

The relationship between psychological factors and spinal motor behaviour in low back pain: a systematic review and meta-analysis

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Abstract

This meta-analysis investigated whether more negative psychological factors are associated with less spinal amplitude of movement and higher trunk muscle activity in individuals with low back pain (LBP). Furthermore, it examined whether pain intensity was a confounding factor in this relationship. We included studies that provided at least one correlation coefficient between psychological (pain-related fear, catastrophizing, depression, anxiety and self-efficacy) and spinal motor behaviour (spinal amplitude and trunk muscle activity) measures. In total, 52 studies (3949 participants) were included. The pooled correlations coefficients (95% CI; number of participants) were -0.13 (-0.18 to -0.09; 2832) for pain-related fear, -0.16 (-0.23 to -0.09; 756) for catastrophizing, -0.08 (-0.13 to -0.03; 1570) for depression, -0.08 (-0.30 to 0.14; 336) for anxiety and -0.06 (-0.46 to 0.36; 66) for self-efficacy. The results indicated that higher levels of pain-related fear, catastrophizing and depression are significantly associated with reduced amplitudes of movement and larger muscle activity, and were consistent across subgroup and moderation analyses. Pain intensity did not significantly affect the association between these psychological factors and spinal motor behaviour, and had a very small independent association with spinal motor behaviour. In conclusion, the very small effect sizes found in the meta-analyses question the role of psychological factors as major causes of spinal movement avoidance in LBP. Experimental studies with more specific and individualized measures of psychological factors, pain intensity and spinal motor behaviour are recommended.

1. Introduction

Low back pain (LBP) is one of the main causes of disability worldwide, with severe socioeconomic burden [38,48]. Physical and psychological factors have been repeatedly reported to contribute to LBP and it was suggested that relationships exist between these elements and play a critical role in LBP-related disability [65,68]. Unfortunately, the existence and exact nature of such relationships remain unclear, which limits the understanding of LBP and hinder the development of better treatment.

On the physical side, previous research demonstrated that patients with LBP have altered spinal motor behaviour [26,47]. Specifically, participants with LBP show reduced spinal amplitude and velocity of movement compared to asymptomatic controls during daily-life activities and maximal range of motion (ROM) tests. For instance, studies have shown that people with LBP have reduced amplitude of lumbar flexion during sit-to-stand, lifting tasks or maximal flexion tests [14–16,62,88,105]. Furthermore, biomechanical models of LBP have suggested that patients with LBP demonstrate higher trunk muscle activity, especially during dynamic tasks. Among these measures of muscle activity, the flexion-relaxation ratio was shown to be consistently higher in patients with LBP, showing an absence of the typical relaxation at the end of maximal flexion [22,32,34,130]. Altogether, these observations indicate that patients with LBP tend to move with a more rigid spinal motor behaviour.

On the other side, pain intensity and disability have been shown to be influenced by psychological factors in LBP populations [39,44,46]. These include cognitive and emotional factors, such as catastrophizing, self-efficacy, pain-related fear, anxiety or depression [18,21,67,96,132]. Studies also indicated that these psychological factors can be mediators and moderators of treatment efficacy [64,131].

Regarding the relationships, psychological factors were often suggested to be the causes of motor behaviour alterations as described by multiple models [4,7,28,65,117,124]. One example is the fear avoidance model (FAM), which states that a threatening appraisal of pain can induce pain-related fear, that can then lead to an avoidance behaviour and disability [124]. This model well adapts to LBP, where the avoidance behaviour is particularly expressed by reduced spinal amplitude and velocity of movement as well as higher trunk muscle activity [31,65]. However, while a relationship of this kind between pain-related fear and motor alterations has a strong theoretical rationale in LBP, it still requires validation and possibly improvement. Indeed, so far studies that addressed the question of the relationship between pain-related fear and motor behaviour alterations in LBP produced inconsistent results [25,111] and are mostly observational [54,83]. Since the variability in findings among publications could be due to differences in study specificities, there is a need for a systematic

review with a meta-analysis to synthesize the available data in literature and clarify the relationship between pain-related fear and motor behaviour in LBP. While a meta-analysis based on observational data cannot demonstrate causality, it could still provide information on the plausibility of such existence. For instance, to be plausible, the size of the relationship should be large, the findings should be consistent across multiple settings and multiple measures, and pain-related fear should precede spinal motor behaviour alterations [45,61,101].

While the FAM presents pain-related fear as the main cause of movement avoidance, other models suggest that other psychological factors also play an important role in the motor behaviour alterations of patients with LBP [4,7,28,95,117]. The first additional factor of interest is catastrophic thinking, which has been shown to increase pain-related fear and has been associated to avoidance behaviours [20,65,68,102]. The second is self-efficacy, which has been reported to mediate the relationship between pain-related fear and disability [136] and was associated with reduced physical performance [107]. Anxiety and depression are also of interest because they have been associated with pain-related fear and catastrophizing [21,94] and are considered as possible contributors to spinal motor behaviour [12,95,118]. Since a relationship between these four psychological factors and spinal motor behaviour can also be present, it is worth including them in the systematic review.

This study aimed to perform a systematic review and meta-analysis of the literature to synthesize current knowledge regarding the associations between psychological factors and spinal motor behaviour in LBP in an effort to improve our understanding of the relationships between these elements. It was hypothesized that higher levels of pain-related fear, catastrophizing, anxiety and depression, as well as lower levels of self-efficacy would be associated with more rigid spinal motor behaviours, characterized by reduced amplitude and velocity of movement and larger trunk muscle activity during dynamic tasks.

When analysing the relationships between psychological factors and spinal motor behaviour, one should be mindful of pain intensity, which could confound the analysis. Indeed, pain intensity has been shown to affect psychological factors, including pain-related fear [60], catastrophizing [77] and depression [115], whereas the relationship between pain intensity and spinal motor behaviour is still unclear [118,134]. Therefore, a secondary aim of this study on LBP was to determine whether pain intensity is a confounder in the associations between psychological factors and spinal motor behaviour.

2. Methods

This review was registered in PROSPERO (CRD42018088680) and the PRISMA principles were followed for its reporting [85].

2.1 Eligibility criteria

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

1. *Population*: studies testing adult with a diagnosis of non-specific LBP, with or without leg pain [73]. Studies on healthy participants with experimental LBP and individuals who recently recovered from LBP (in the last 3 months) were also included, as individuals who recently recovered from an acute LBP episode have been shown to continue to demonstrate spinal motor behaviour alterations and elevated pain-related fear scores [113].
2. *Psychological factors*: studies reporting measurement of at least one of the following factors: (1) pain-related fear, (2) catastrophizing, (3) depression, (4) state anxiety or (5) self-efficacy.
3. *Spinal motor behaviour*: studies reporting measurement of at least one of the following characteristics during a dynamic task: (1) spinal amplitude of movement, (2) spinal velocity of movement or (3) trunk muscle activity. Additionally, to be included, studies reporting amplitude or velocity of movement had to have measured the lumbar region alone or in combination with other regions (e.g. lumbar + thoracic spine or hips + lumbar spine + thoracic spine). These measures of spinal movement can be collected during maximal ROM tests (e.g. maximal bending, fingertip-to-floor (FTF)) or functional activities (e.g. lifting a box). Measures of amplitude of movement had to be described in degrees (e.g. lumbar flexion angle) or in centimetres (e.g. FTF or Schober tests) and measures of velocity of movement in degree per second. Studies reporting spinal amplitude of movement using the sit-and-reach test were excluded, as it primarily measures the hamstrings flexibility [80]. Studies with muscle activity data had to report the level of activity of anterior or posterior trunk muscles or the flexion-relaxation ratio (FRR) to be included.
4. *Study design*: observation and intervention studies of cross-sectional and longitudinal design reporting at least one psychological and one spinal motor behaviour measures. Because LBP symptoms are known to fluctuate over time [58], to be included studies had to have measured psychological factors and spinal motor behaviour on the same day. Additionally, to avoid statistical bias, only baseline measurement was used in longitudinal studies with multiple data collection episodes.
5. *Temporal precedence*: studies measuring psychological factors before spinal motor behaviour. This criterion was used because temporal precedence is a compulsory

condition to evaluate the plausibility of a causal relationship [45,59]. Because this information is often unavailable, studies for which the timing of measurement could not be determined were also included, but they were rated with a higher risk of bias and analyzed separately in sensitivity analyses.

