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The association between pain-related psychological variables and postural control in low back pain: A systematic review and meta-analysis

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A R T I C L E I N F O

Keywords:
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Postural control
Center of pressure
Pain-related fear
Pain catastrophizing

A B S T R A C T

Background: Alterations in postural control have been found in individuals with low back pain (LBP), particularly during challenging postural tasks. Moreover, higher levels of negative pain-related psychological variables are associated with increased trunk muscle activity, reduced spinal movement, and worse maximal physical performance in individuals with LBP.
Research question: Are pain-related psychological variables associated with postural control during static bipedal standing tasks in individuals with LBP?
Methods: A systematic review and meta-analysis were conducted. Pubmed, Web of Science, and PsycINFO were searched until March 2023. Studies were included if they evaluated postural control during static bipedal standing in individuals with LBP by measuring center of pressure (CoP) variables, and reported at least one pain-related psychological variable. Correlation coefficients between pain-related psychological variables and CoP variables were extracted. Study quality was assessed with the "Quality In Prognosis Studies" tool (QUIPS). Random-effect models were used to calculate pooled correlation coefficients for different postural tasks. Sub-analyses were performed for positional or dynamic CoP variables. Certainty of evidence was assessed with an adjusted "Grading of Recommendations, Assessment, Development, and Evaluations" tool (GRADE). The protocol was registered on PROSPERO (CRD42021241739).
Results: Sixteen studies ($n = 723$ participants) were included. Pain-related fear (16 studies) and pain catastrophizing (three studies) were the only reported pain-related psychological variables. Both pain-related fear ($-0.04 < \text{pooled } r < 0.14$) and pain catastrophizing ($0.28 < \text{pooled } r < 0.29$) were weakly associated with CoP variables during different postural tasks. For all associations, the certainty of evidence was very low.
Significance: Pain-related fear and pain catastrophizing are only weakly associated with postural control during static bipedal standing in individuals with LBP, regardless of postural task difficulty. Certainty of evidence is very low thus it is conceivable that future studies accounting for current study limitations might reveal different findings.

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1. Introduction

Low back pain (LBP) is the leading cause of disability worldwide [1]. It is a complex condition with multiple contributors, such as biological, psychological, and social factors [2]. One of the biological factors associated with LBP is an altered postural control [3]. Postural control is the ability to achieve, maintain, or restore a state of balance during any activity or posture [4]. To maintain this state of balance (i.e., postural stability), the central nervous system needs to accurately process sensory inputs from visual, vestibular, and proprioceptive systems in order to produce adequate motor output [5].

A common method to evaluate postural control is by measuring the motion of the body's center of pressure (CoP) in upright standing [6]. In general, it is stated that an increase in the amplitude and velocity of CoP motion reflects impaired postural control [7]. Numerous studies examined CoP motion in patients with LBP. However, the findings were inconsistent. Although the majority of the studies concluded that patients with LBP exhibited greater CoP motion compared to healthy controls [3], other studies reported no differences [8], inconsistent results [9], or less CoP motion [10]. Differences in postural task difficulty between studies and the potential influence of psychological variables may explain the heterogeneity of the results [3,11].

Increasing postural task difficulty by manipulating visual or proprioceptive input may affect CoP motion, as it forces individuals to reweight sensory inputs [12]. For example, during standing with eyes closed, individuals must upweight proprioceptive and vestibular inputs to maintain postural stability [13]. Compared to pain-free individuals, patients with LBP are less able to compensate for increased postural task difficulty by sensory reweighting [14], leading to decreased postural variability [15]. Consequently, they exhibit greater CoP motion when standing on an unstable support surface [15], when standing with vision occluded [16], or while being exposed to vibrational stimuli on the calf muscles [14] compared to healthy controls. Accordingly, recent systematic reviews reported a tendency of more notable differences in CoP motion between individuals with and without LBP when postural task difficulty increased [3,11].

In addition to task difficulty, pain-related psychological variables may also account for some of the heterogeneity observed in the CoP motion of patients with LBP. Pain-related psychological variables describe the individual's emotions and cognitions regarding their pain. They can be classified into either positive (e.g., pain-related self-efficacy) or negative (e.g., pain-related fear, pain catastrophizing) variables according to their implications on pain-related emotions and cognitions [17]. Research shows that negative pain-related psychological variables are related to alterations in motor behavior, more specifically to the use of protective postural strategies, in individuals with LBP [18]. The fear-avoidance model offers a plausible framework for these findings. It states that the presence of maladaptive pain-related cognitions (e.g. pain catastrophizing) may induce pain-related fear, resulting in avoidance and protective behaviors (e.g., tight control strategies) [19]. This framework is supported by recent meta-analyses indicating that higher levels of negative pain-related psychological variables in individuals with LBP are (weakly) associated with increased trunk muscle activity, reduced spinal movement, and worse maximal physical performance [20–22]. As such, it is likely that negative pain-related psychological variables could also be related to reduced CoP motion.

