)	−0.14	−0.25		−0.04	57.9	0.003

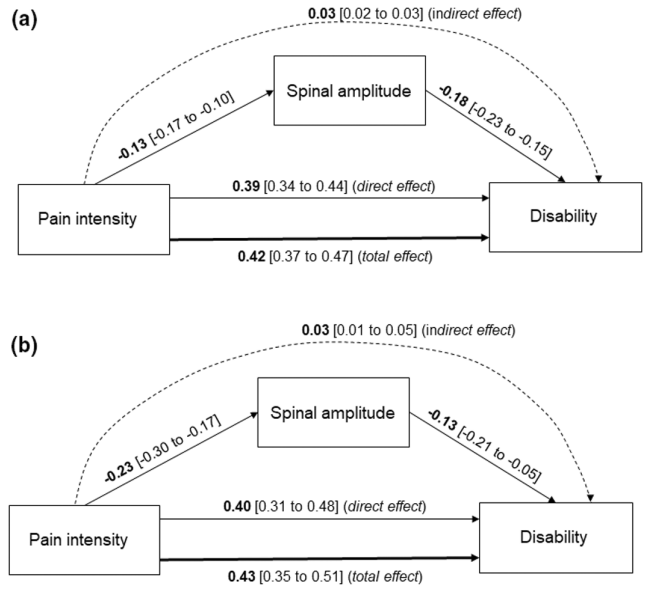

FIGURE 6 Results of MASEM analyses. (a) cross-sectional data; (b) longitudinal data.

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.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

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SUPPORTING INFORMATION

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

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