6. *Relationship assessment*: studies for which at least one coefficient of correlation could be obtained between psychological and spinal motor behaviour measures. When one or more correlation coefficient was not reported in the article, the authors of the possibly eligible studies were contacted to obtain the missing correlations. All authors were contacted at least three times before excluding the study.
7. *Language*: articles written in French, English, German or Spanish.

2.2 Study selection

First, PubMed, CINAHL, PsychINFO, Embase, OTseeker and the Cochrane Central Register of Controlled Trials were searched from their inception until February 2018 for relevant articles. Searches were also made in the clinical registries of ClinicalTrials.gov and Current Controlled Trials Register. Then, the reference lists of the selected articles and the ePublication lists of the key journals where the selected articles were published were searched for additional relevant studies. Finally, a forward citation search for the selected articles was performed in Web of Science. Specific search strategies were used for each database, as detailed in Supplementary Material I.

Publications were screened in two stages. First, two authors (GC and SE) independently assessed titles and abstracts against inclusion and exclusion criteria. Differences were discussed until consensus was reached between the two authors. In case of uncertainty, the publication was kept to the next stage. Second, the two authors assessed the full text of the possibly eligible studies with the same criteria. The results were compared between the two authors and disagreements were resolved by consensus. If necessary, a third author of this work was consulted (EO).

2.3 Risk of bias assessment

Risk of bias was assessed using an adapted version of the Quality in Prognostic Studies (QUIPS) tool [40]. This tool was selected because it is particularly adapted to assess the risk of bias in prognostic studies. It evaluates the risk of bias of six different domains that may influence the analyses of interest in the present study (see Supplementary Materials II) [40]. It should not be interpreted as an assessment of the included study quality per se, but as an assessment of the possible bias in the context of the present review study. Two authors (GC

and SE) independently assessed the risk of bias of the included studies. Any disagreement was resolved by consensus.

2.4 Data extraction and coding

One author (GC) extracted the data for all the included studies. A second author (SE) verified the extraction tables. Any inconsistencies were resolved together by the two authors.

The first information to be extracted was the study objective, coded as either a study conducted primarily to assess the relationship between psychological and spinal motor behaviour measures, or a study whose primary objectives was not to assess this relationship.

For participant characteristics, the following data was extracted: study population (coded as chronic, subacute and acute LBP, recovered or healthy with induced LBP), age, disability, gender (% female) and body mass index (BMI).

The psychological measures, as well as the type of questionnaire used for the measurement, were also recorded. For questionnaires assessing a single psychological construct, the total score was extracted (e.g. total score of the Pain Anxiety Symptom Scale (PASS) for pain-related fear). When a questionnaire assessed different constructs (e.g. Common Mental Disorders Questionnaire (CMDQ) with the anxiety and depression subscales), only the data of the subscale of interest was extracted. For the Fear Avoidance Beliefs Questionnaire (FABQ), if the total score was not available, the Physical Activity subscale was used.

For spinal motor behaviour, the type of measurement (coded as amplitude of movement, velocity of movement or muscle activity), the method of measurement and the actual measures were extracted. The following information was also recorded: the plane of motion (coded as sagittal, frontal or transverse), the region of measurement (coded as lumbar, trunk: lumbar and thoracic or global: hips, lumbar and thoracic) and the type of activity that was measured (coded as maximal ROM tests (e.g. maximal flexion) or functional movements). In addition, the direction of movement was recorded (coded as flexion, extension or lateral flexion).

Pain intensity measures were also extracted, when available. The tool used to measure pain intensity (e.g. Numeric Pain Rating Scale (NPRS) or Visual Analog Scale (VAS)) and the recall period (coded as during specific activity, current, past day, past week or unknown) were recorded alongside.

The correlation coefficients between (1) psychological and spinal motor behaviour measures, (2) psychological and pain intensity measures and (3) spinal motor behaviour and pain intensity measures, as well as the corresponding sample sizes, (present in the publications

or obtained after having contacted the authors) were recorded in the extraction tables. Pearson and Spearman correlation coefficients were recorded without distinction [50]. When a correlation coefficient was not reported, other strategies were used to determine the effect size of the association between psychological, motor behaviour and pain intensity measures. First, if a linear regression was available, the standardized beta coefficient was used instead of the correlation coefficient, as suggested by Peterson & Brown (2005) [93]. Furthermore, in the case of reported group average values (e.g. mean and standard deviation of low and high depressed groups), a correlation coefficient was calculated using the mean standardized differences [51]. Studies without explicit correlation coefficient reporting were rated with a high risk of bias and tested separately in sensitivity analyses. When necessary, the sign of the correlation coefficients was reversed to be consistent among studies and always have negative correlations corresponding to an association between worse psychological measures (e.g. higher pain-related fear) and worse spinal motor behaviour measures (e.g. less amplitude or higher trunk muscle activity). Therefore, associations between higher levels of pain-related fear, catastrophizing, depression, anxiety and a more rigid spinal motor behaviour (less spinal amplitude and higher trunk muscle activity) are demonstrated with negative correlations. Negative correlations also indicate an association between lower levels of self-efficacy and less spinal amplitude and higher trunk muscle activity.

2.5 Data synthesis and meta-analysis

To test our primary hypothesis, an overall meta-analysis for each psychological factor was performed, where results were averaged for studies measuring some characteristics in multiple ways. Based on current literature, it was not possible to select *a priori* specific measures of spinal motor behaviour. Therefore, if a study included multiple measures for one psychological factor and/or the spinal motor behaviour, the correlation coefficients were averaged across the multiple measures to yield to a single correlation coefficient [50]. For instance, studies that had one motor behaviour measure, but measured pain-related fear with two different questionnaires (e.g. FABQ and Tampa Scale of Kinesiophobia (TSK)), had their two correlation coefficients averaged [103]. For the overall meta-analyses, spinal motor behaviour measures from different types, movements, planes of motion and regions of measurement were considered comparable and the correlation coefficients obtained with these measures were averaged [27]. In addition to the overall meta-analyses, subgroups, moderation and sensitivity analyses were conducted to determine the effect of the variations in measurement specificities and of averaging multiple measures from the same study.

Before performing the meta-analytic procedures, the correlation coefficients were transformed using a Fisher's Z transformation. An inverse Fisher's Z transformation was then

used to calculate the pooled correlation coefficient resulting from the meta-analyses [37,98]. The meta-analyses were conducted using random-effects model, as measurements differed among studies [43,98]. Statistical heterogeneity was assessed using Q and I² statistics. All the correlation coefficients were inspected visually in the forest plots to find influential cases and correctly interpret the results [120].

Moderation analyses were conducted with respect to age, gender, disability, study population, study objective and psychological and motor behaviour measurements, using meta-regression models. Subgroup analyses were also performed to evaluate the effect of variations in these properties.

Sensitivity analyses were conducted, as well. First, we performed a sensitivity analysis to test the effect of selecting only flexion and FRR vs averaging them with other spinal behaviour measures, as these are particularly affected by pain and fear of movement [9,23,31]. We also tested if excluding measures that have opposite effect sizes than expected from the overall meta-analyses lead to the same results. Furthermore, three sensitivity analyses were performed to evaluate the effect of excluding studies with a high risk of bias with respect to the QUIPS items of: Study Participation, Outcome Measurement and Statistical Analysis. Lastly, a sensitivity analysis was conducted to test the effect of excluding studies with unknown temporal precedence.

Finally, a meta-analytic structural equation modelling (MASEM) was used to test the hypothesis that pain intensity is a confounder in the relationship between psychological factors and spinal motor behaviour [13,36].

Publication bias was assessed with funnel plots, as well as Egger's regression (<25 studies) or rank correlation (>25 studies) tests [98]. All the calculations were performed using R software (R Development Core Team, 2017), particularly the "metafor", "robumeta" and "metaSEM" packages [98].