One recent systematic review and meta-analysis of Shanbehzadeh et al. (2022) on the association between pain-related psychological variables and CoP motion in individuals with LBP revealed non-significant correlations for the majority of the studies (75%) [22]. However, they reported a large methodological heterogeneity between studies in terms of test conditions and CoP variables. To elaborate on these findings, the current review aimed to elucidate the association between pain-related psychological variables and postural control by focusing on CoP variables during static bipedal tasks only. To further reduce the potential impact of methodological heterogeneity between studies, subgroup-analyses based on task conditions were performed. This is particularly relevant considering the influence of postural task difficulty on CoP motion [23].

We performed a systematic review and meta-analysis of the current evidence on associations between pain-related psychological variables and CoP motion in patients with LBP in different task conditions during static bipedal standing. We hypothesized that higher levels of negative pain-related psychological variables in patients with LBP correlate with less CoP motion, as they might result in the use of protective, "stiffening" postural strategies. The opposite was hypothesized for higher levels of positive pain-related psychological variables, as the absence of the protective aspect is postulated to result in less stiffening behaviors. Moreover, we hypothesized that correlations would be particularly apparent during more demanding postural tasks, given the decreased postural variability in individuals with LBP.

2. Methods

This review was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [24]. The study protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO: CRD42021241739).

2.1. Search strategy

Pubmed, Web of Science, and PsycInfo were searched from inception to March 2023. Eligible literature was obtained by combining two clusters of keywords. The first cluster contained terms related to LBP, the second comprised terms related to postural control. Specific search strategies for each database are reported in Appendix 1.

1. *Cluster 1:* 'low back pain', 'spinal pain', 'back pain', 'lumbago', 'LBP', 'CLBP', 'back aches', 'lumbar pain', 'lumbopelvic pain'
   AND
2. *Cluster 2:* 'postural balance', 'postural control', 'postural sway', 'sway', 'postural stability', 'center of pressure', 'stabilometry'

Although studies often measure both CoP variables and pain-related psychological variables, correlations between those variables are not always reported. Therefore, the search strategy did not contain terms regarding pain-related psychological variables. As such, unreported useful data could still be obtained by contacting the authors, and loss of potentially relevant data could be avoided. In addition to searching the electronic databases, registers and the reference lists of relevant and included studies were screened as well.

2.2. Study selection

Studies were considered eligible if they met the criteria reported in Table 1.

The studies were uploaded in Rayyan (Cambridge, MA, USA) and duplicates were removed [25]. Primarily, studies were screened by evaluating title and abstract against the eligibility criteria. Then, a second screening based on the full texts of the potentially eligible studies was conducted. Studies were screened by three independent reviewers (C.A., S.V.W., and S.S.) and discrepancies between them were resolved by a fourth reviewer (L.J.).

2.3. Quality assessment

The risk of bias assessment of the included studies was conducted by three independent reviewers (S.V.W., C.A., and S.S.) by using an adapted version of the 'Quality in Prognosis Studies' tool (QUIPS) [26], as recommended by the Cochrane Handbook for Systematic Reviews for prognostic studies. The adaptations were implemented because the QUIPS tool was originally developed for prognostic instead of

Table 1
Eligibility criteria.