3. Results

Fifty-two studies, with 3949 participants, were included in this review (Fig. 1). Twenty-eight of these studies (1923 participants) were conducted primarily to assess the relationship between psychological and spinal motor behaviour measures. All studies focused on a single population, except one study that tested a group of acute LBP patients and a group of chronic LBP patients [35]. The population in this review was composed as follow: chronic LBP in 42 studies (3013 participants), acute LBP in 4 studies (250 participants), subacute LBP in 2 studies (77 participants), LBP without duration distinction in 2 studies (228

participants), recurrent LBP in 1 study (209 participants), healthy participants with induced LBP in 1 study (55 participants) and recovered LBP in 1 study (52 participants). Study characteristics are reported in Supplementary materials III.

3.1 Risk of bias

The full evaluation of the risk of bias is reported in Supplementary Material V.

Study Participation: The most frequent source of bias in the included studies was the inclusion of participants with a history of surgery, as some spinal surgery might affect movement behaviour. Indeed, 8 studies that reported a history of spine surgery for their participants and 18 studies that did not mention this population characteristic were rated as moderate risk. In addition, 6 studies were rated with a high risk of bias with respect to the study participation. This rating was due to an inclusion restricted to participants with limited kinesiophobia [104], the study of healthy participants with induced back pain [116], the study of participants who recently recovered from an acute episode of back pain [113], the study of CLBP patients that received noxious stimuli [41] and the study of participants who had a recent discectomy [89,103].

Attrition: The risk of attrition was considered low in all studies because psychological factors and spinal motor behaviour were always measured within a short time window.

Prognostic Factor and Outcomes Measurements: There was very limited risk of bias in the psychological factor measurement, as most of studies used reliable and validated questionnaires. For the motor behaviour measurement, 5 studies were rated as moderate risk because they measured the amplitude of movement of the entire trunk (including the thoracic spine) [31,55,81,127,138] and 12 studies were rated as high risk because they used global measures of spinal amplitude of movement (e.g. FTF) [10,25,29,35,56,69–71,89,92,109,110].

Study Confounding: Twenty-nine studies were rated as moderate risk of bias because no measure of pain intensity at the time of the psychological and motor behaviour measurements was available (e.g. pain intensity was only measured as the average during the past week or information was missing) [3,5,10,25,29–31,52,55,57,66,69–71,74,81,84,87,89,91,92,100,104,109,112,122,127,128,137,138]. When the correlation coefficients with pain intensity was not available, the studies were rated as high risk of bias [5,41,86,100,103,108,122]. This absence did not affect the overall meta-analyses; it only limited the MASEM procedure assessing the confounding role of pain intensity. Additionally, 35 studies were rated with moderate risk of bias because it was not possible to determine whether the psychological factors were measured before the spinal motor behaviour

[3,5,10,19,27,29,31,33,35,42,52,53,57,66,69–71,74,76,78,81,84,87,89,91,97,100,103,110,113,122,128,129,135,138].

Statistical Analysis and Reporting: Twenty-five studies were rated as moderate risk of bias because they reported multiple measures for the same characteristics and correlation coefficients had to be averaged for the meta-analyses [3,25,27,29,30,41,42,53,55–57,74,78,81,87,90–92,104,112,118,122,127,129,138]. In addition, 7 studies were rated as high risk of bias. This was due an incomplete reporting of the correlation data [91,100,108], a reporting limited to the standardized beta [5], the use of partial correlations [57] and the necessity to calculate the effect size from group comparisons [86,113].

3.2 Overall meta-analyses: Association between psychological factors and spinal motor behaviour

Only 6 studies reported velocity of movement measures, 3 with respect to pain-related fear, 2 with respect to depression, and 1 with respect to anxiety and catastrophizing. Because of this low number in comparison with amplitude of movement and muscle activity measures, velocity of movement measures were not entered in the overall meta-analyses. Correlations for velocity of movement are reported separately in Supplementary materials V.

The meta-analyses for pain-related fear indicated a pooled correlation coefficient of -0.13 (95% CI -0.18 to -0.09), with low heterogeneity ($I^2=25.5$, Q statistic: $p=0.1$), meaning that higher levels of pain-related fear were associated with a more rigid spinal motor behaviour (less spinal amplitude and higher trunk muscle activity) (Fig. 2). This analysis was based on 41 studies (2832 participants) [3,5,10,19,25,27,29,31,33,35,41,42,53,55–57,66,69–71,74,76,78,81,87,89,90,103,104,108,109,112,113,116,118,122,129,135].

Regarding catastrophizing, the pooled correlation coefficient was -0.16 (95% CI -0.23 to -0.09) and the heterogeneity low ($I^2=1\%$, Q statistic: $p=0.41$) (Fig. 3). Therefore, higher levels of catastrophizing were associated with less spinal amplitude and higher trunk muscle activity. This meta-analysis included 13 studies (756 participants) [10,19,25,27,41,49,74,89,91,92,108,112,118].

The pooled correlation coefficient for depression was -0.08 (95% CI -0.13 to -0.03) (Fig. 4), showing that higher levels of depression were associated with less spinal amplitude and higher trunk muscle activity. This meta-analysis, based on 14 studies (1570 participants) [10,30,52,74,81,84,86,87,92,100,109,127,137,138], demonstrated a low heterogeneity ($I^2=1\%$, Q statistic: $p=0.41$).

The meta-analysis for anxiety, which was based on 4 studies (336 participants) [41,52,97,118], reported a large heterogeneity ($I^2=64\%$, Q statistic: $p=0.08$) (Fig. 5). The pooled correlation coefficient was -0.08 (95%CI -0.30 to 0.14).

Two studies reported self-efficacy data (130 participants) [110,129]. This resulted in a meta-analysis of large heterogeneity ($I^2=67\%$, Q statistic: $p=0.08$), with a pooled correlation coefficient of -0.06 (95%CI -0.46 to 0.36) (Fig. 6).

3.3 Moderation and subgroups analyses

Moderation and subgroups analyses could only be conducted for three psychological factors: pain-related fear (Table 1), catastrophizing (Table 2) and depression (Table 3). Insufficient data were available for anxiety and self-efficacy.

Age, gender and disability: These elements were not significant moderators in the association between psychological factors and spinal motor behaviour.

Study population: This element was not a significant moderator in the association between psychological factors and spinal motor behaviour for catastrophizing and depression. However, it significantly influenced the results of the meta-analysis for pain-related fear ($Q(4) = 25.66$ $p < 0.001$). Because this result was largely due to one study with recovered LBP participants, we also performed a moderation analysis with only acute and chronic LBP participants. This time, the study population was not a significant moderator ($Q(1) = 1.89$, $p=0.2$).

Psychological factors measurement: The questionnaires used to measure catastrophizing and depression were not significant moderators in the association between psychological factors and spinal motor behaviour. On the contrary, moderation analyses demonstrated a significant effect of the questionnaires used to measure pain-related fear ($Q(5) = 12.66$, $p=0.03$), with the PASS being significantly different from the others ($p=0.03$). Subgroups analyses reported pooled correlation coefficients for the PASS of -0.32 (95%CI -0.51 to -0.11), the TSK of -0.19 (95%CI -0.26 to -0.12) and the FABQ of -0.09 (95%CI -0.14 to -0.03).

Spinal motor behaviour measurement: Measuring spinal motor behaviour with spinal amplitudes or trunk muscle activity did not significantly moderate the results. However, subgroups analyses showed smaller or non-significant effect sizes when trunk muscle activity is analysed alone (pain-related fear ($r=-0.08$ 95%CI -0.15 to -0.01), catastrophizing: ($r=-0.07$, 95%CI -0.33 to 0.21), depression ($r=-0.08$ 95%CI -0.27 to 0.11)). For pain-related fear, the type of muscle activity measure significantly moderated the results ($Q(2) = 10.28$, $p=0.006$). Specifically, muscle activity of posterior muscles had an opposite effect ($r=0.21$, 95%CI 0.002 to 0.41 ; 4 studies) compared to other muscle activity measures (anterior muscles ($r=-0.16$, 95%CI -0.43 to 0.13 ; 3 studies) or FRR ($r=-0.15$, 95%CI -0.28 to -0.02 ; 8 studies)).

The type of activity was not a moderator in the meta-analyses and studies assessing functional movements (e.g. reaching tasks, gait) did not have correlation coefficients

statistically significantly different than studies assessing maximal ROM. Similarly, the plane of motion was not a moderator and no significant differences were found between studies measuring flexion, extension or lateral flexion. Finally, the method used to measure spinal amplitudes of movement (e.g. FTF, inclinometer or marker-based measurement) was not a significant moderator.

3.4 Sensitivity analyses and publication bias

Results of all sensitivity analyses demonstrated similar results to the overall meta-analyses (Supplementary materials VI).

No publication bias was detected in the data ($p > 0.5$). However, the study objective was a significant moderator in the association between pain-related fear and spinal motor behaviour ($Q(1) = 5.86, p = 0.02$). Studies that did not include in their objective to assess the relationship between pain-related fear and spinal motor behaviour produced a smaller effect size ($r = -0.08, 95\%CI -0.13$ to -0.02) than studies that had this objective ($r = -0.19, 95\%CI -0.26$ to -0.12). While the differences were non-significant for catastrophizing ($Q(1) = 2.01, p = 0.2$) and depression ($Q(1) = 2.00, p = 0.1$), studies that included in their objective to assess the relationship between psychological factor and spinal motor behaviour had larger effect sizes in the subgroup analyses.

3.5 Meta-analytic structural equation modelling (MASEM)

The effect of pain intensity on the association between psychological factors and spinal motor behaviour was tested separately for pain-related fear, catastrophizing and depression using the same dataset as for the overall meta-analyses. The effect of pain intensity with respect to anxiety and self-efficacy was not tested, as insufficient data was available.

As reported in Figure 7, the pooled correlation coefficient between pain-related fear and spinal motor behaviour without the confounding effect of pain intensity was -0.11 ($95\%CI -0.16$ to -0.07), which is only slightly less than the correlation reported above with the confounding effect of pain intensity ($-0.13, 95\% CI -0.18$ to -0.09). Similarly, the pooled correlation coefficients for catastrophizing and depression were only slightly reduced without the confounding effect of pain intensity.

This analysis also showed a small effect of pain intensity on spinal motor behaviour, with correlation coefficients ranging from -0.11 to -0.08 , depending on the psychological factors (Fig. 7). On the other hand, the correlation between pain intensity and psychological factors was 0.18 ($95\%CI 0.12$ to 0.24) for pain-related fear, 0.30 ($95\%CI 0.22$ to 0.39) for catastrophizing and 0.17 ($95\%CI 0.12$ to 0.23) for depression.

4. Discussion

4.1 Relationships between psychological factors and spinal motor behaviour

As hypothesized, pain-related fear and catastrophizing were found to be associated with a more rigid spinal motor behaviour (smaller spinal amplitude of movement and higher trunk muscle activity). Nevertheless, the effect sizes were small ($r=-0.13$ and -0.16 , respectively) and do not support pain-related fear and catastrophizing as major causes of a more rigid spinal motor behaviour. The results of our meta-analyses can be considered as particularly robust, as they demonstrated a low heterogeneity, a narrow confidence interval and were consistent among studies (see sections 4.2 and 4.3). Therefore, the present synthesis suggests that spinal motor behaviour alterations in patients with LBP only have a small relationship with pain-related fear and catastrophizing.

Higher levels of depression were also associated with a more rigid spinal motor behaviour, but to an even smaller extent than pain-related fear and catastrophizing. This suggests that not all psychological factors have the same relationship with spinal motor behaviour. As psychological factors are associated between them [6,17], it is not possible to determine if depression has an independent relationship with spinal motor behaviour.

Anxiety was not associated with spinal motor behaviour, but these results relied on only four studies with large heterogeneity. Nevertheless, pain-related fear and anxiety are two concepts that frequently overlap in the FAM [21,65]. Furthermore, it is interesting to note that the PASS, which also includes aspects of anxiety [72] (although it was used as a measure of pain-related fear in the present meta-analyses) reported the largest effect size. Altogether, this suggests that anxiety might have a role in spinal movement avoidance in patients with LBP and warrant further research.

Unfortunately, only two studies with opposite correlation coefficients were available for self-efficacy and no conclusion could be drawn from the meta-analysis.

4.2 Pain intensity

The meta-analytic structural equation modelling analyses showed that the association between pain-related fear, catastrophizing and depression with spinal motor behaviour are independent from pain intensity. This suggests that the effects of psychological factors are not confounded by pain intensity, therefore giving further support to our hypotheses.

Interestingly, higher pain intensity was independently associated with less spinal amplitude and higher trunk muscle activity. Although pain intensity has often been considered as an important factor influencing movement [47], the effect sizes found in the meta-analyses were very small. Therefore, our results suggest that pain intensity is not a major cause of spinal

motor alteration in patients with LBP. While it was not the primary purpose of our review, to our knowledge, this is the largest meta-analyses testing the relationship between pain intensity and spinal motor behaviour.

These results suggest that psychological factors and pain intensity have an independent and direct effect on spinal motor behaviour. Nevertheless, future longitudinal studies should assess the theoretical cyclical relationship between pain intensity, pain-related fear and spinal movement. In this regard, our work rather supports the use of multidimensional cumulative factors to explain spinal movement avoidance in patients with LBP [133].

4.3 Influence of study specificities

Moderation and subgroup analyses demonstrated consistent effect sizes across a wide range of study specificities, thus strongly supporting the findings in the overall meta-analyses.

First, individual characteristics, such as age, gender, BMI, duration of LBP and level of disability did not moderate the result of the meta-analyses. Interestingly, this suggests that psychological factors influence spinal motor behaviour regardless of the stage of LBP and the level of disability. Nevertheless, future work is still needed to confirm this interpretation. Additional studies with acute LBP participants are required and future meta-analyses should consider integrating disability in the analyses, as we did with pain intensity.

Second, different types of measures of spinal motor behaviour resulted in similar effect sizes. Including only spinal amplitude of movement measures produced similar effect sizes as the overall meta-analyses and there were no differences when they were measured during flexion, extension or lateral flexion. While flexion is often described as the most feared movement by patients with LBP [8,24], our results did not indicate that pain-related fear has a larger relationship with spinal motor behaviour during flexion movements. Furthermore, the method of assessment of spinal amplitudes of movement did not influence the results of the meta-analyses. Specifically, measuring spinal kinematics during functional activities or maximal ROM tests, locally at the lumbar spine or with measures that included the whole trunk and the hips, did not produce statistically different effect sizes. Some subgroup analyses suggested small differences, yet without statistical significance. They will need to be further analysed when there will be more data in the literature.

Third, the type of questionnaire did not significantly influence the results for catastrophizing and depression. The moderation analysis was however significant for pain-related fear, with the PASS being the only questionnaire reporting a significantly larger effect size. However, this result should be interpreted cautiously because of the large heterogeneity in the studies using the PASS and one major influential work [113]. The small differences reported in

subgroup analyses between questionnaires assessing pain-related fear may be due to different constructs assessed by these questionnaire, such as beliefs about pain and movement, fear of pain, movement or activity and avoidance of movements or activities [72,95].