Population	Studies were included if they recruited adults (≥18 years) with low back pain, defined as pain between the lower edge of the ribs and the buttock. Both specific and non-specific low back pain were included and no restrictions on pain duration were applied. Studies were excluded if low back pain was experimentally induced or if participants were pregnant.
Pain-related psychological variables	Studies were included if they reported at least one pain-related psychological variable (e.g., fear of movement, pain catastrophizing) that was measured by a validated instrument. Studies were excluded if they measured psychological variables not specifically related to pain (e.g., depression, anxiety), or if a non-validated measurement instrument was used.
CoP variables	Studies were included if postural control was reported in terms of CoP variables (e.g., CoP displacement, CoP velocity). Studies that solely used other measures of postural control, such as clinical measures (e.g., Berg Balance Scale, Timed Up & Go Test), kinetics, kinematics (e.g., 2D/3D motion capture, center of mass), or muscle activity (by electromyography) were excluded.
Postural task	Studies were included if CoP was measured during static bipedal upright standing with parallel foot positioning in the frontal plane. Studies were excluded if CoP was measured during any other postural task (e.g., unipedal standing, tandem stance, sitting, supine lying), during dynamic tasks, or if external force plate perturbations were applied. This decision was made to reduce methodological heterogeneity between the included studies.
Reporting of data	Studies were included if they reported at least one correlation coefficient between a pain-related psychological variable and a CoP variable, or if they reported at least one pain-related psychological variable and one CoP variable without reporting the correlation coefficient between these variables. In the latter case, the corresponding author was contacted at least three times to obtain raw data or unpublished correlation coefficients between pain-related psychological variables and CoP variables. When raw data or correlation coefficients between CoP and pain-related psychological variables were obtained through author contact, studies were included.
Study design	Cross-sectional studies and longitudinal studies were considered eligible. In the latter case, only baseline data were used. Case reports, study protocols, and reviews were considered non-eligible.
Language	Studies were considered eligible if they were written in English or Dutch.

Abbreviations: CoP= center of pressure

cross-sectional studies. Hence, some items (e.g. about drop-outs) were not applicable and could therefore not be scored. The QUIPS-tool assesses risk of bias in six domains: study participation, study attrition, prognostic factor measurement, outcome measurement, confounding factors, and statistical analysis and reporting. All domains were rated as low, moderate, or high risk of bias, based on predetermined scoring criteria. The scoring criteria for each domain were specified based on recent systematic reviews assessing the association between pain-related psychological variables and protective movement behavior in individuals with LBP [20,21]. The studies' QUIPS assessment should be interpreted as the risk of bias in context of inclusion in this review, rather than the risk of bias within the study itself [20]. For example, correlation coefficients obtained through author contact were rated with high risk of bias because these data were not peer-reviewed [27]. The adapted QUIPS assessment form and predetermined scoring criteria are available in Appendix 2.

2.4. Data extraction

Different clusters were made regarding CoP variables (i.e., linear, non-linear), and postural task difficulty (i.e., number of postural manipulations) to reduce heterogeneity between studies. CoP variables were categorized as linear variables if they represented the magnitude or variability of CoP motion, and as non-linear variables if they reflected the dynamic time-dependent structure of CoP motion. Linear CoP variables were further divided into positional, dynamic, and frequency variables [28]. Considering the influence of postural task difficulty on CoP variables and the extensive number of combinations of postural manipulations in the included studies, postural task difficulty was quantified as the number of postural manipulations applied during the postural task (e.g., exclusion of vision, standing on an unstable surface, applying muscle vibration), with standing on a stable support surface with eyes open as the reference condition (i.e., score= 0). For example, when CoP motion was assessed during standing on an unstable support surface with eyes open, a score of 1 was given. After data extraction, pain-related psychological variables could be subdivided into pain-related fear and pain catastrophizing. Pain-related fear reflects the individual's fear, anxiety, and avoidance regarding pain or movement [29]. Pain catastrophizing is conceptualized as a negative cognitive–affective response to anticipated or actual pain and is characterized by rumination, magnification, and helplessness [30].

One author (S.V.W.) extracted data from the included studies by using a data extraction table. This was verified by a second author (S.S.). Data were extracted with regards to (1) study details: first author and publication year; (2) sample characteristics: LBP characteristics (chronic, recurrent, non-specific), age, sex (% female), body mass index, pain intensity levels, disability levels, pain-related psychological levels; (3) postural task characteristics: task description, number of postural manipulations, stance width of feet on force plate; (4) pain-related psychological variables: pain-related psychological variable (pain-related fear, pain catastrophizing), questionnaire for measuring pain-related psychological variable, whether the pain-related psychological variable was measured before or after the CoP measurement (temporal precedence); (5) CoP variables: category (linear with subcategories positional, dynamic, frequency, or non-linear), specific CoP variable; (6) results: significant correlation coefficients between pain-related psychological variables and CoP variables (if reported), and (8) whether correlation coefficients were extracted from the study, received through author contact, or calculated from raw data received through author contact.