While most of the study specificities did not influence the results of the meta-analyses, there were two interesting aspects that did influence the effect sizes. First, the study objective was a significant moderator in the pain-related fear meta-analysis, with studies that primarily assessed the association between psychological factors and spinal motor behaviour having larger effect sizes than studies that did not include this objective. Subgroup analyses with catastrophizing and depression also suggested an influence of the study objective. These results suggest a publication bias in the literature, with studies aiming and publishing this association having larger effects. Second, in subgroups analyses, studies based on muscle activity measurements produced smaller effect sizes for pain-related fear ($r=-0.08$) and catastrophizing ($r=-0.07$) than the overall analyses. Results for catastrophizing and depression were no more statistically significant when analysing only muscle activity measures. In addition, the effect size of posterior trunk muscles activity was positive with pain-related fear ($r=0.21$, 95%CI 0.002 to 0.41; 4 studies), but was negative with catastrophizing ($r=-0.08$, 95%CI -0.43 to 0.19; 4 studies), showing no consistency in the direction of the effect sizes for posterior muscle activity. While the FRR is usually considered as a more robust measure in patients with LBP [32,130], our results also demonstrated inconsistencies for this measure. The FRR showed a similar effect size than the overall meta-analysis for pain-related fear ($r=-0.15$), but was in the opposite direction for catastrophizing ($r=0.20$). Possible explanation for these inconsistent results may be related to the heterogeneity of the methods to measure trunk muscle activity, such as data normalization or the angle of spinal flexion, and is in agreement with prior observations of variability of muscle data [1,31,32,87,121,130]. Overall, these findings suggest that measures of spinal amplitude are more consistently associated with psychological factors than measures of trunk muscle activity, and may better reflect movement avoidance.

4.4 Considerations for future research

The small effect sizes found in the meta-analyses do not support that pain-related fear, catastrophizing and depression are major causes of avoidance of spinal movement. Based on the Bradford Hill criteria [45], the strength of the association in observational studies should be high for causal relationship to be plausible, which was not the case in our meta-analyses. Similarly to our results, prior studies that tested the relationship between pain-related fear or catastrophizing with other physical measures of avoidance found inconsistent results at best (e.g. physical activity level [11,29,106], walking endurance capacity and

maximal oxygen consumption [106,119,123] or back muscles strength [2,25,29,63,75,114]). Furthermore, temporal precedence was not guaranteed in most of the included studies, which is another criteria needed to determine the plausibility of a causal relationship [45]. While the results were similar when including or excluding these studies with unknown temporal precedence (see sensitivity analyses), future studies should describe the temporality of the measurements. Finally, the only element supporting the plausibility of a causal relationship is the consistency of the findings among studies, indicated by the small heterogeneity in the meta-analyses and the consistent results across subgroups and moderation analyses. Consequently, there is a need for future experimental research to detangle the complex relationships between psychological factors, spinal motor behaviour and pain in individuals with LBP. Interestingly, a recent study reported a bidirectional relationship between fear and avoidance [126], suggesting that the causal relationship between these elements may need to be revisited. Future research should also develop more relevant and specific measures of psychological factors and spinal motor behaviour, which may vary among individuals.

4.5 Limitations

This review has some limitations related to the measurement of psychological factors, spinal motor behaviour and pain intensity. First, included studies measured pain-related fear mostly with general questionnaires. However, avoidance may well be context-dependent, with some specific movements being feared and avoided, whereas others are not [125,133]. The lack of relationship between self-report questionnaires and physical tests may be due to the lack of specificity of these questionnaires for particular tasks [95]. Therefore, there is a need for studies using specific measures of pain-related fear, in relation to feared movements or activities [79]. Clinicians should also tailor the assessment of pain-related fear and spinal motor behaviour to the individual [99], taking into account the movements that are feared, avoided and painful. Second, the avoidance of a specific movement might change depending on the context and the presence of competing goals [21]. For instance, in studies assessing spinal kinematics during maximal ROM tests, fearful participants might have performed better than in daily living because they were following instructions. If this would be the case, the amplitudes of movement and muscle activities in this review need to be considered more as indicator of capacity of movement, rather than as a particular motor behaviour. Therefore, future studies should use objective measures of spinal motor behaviour that can capture avoidance behaviours and not only movement capacity. Third, in many studies the recall period for pain intensity was undocumented or not limited to the day the other measures were recorded. This may have decreased the precision of the relationships between pain intensity and spinal motor behaviour or psychological factors. Therefore, future studies

should measure pain intensity at the same time as spinal motor behaviour and psychological factors. Measuring pain with pain questionnaires could also provide additional information [82].

Another limitation is related to our broad inclusion criteria. While studies with high risk of bias in terms of population, motor behaviour measurement or statistical analysis might have influenced the results, the sensitivity analyses demonstrated that the same general findings would have been obtained without these studies.

There were also limitations regarding data analysis. First, our moderation analyses for disability, age and gender were performed with the mean characteristics of the study populations. Therefore, the effect of these variables was tested based on differences between studies, but not based on individual differences. Second, averaging data in studies reporting several measures of psychological factors and/or motor behaviour characteristics may have reduced the heterogeneity among movements, individuals, and studies and consequently lowered the pooled correlation coefficients [50]. While averaging data in case of multiple measurements is standard practice in meta-analyses, this approach could be particularly critical in the present work as spinal motor behaviour in patients with LBP is a complex and heterogeneous phenomenon, and it is yet unclear which measures of motor behaviour to take into account during which movements. It should be noted that the absence of a standard to measure motor behaviour in LBP not only required the averaging of data within studies, but also contributed to a heterogeneity of data across studies. This heterogeneity could also have attenuated the findings of this systematic review.

Nevertheless, sensitivity and subgroups analyses demonstrated that including only a selection of measures from a study (flexion for spinal amplitude of movement and FRR for muscle activity), excluding measures with opposite effect sizes (posterior muscles activity), analysing only spinal amplitude of movement (all directions) or only spinal amplitude of flexion led to comparable effect sizes. Nonetheless, further research is warranted to identify the most relevant measures of psychological factors and/or motor behaviour characteristics. Third, correlation analyses have limitations, amongst which range restriction, which may have influenced the estimation of the pooled correlations [50].

5. Conclusion

The meta-analyses demonstrated consistently that higher levels of pain-related fear, catastrophizing and depression are associated with less spinal amplitudes and higher trunk muscle activity in individuals with LBP. Importantly, the relationships were independent from pain intensity. However, the effect sizes were small, questioning the major role of these psychological factors in more rigid spinal motor behaviour. In addition, this review identified

associations of very small effect sizes between higher pain intensity and reduced spinal amplitudes and increase trunk muscle activity. These results suggest that future research should consider using specific and individualized measures of psychological factors, pain intensity and spinal motor behaviour. Importantly, there is a strong need for research testing the causal relationship between psychological factors and spinal movement avoidance in individuals with LBP.

Conflict of interest statement

The authors have no conflict of interest with this work. The study was supported by a grant from the University of Applied Sciences and Arts Western Switzerland//HES-SO, Faculty of Health Science and by the Profectus Foundation. Both BMJ and JF supervised this research and should be considered as last authors.

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Tables

Table 1: Pain-related fear meta-analyses

	Studies (n)	Participants (n)	I ² (%)	Q statistic (p value)	r	95%CI
Overall analysis	41	2832	25.54	0.10	-0.13	(-0.18 to -0.09)
Subgroup analyses						
Amplitude of movement	33	2654	51.88	0.00	-0.16	(-0.21 to -0.1)
Only flexion	31	2401	53.76	0.00	-0.17	(-0.23 to -0.1)
Only extension	6	318	0.00	0.95	-0.16	(-0.27 to -0.05)
Only lateral flexion	6	658	22.61	0.28	-0.07	(-0.16 to 0.019)
Muscle activity	14	778	0.00	0.84	-0.08	(-0.15 to -0.01)
Only anterior muscles	3	54	0.40	0.39	-0.16	(-0.43 to 0.131)
Only posterior muscles	4	169	40.42	0.19	0.21	(0.002 to 0.407)
Only FRR	8	631	55.41	0.04	-0.15	(-0.28 to -0.02)
Questionnaires						
TSK	17	917	5.82	0.43	-0.19	(-0.26 to -0.12)
FABQ	19	1384	0.00	0.81	-0.09	(-0.14 to -0.03)
PASS	6	381	78.32	0.00	-0.32	(-0.51 to -0.11)
Population						
CLBP	32	2203	0.00	0.98	-0.11	(-0.15 to -0.07)
ALBP	3	222	64.25	0.06	-0.26	(-0.47 to -0.02)
Study Objective						
Objective included	22	1423	36.83	0.07	-0.19	(-0.26 to -0.12)
Objective not included	19	1424	0.00	0.79	-0.08	(-0.13 to -0.02)
Type of activity						
Functional movement	6	278	63.99	0.01	-0.21	(-0.41 to 0.009)
Maximum ROM	35	2589	0.00	0.69	-0.11	(-0.15 to -0.07)