2.5. Data syntheses and meta-analyses

We performed separate meta-analyses for each postural task (e.g., standing on a stable support surface with eyes open) within each psychological variable (pain-related fear, pain catastrophizing). For the linear CoP variables, further sub-analyses were performed for the positional and dynamic linear CoP variables. At least three studies had to be available to proceed with a meta-analysis.

The meta-analyses were performed based on correlation coefficients, without making a distinction between Spearman or Pearson correlation coefficients [31]. In line with recent reviews, if a study reported multiple correlation coefficients for a particular meta-analysis, these correlation coefficients were averaged [20,31]. Prior to performing the meta-analyses, correlation coefficients were transformed using a Fisher's z-transformation. Then, meta-analyses were executed based on the z-score, and an inverse Fisher's z-transformation was used to obtain the pooled correlation coefficient and 95% confidence interval (95% CI) [32,33]. The effect size of the pooled correlation coefficients was interpreted as weak ($r < 0.30$), moderate ($0.30 \leq r < 0.50$), or strong ($r \geq 0.50$) [34]. All meta-analyses were conducted using a random-effects model [32,35]. The I^2 statistics were calculated to assess statistical heterogeneity [35]. Furthermore, potential outliers and influential cases were assessed according to Viechtbauer et al. (2012) [36], and publication bias was assessed with funnel plots and Egger's regression if more than ten studies were included in the meta-analysis [32,37]. All statistical analyses were performed using calculations based on R within the 'Jamovi 2.3.18' software.

If heterogeneity was moderate or high ($I^2 \geq 30\%$), moderation and sensitivity analyses were performed to determine whether study characteristics explained this heterogeneity [38]. Moderation analyses were conducted with respect to characteristics that may affect the strength and direction of the relationship between pain-related psychological variables and CoP variables: demographic characteristics (age [39], sex [40], body mass index [41]), pain characteristics (pain duration [42], pain intensity [43]), and stance width on the force plate [44]. Furthermore, the influence of the following factors was determined by performing moderation analyses: result of risk of bias assessment, whether the correlation coefficient was reported in the study or obtained by contacting the author, and whether the pain-related psychological variables were assessed before or after the CoP measurement. When influential cases were present, sensitivity analyses were performed by excluding these cases. To conduct moderation and/or sensitivity analyses, at least four studies had to be available [45].

2.6. Certainty of evidence

The Grading of Recommendations, Assessment, Development, and Evaluation criteria (GRADE) were used to assess the certainty of evidence of the conducted meta-analyses [46]. Based on these criteria, the certainty of evidence was classified as high (4 +), moderate (3 +), low (2 +), or very low (1 +). Similar to previous reviews, some modifications were made to optimize the use of the GRADE criteria for the current review [21]. Evidence of non-randomized controlled trial designs was

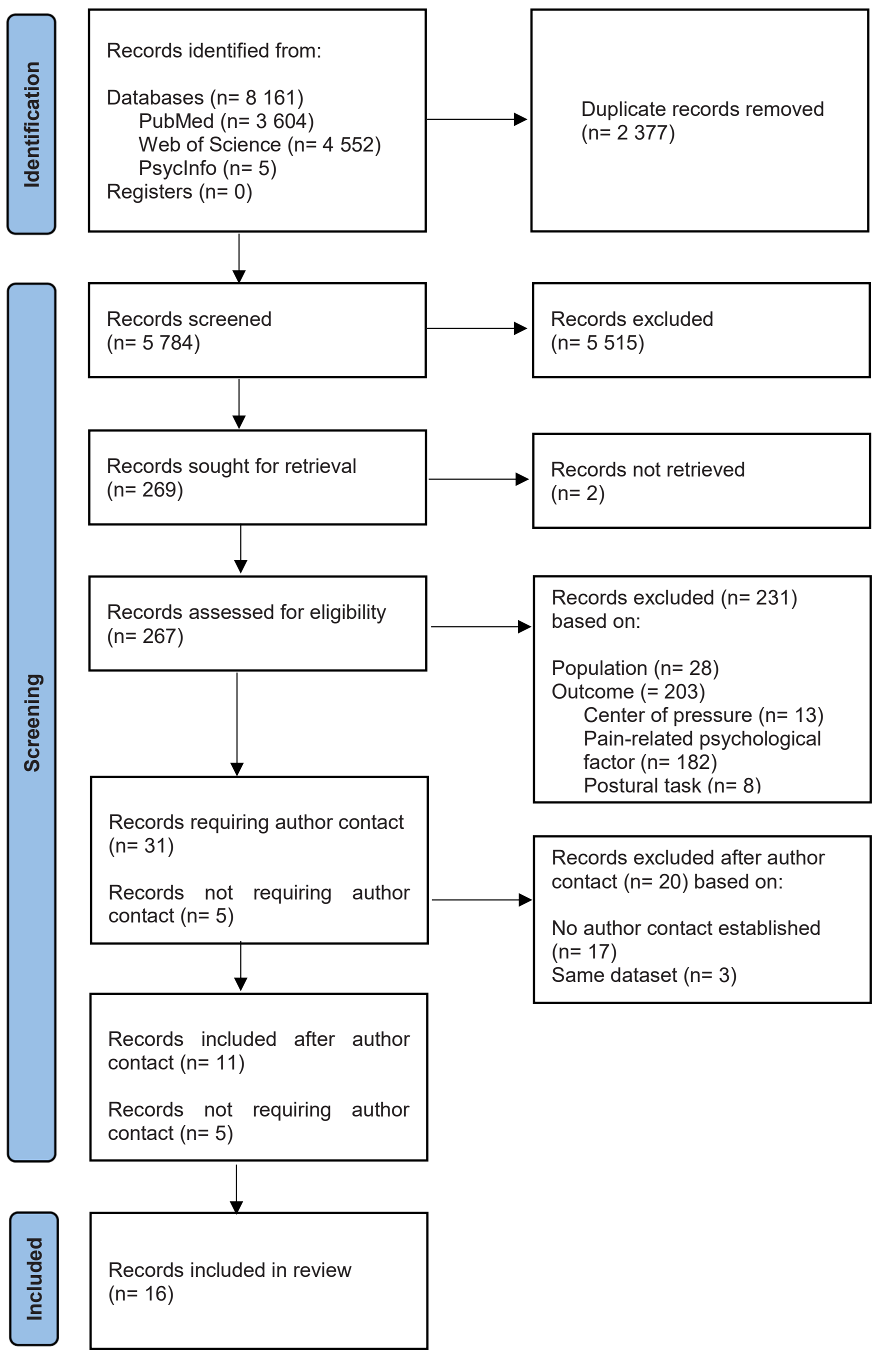

Fig. 1. PRISMA flow-chart of search results. Fig. 1 displays the results of the conducted search strategy and the study selection process.

not downgraded, as this review did not aim to investigate the effect of interventions. Therefore, all certainty of evidence started as 'high' (+4), and could be downgraded for (1) study limitations when > 25% (−1 level) or > 50% (−2 levels) of the participants came from studies with high risk of bias; (2) inconsistency when I^2 was > 30% (−1 level); (3) imprecision when the meta-analysis contained < 400 participants (−1 level) or < 100 participants (−2 levels); or (4) publication bias if present on funnel plots and Egger's regression, solely for meta-analyses including ≥ 10 studies. Certainty of evidence was not downgraded for indirectness, since the eligibility criteria resulted in satisfaction of this criterion. The certainty of evidence was upgraded if the effect size was moderate or large (i.e., absolute value of pooled correlation coefficient ≥0.30) (+1 level).

2.7. Deviations from protocol

The study protocol on PROSPERO was updated once due to the involvement of additional authors. Moreover, to reduce methodological heterogeneity, small adjustments were made regarding the postural task requirements, and sub-analyses were added in terms of linear CoP variables.

3. Results

3.1. Study selection

Fig. 1 shows the PRISMA flowchart. The search strategy resulted in 8161 unique records. After removing the duplicates and screening the titles, abstracts, and full texts, 16 studies with a total of 723 participants were included. Three additional studies also fulfilled the eligibility criteria, but were excluded [47–49] because they reported results of the same dataset [15,50].

3.2. Study characteristics

The extracted study characteristics are presented in Table 2. Additionally, an overview of data clusters based on pain-related psychological variables, postural task difficulty, CoP variables, and the conducted meta-analyses is reported in Fig. 2.