Subgroups analyses included only studies that tested the parameter noted in the first column. ALBP: acute low back pain; CLBP: Chronic low back pain; FABQ: Fear-Avoidance belief Questionnaire; FRR: Flexion relaxation ratio; PASS: Pain Anxiety Symptoms Scale; TSK: Tampa Scale of Kinesiophobia

Table 2: Catastrophizing meta-analyses

	Studies (n)	Participants (n)	I ² (%)	Q statistic (p value)	r	95%CI
Overall analysis	13	756	0.00	0.10	-0.16	(-0.23 to -0.09)
Subgroup analyses						
Amplitude of movement	8	617	0.01	0.44	-0.16	(-0.24 to -0.08)
Only flexion	8	617	0.02	0.31	-0.17	(-0.25 to -0.09)
Only extension	2	206	0	0.67	-0.22	(-0.35 to -0.09)
Muscle activity	6	175	64.0	0.02	-0.07	(-0.33 to 0.21)
Only anterior muscles	2	42	0	0.93	-0.42	(-0.65 to -0.12)
Only posterior muscles	4	141	56.8	0.07	-0.08	(-0.34 to 0.19)
Only FRR	2	58	73	0.05	0.20	(-0.33 to 0.63)
Questionnaires						
PCS	9	352	45.3	0.06	-0.09	(-0.24 to 0.07)
CSQ	4	404	0.00	0.78	-0.21	(-0.30 to -0.12)
Population						
CLBP	11	708	8.9	0.09	-0.14	(-0.22 to -0.06)
Study objective						
Objective included	8	414	53.2	0.05	-0.20	(-0.35 to -0.03)
Objective not included	5	342	0.00	0.66	-0.10	(-0.21 to 0.01)

Subgroups analyses included only studies that tested the parameter noted in the first column. CLBP: Chronic low back pain; CSQ: Coping Strategy Questionnaire; PCS: Pain Catastrophizing Scale

Table 3: Depression meta-analyses

	Studies (n)	Participants (n)	I ² %	Q statistic (p value)	R	95%CI
Main analysis	14	1570	1.13	0.41	-0.08	(-0.13 to -0.03)
Subgroup analyses						
Amplitude of movement	12	1433	0.00	0.62	-0.08	(-0.13 to -0.03)
Only flexion	11	1215	13.53	0.38	-0.09	(-0.15 to -0.02)
Only extension	5	435	0.00	0.91	-0.11	(-0.20 to -0.01)
Only lateral flexion	5	480	48.78	0.09	-0.14	(-0.28 to 0.00)
Muscle activity (only FRR)	3	289	60.07	0.09	-0.08	(-0.27 to 0.11)
Questionnaire						
BDI	5	465	0.00	0.46	-0.07	(-0.16 0.02)
Population						
CLBP	10	908	0.00	0.43	-0.12	(-0.19 -0.06)
Study objective						
Objective included	4	382	0.00	0.51	-0.14	(-0.24 -0.04)
Objective not included	10	1188	0.00	0.43	-0.06	(-0.12 0.00)

Subgroups analyses included only studies that tested the parameter noted in the first column. BDI: Beck Depression Inventory; CLBP: Chronic low back pain

Figure 1: Flow chart of study inclusion in the systematic review

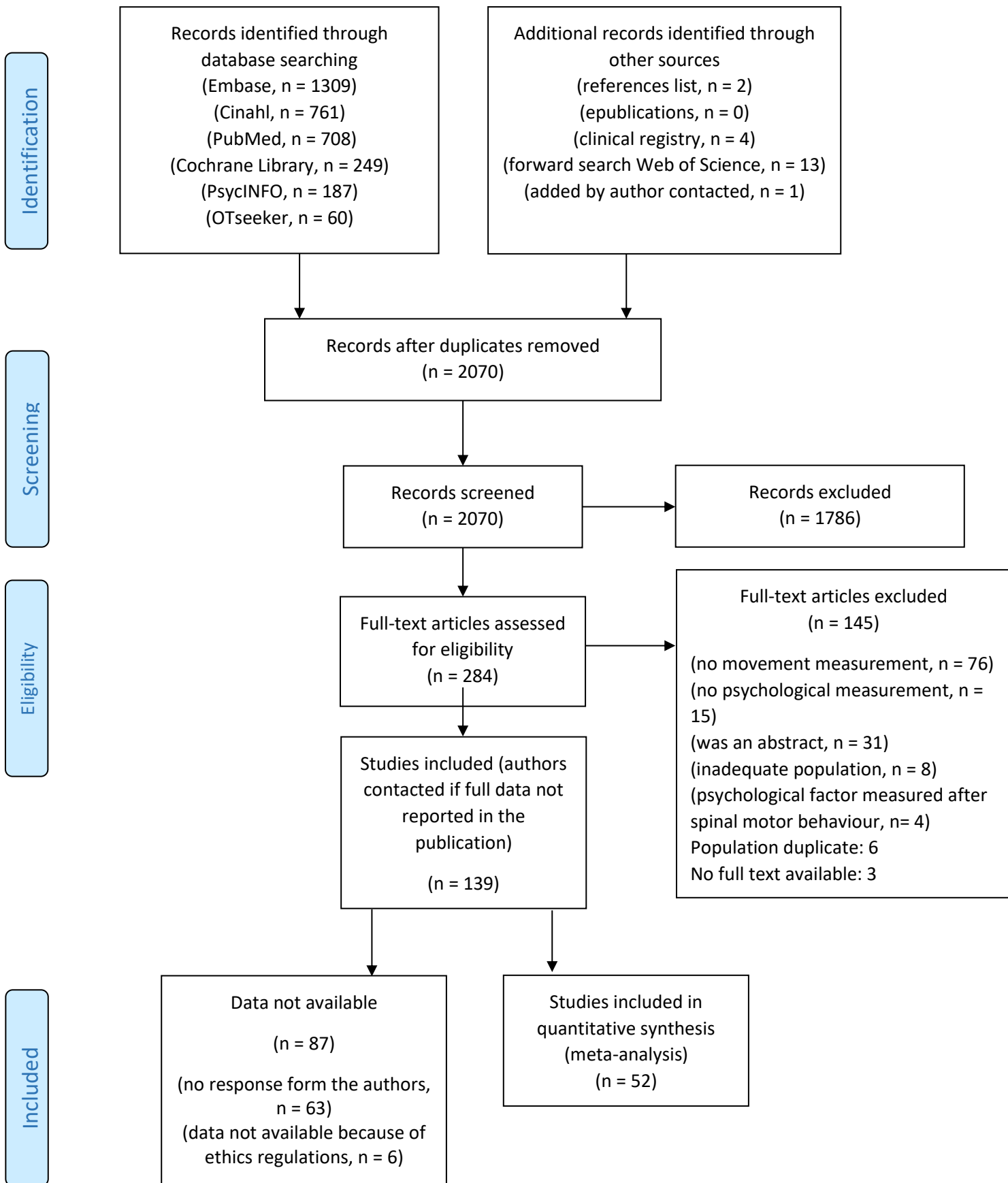
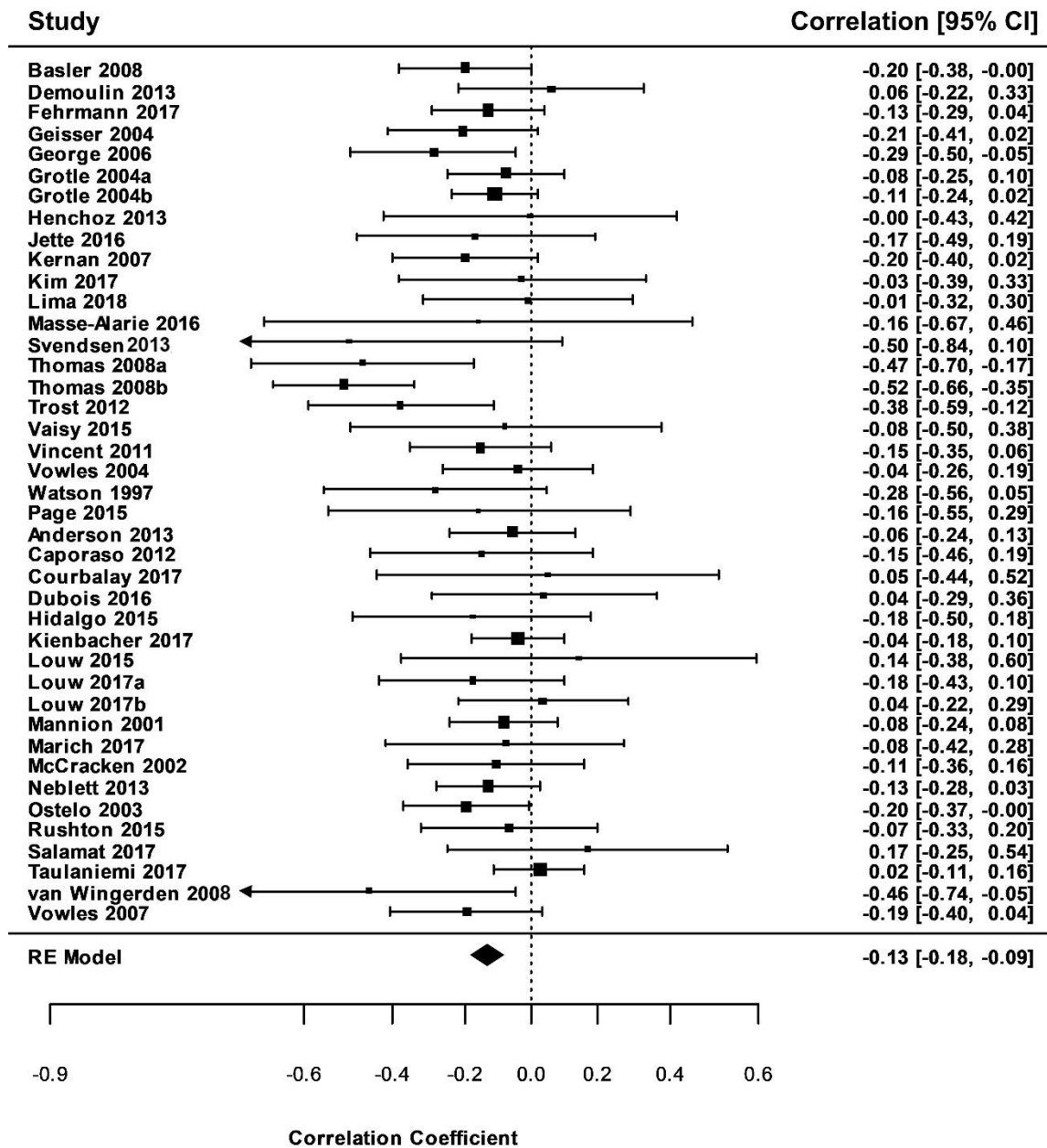