Across the 16 included studies, the average age of the participants was 34.4 (± 7.7) years [8,15,23,50–62], the average body mass index was 25.5 (± 3.0) kg/m^2 [15,23,53–57,60,61], and 60.3% (± 12.6%) of the participants were female [8,15,23,50,51,53–61]. The average intensity of LBP was 3.4 (± 1.5) measured by the numeric rating scale (NRS) and visual analogue scale (VAS) (converted to a score on 10) [8,15,23,50–62]. The average disability score was 18.4% (± 4.5%) for the Oswestry Disability Index (ODI) [8,15,50–52,54–56,58,61,62] and 6.9 (± 2.9) for the Roland Morris Disability Questionnaire (RMDQ) [23,53,57,60]. Individuals with chronic, recurrent, and subacute LBP were included in respectively six [23,50–52,60,62], three [54,56,61], and one [58] study. Six studies did not specify the patient population based on the duration of the LBP complaints [8,15,53,55,57,59].

Regarding the pain-related psychological variables, all 16 studies measured pain-related fear [8,15,23,50–62], and three studies additionally assessed pain catastrophizing [52,58,61]. No other pain-related psychological variables were measured. The pain-related fear variables contained data measured by the Tampa Scale for Kinesiophobia (TSK-17 and TSK-11), Fear-Avoidance and Beliefs Questionnaire (FABQ), and Pain Anxiety Symptom Scale (PASS-20). The pain catastrophizing variables contained data measured by the Pain Catastrophizing Scale (PCS). The average scores were; 36.3 (± 6.1) on TSK-17 [15,50–52,54–56,58,60–62], 20.0 (± 5.6) on TSK-11 [59], 10.6 (± 2.6) on FABQ-PA [8,23,52–54,56,57,61,62], 9.9 (± 3.1) on FABQ-W [8,23,52–54,56,61], 11.6 (± 7.7) on PCS [52,58,61], and 31.6 (± 9.3) on PASS-20 [62].

Regarding CoP motion, all 16 studies measured linear variables [8,15,23,50–62]. Within the linear variables, positional CoP variables were assessed in 15 studies [8,15,23,50–60,62]. Dynamic CoP variables and frequency CoP variables were reported in respectively 12 [8,23,50–53,57–62], and two studies [8,58]. Four studies measured non-linear CoP variables [8,50,51,58].

Regarding postural task difficulty, nine studies assessed CoP motion during standing on a stable support surface with eyes open, labelled as the reference condition [8,23,50–52,58,60–62]. Twelve studies used one postural manipulation; i.e., standing on a stable support surface with eyes closed [8,15,23,50,51,53,55,57,59,60,62], unstable support surface with eyes open [60], stable support surface with eyes open and muscle vibration [62], and stable support surface with eyes open while performing a dual task [58,62]. Ten studies measured CoP motion during tasks involving two postural manipulations; i.e., standing on an unstable support surface with eyes closed [8,15,50,51,53,55,60], stable support surface with eyes closed and muscle vibration [8,15,54–56,62], stable support surface with eyes closed while performing a dual task [62], and stable support surface with eyes open and muscle vibration while performing a dual task [62]. Finally, six studies used three postural manipulations; i.e., standing on an unstable support surface with eyes closed and vibration [8,15,54–56], and stable support surface with eyes closed and vibration while performing a dual task [62].

3.3. Risk of bias and publication bias

The risk of bias regarding study participation was rated low in four studies [23,50,54,60], moderate in five studies [51,56,58,61,62], and high in seven studies [8,15,52,53,55,57,59]. The most prevalent reasons for risk of participation bias were limited reporting of the eligibility criteria, and not specifying the recruitment time and location. There was a low risk of bias due to study attrition, prognostic factor measurement, and outcome measurement in the majority of the studies. Regarding study confounding, 12 studies were rated as high risk of bias [8,15,50–56,58,61,62], three studies as moderate risk of bias [23,57,59], and only one study was rated as low risk of bias [60]. This was mostly because correlations of interest were not reported by the study itself. Due to a similar reason, risk of bias in statistical analysis and reporting was high for 11 studies [8,15,50–53,55,56,58,61,62], moderate for one study [54], and low for four studies [23,57,59,60]. Table 3 shows the QUIPS risk of bias assessment in detail. Publication bias was not present in the two meta-analyses containing ≥ 10 studies (Appendix 3).

3.4. Correlations between pain-related psychological variables and CoP variables

The results and forest plots of the conducted meta-analyses are reported in respectively Table 4 and Fig. 3. The forest plots of the sub-analyses and the GRADE certainty of evidence assessment can be found in Appendices 4 and 5, respectively.

3.4.1. Pain-related fear

3.4.1.1. Pain-related fear and linear CoP without postural manipulations. A non-significant pooled correlation coefficient of 0.07 (95% CI= −0.04, 0.18) (nine studies, n = 303) [8,23,50–52,58,60–62] was found between pain-related fear and CoP variables during standing on a stable support surface with eyes open (see Fig. 3a). Sub-analyses for positional CoP variables yielded a significant pooled correlation coefficient of 0.14 (95% CI= 0.03, 0.26) (eight studies, n = 284) [8,23,50–52,58,60,62]. No significant pooled correlation coefficient was found for dynamic CoP variables (nine studies, n = 303; pooled r = 0.05, 95% CI= −0.07, 0.16) [8,23,50–52,58,60–62]. The certainty of evidence for all pooled correlation coefficients was very low.

3.4.1.2. Pain-related fear and linear CoP with one postural manipulation. A non-significant pooled correlation coefficient of 0.05 (95% CI= −0.03,

Table 2
Study characteristics.

First author (publication year)	Sample characteristics	Postural task description (number of postural manipulations) and stance width	Pain-related psychological variable (questionnaire) and temporal precedence with center of pressure measurement	Center of pressure subcategory (specific variable)	Significant correlation coefficient (significance level)	Meta-analysis
Azadinia, F. et al. (2017 & 2019)	CLBP (n= 44) Age= 27.2 (±5.3) Sex= 63% female BMI= not reported VAS= 3.1 (±3.4) ODI= 21.5 (±5.8) TSK-17= 38.6 (±5.8)	EOS (0) ECS (1) ECU (2) Stance width= 'feet close together'	Pain-related fear (TSK) Temporal precedence= not reported	Positional (CoP area (95%)) Dynamic (CoP velocity (TOT), SD of CoP velocity (AP & ML, Phase plan portrait (TOT, AP & ML)) Non-linear (Sample entropy (AP & ML), Correlation dimension (AP & ML), %Determinism (AP & ML))	/	# MA 1.1 MA 1.2 MA 1.3
Azadinia, F. et al. (2020)	CLBP (n= 14) Age= 26.7 (±3.9) Sex= 85% female BMI= not reported VAS= 3.2 (±1.7) ODI= 21.0 (±7.5) TSK-17= 36.6 (±8.6)	EOS (0) ECS (1) ECU (2) Stance width= 'feet close together'	Pain-related fear (TSK) Temporal precedence= not reported	Positional (CoP area (95%), SD of CoP displacement (AP & ML)) Dynamic (CoP velocity (TOT), SD of CoP velocity (AP & ML, Phase plan portrait (TOT, AP & ML)) Non-linear (Sample entropy (AP & ML), Correlation dimension (AP & ML), Lyapunov exponent (AP & ML))	/	# MA 1.1 MA 1.2 MA 1.3
Claeys, K. et al. (2011, 2012, 2015)	NSLBP (n= 17) Age= 27 (±5.3) Sex= 76% female BMI= 22.3 (±2.2) NRS= 3.9 (±2.0) ODI= 9.2 (±4.5) TSK-17= 35.3 (±4.9)	ECS (1) ECU, ECSV (2) ECUV (3) Stance width= 10 cm	Pain-related fear (TSK, FABQ) Temporal precedence= not reported	Positional (CoP displacement (AP), SD CoP displacement (AP))	/	# MA 1.2 MA 1.3 MA 1.4 MA 1.5
da Silva, R.A. et al. (2018)	CLBP (n= 10) Age= 34.4 (±2.9) Sex= 50% female BMI= 27.2 (±3.9) VAS= 4.5 (±2.2) RMDQ= 7.6 (±5.2) FABQ-PA= 9.3 (±9.8) FABQ-W= 9.4 (±7.5)	EOS (0) ECS (1) Stance width= not reported	Pain-related fear (FABQ) Temporal precedence= before CoP measurement	Positional (CoP area (95%)) Dynamic (CoP velocity (AP & ML), CoP frequency (AP & ML))	None	* MA 1.1 MA 1.2
Daneau, C. et al. (2021)	CLBP (n= 28) Age= 36.5 (±16.0) Sex= not reported BMI= not reported VAS= 1.9 (±2.2) ODI= 10.9 (±6.9) TSK-17= 33.1 (±6.6) FABQ-PA= 7.1 (±5.0) FABQ-W= 7.5 (±9.9) PCS= 9.7 (± 6.9)	EOS (0) Stance width= not reported	Pain-related fear (TSK, FABQ) Pain catastrophizing (PCS) Temporal precedence= before CoP measurement	Positional (CoP displacement (AP)) Dynamic (CoP velocity (TOT))	/	#, § MA 1.1 MA 2.1
Goertz, C.M. et al. (2016)	LBP (n= 220) Age= 44.3 (±10.4) Sex= 46% female BMI= 29.4 (±6.0) NRS= 5.5 (±1.7) RMDQ= 5.6 (±3.8)	ECS (1) ECU (2) Stance width= not reported	Pain-related fear (FABQ) Temporal precedence= before CoP measurement	Positional (CoP displacement (AP & ML)) Dynamic (CoP velocity (TOT))	/	# MA 1.2 MA 1.3