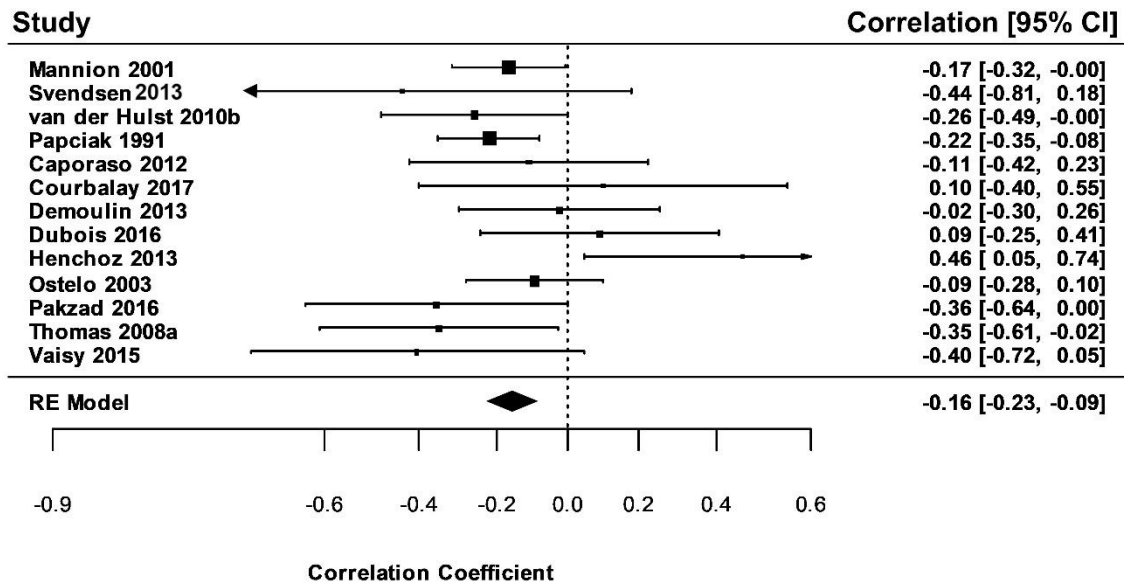
Figure 2: Association between pain-related fear and spinal motor behaviour



The forest plot shows the association between pain-related fear and spinal motor behaviour. Negative correlation means that a higher level of pain-related fear is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

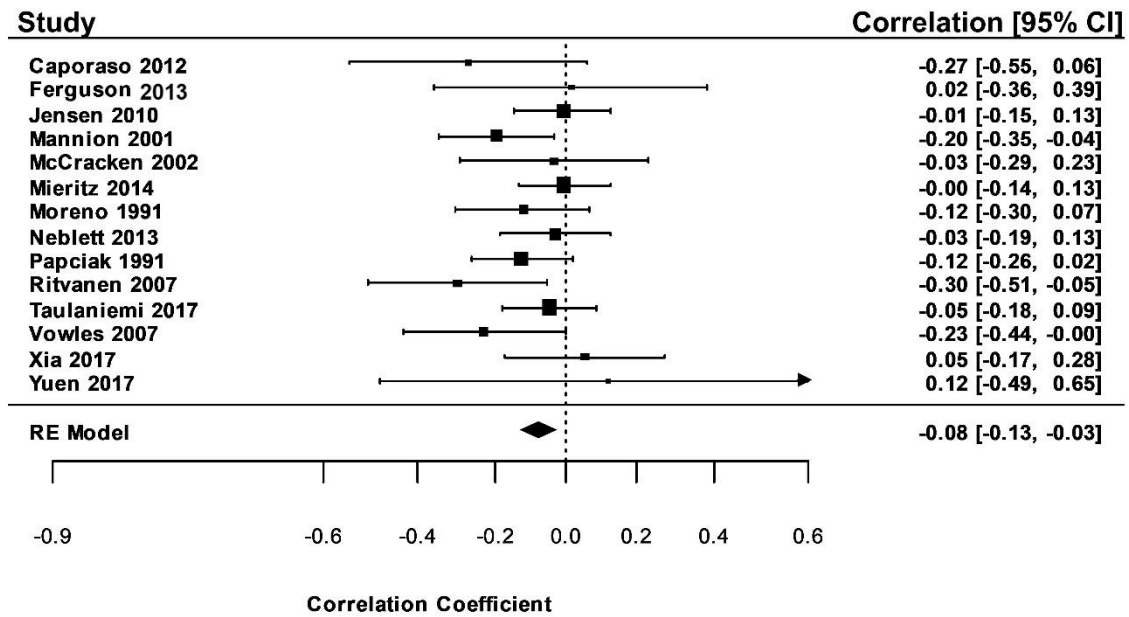
Note: after acceptance, when the paper will be sent to the publishing office, all the references will be added to the figure (e.g. Anderson 2013 [12]).

Figure 3: Association between catastrophizing and spinal motor behaviour



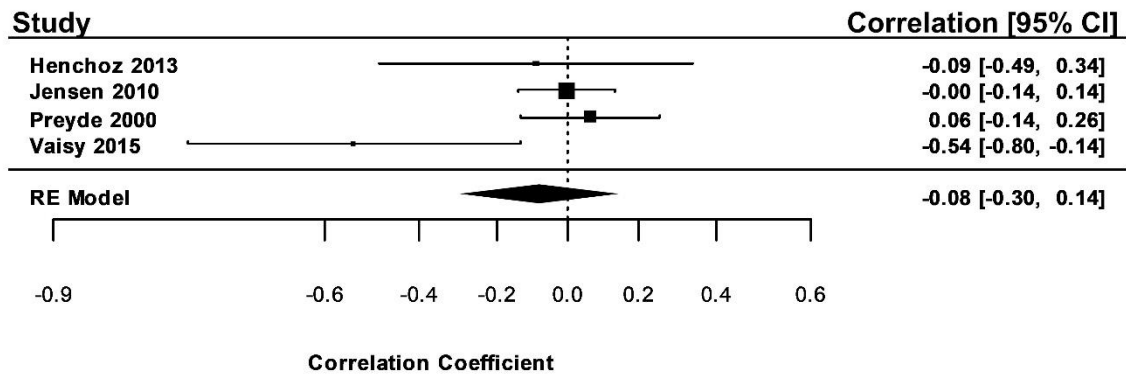
The forest plot shows the association between catastrophizing and spinal motor behaviour. Negative association means that a higher level of catastrophizing is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

Figure 4: Association between depression and spinal motor behaviour



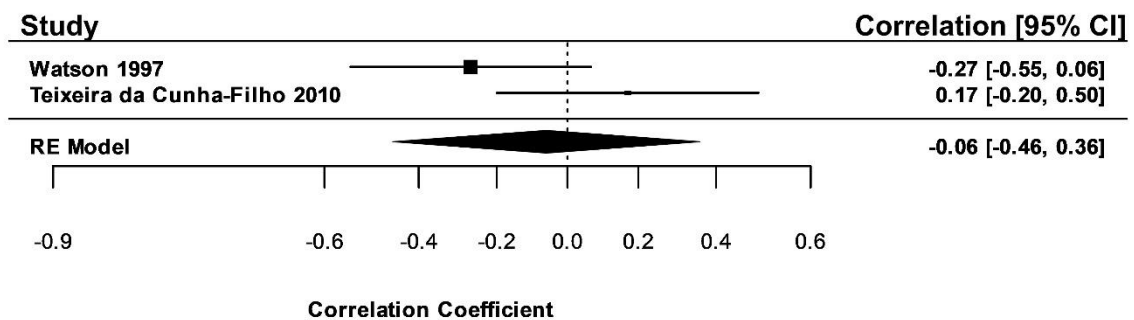
The forest plot shows the association between depression and spinal motor behaviour. Negative association means that a higher level of depression is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

Figure 5: Association between anxiety and spinal motor behaviour



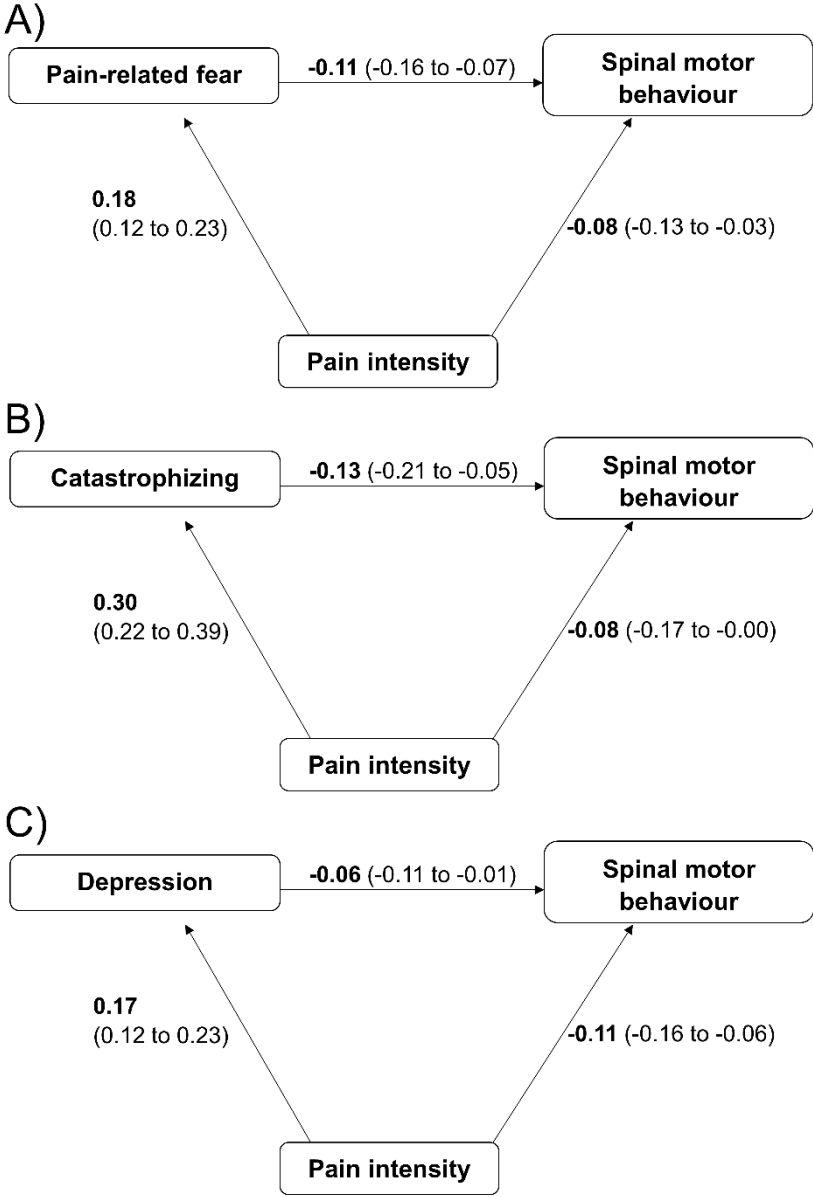
The forest plot shows the association anxiety and spinal motor behaviour. Negative association means that a higher level of anxiety is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

Figure 6: Association between self-efficacy and spinal motor behaviour



The forest plot shows the association between self-efficacy and spinal motor behaviour. Negative association means that a higher level of self-efficacy is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

Figure 7: Relationships between psychological factors, spinal motor behaviour and pain intensity modelled using meta-analytic structural equation modelling (MASEM)



Direct effect Standardized Path Coefficients for (A) pain-related fear, (B) catastrophizing and (C) depression. 95% confidence interval are in brackets.

Figures legends

Figure 1: Flow chart of study inclusion in the systematic review

Figure 2: Association between pain-related fear and spinal motor behaviour

The forest plot shows the association between pain-related fear and spinal motor behaviour. Negative correlation means that a higher level of pain-related fear is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

Note: after acceptance, when the paper will be sent to the publishing office, all the references will be added to the figure (e.g. Anderson 2013 [2]).

Figure 3: Association between catastrophizing and spinal motor behaviour

The forest plot shows the association between catastrophizing and spinal motor behaviour. Negative association means that a higher level of catastrophizing is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

Figure 4: Association between depression and spinal motor behaviour

The forest plot shows the association between depression and spinal motor behaviour. Negative association means that a higher level of depression is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

Figure 5: Association between anxiety and spinal motor behaviour

The forest plot shows the association anxiety and spinal motor behaviour. Negative association means that a higher level of anxiety is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

Figure 6: Association between self-efficacy and spinal motor behaviour

The forest plot shows the association between self-efficacy and spinal motor behaviour. Negative association means that a higher level of self-efficacy is associated with less spinal amplitude of movement and higher trunk muscle activity. The black squares represents the correlation coefficient and the horizontal line the 95% confidence interval (also display in number on the right side of the image). The size of the square indicates by how much weight the study contributes to the pooled effect estimate. The diamond represents pooled effect estimates.

Figure 7: Relationships between psychological factors, spinal motor behaviour and pain intensity modelled using meta-analytic structural equation modelling (MASEM)

Direct effect Standardized Path Coefficients for (A) pain-related fear, (B) catastrophizing and (C) depression. 95% confidence interval are in brackets.