(*continued on next page*)

Table 2 (*continued*)

First author (publication year)	Sample characteristics	Postural task description (number of postural manipulations) and stance width	Pain-related psychological variable (questionnaire) and temporal precedence with center of pressure measurement	Center of pressure subcategory (specific variable)	Significant correlation coefficient (significance level)	Meta-analysis
	FABQ-PA= 12.2 (±5.6) FABQ-W= 11.5 (±9.3)					
Goossens, N., et al. (2019)	RNSLBP (n= 20) Age= 25.0 (23.4–28.0) Sex= 70% female BMI= 21.7 (20.4–24.1) NRS= 2.4 (± 1.9) ODI= 18.0 (18–20) TSK-17= 33.0 (± 8.0) FABQ-PA= 10.6 (± 5.9) FABQ-W= 15.5 (± 9.5)	ECSV (2) ECUV (3) Stance width= 10 cm	Pain-related fear (TSK, FABQ) Temporal precedence= after CoP measurement	Positional (CoP displacement (AP))	None	* MA 1.4 MA 1.5
Janssens, L. et al. (2015)	RNSLBP (n= 26) Age= 32.1 (±7.6) Sex= 63% female BMI= 23.8 (±3.6) NRS= 5.3 (±1.7) ODI= 19.1 (±8.0) TSK-17= 36.8 (± 5.8) FABQ-PA= 13.8 (± 4.0) FABQ-W= 14.3 (± 7.3)	ECSV (2) ECUV (3) Stance width= 10 cm	Pain-related fear (TSK, FABQ) Temporal precedence= after CoP measurement	Positional (CoP displacement (AP))	/	# MA 1.4 MA 1.5
Janssens, L. et al. (2016)	LBP (disc herniation) (n= 19) Age= 46.2 (± 9.2) Sex= 52% female BMI= 25.8 (±3.8) NRS= 2.6 (±2.1) ODI= 25.6 (±13.3) TSK-17= 43.0 (±6.1)	ECS (1) ECU, ECSV (2) ECUV (3) Stance width= 10 cm	Pain-related fear (TSK) Temporal precedence= not reported	Positional (CoP displacement (AP))	/	#, § MA 1.2 MA 1.3 MA 1.4 MA 1.5
Kiers, H. et al. (2015)	LBP (n= 33) Age= 41.3 (±11) Sex= 36% female BMI= not reported NRS= 4.5 (±1.4) ODI= 21.6 (±20.0) FABQ-PA= 7.4 (± 6.3) FABQ-W= 7.3 (± 6.9)	EOS (0) ECS (1) ECU, ECSV (2) ECUV (3) Stance width= 'shoulder width'	Pain-related fear (FABQ) Temporal precedence= before CoP measurement	Positional (CoP displacement (AP & ML), SD CoP displacement (AP & ML)) Dynamic (CoP velocity (TOT, AP & ML)) Frequency (Mean power frequency (AP & ML)) Non-linear (Recurrence entropy, Determinism, Recurrence rate, Mean diagonal length, Lyapunov exponent)	/	# MA 1.1 MA 1.2 MA 1.3 MA 1.4 MA 1.5
Maribo, T. et al. (2012)	LBP (n= 91) Age= 44,9 (±10,0) Sex= 51% female BMI= 30.1 (±6.2) NRS= 5.9 (±2.5)	ECS (1) Stance width= 2 cm	Pain-related fear (FABQ) Temporal precedence= not reported	Positional (CoP displacement (AP)) Dynamic (CoP velocity (TOT))	None	* MA 1.2

(*continued on next page*)

Table 2 (*continued*)

First author (publication year)	Sample characteristics	Postural task description (number of postural manipulations) and stance width	Pain-related psychological variable (questionnaire) and temporal precedence with center of pressure measurement	Center of pressure subcategory (specific variable)	Significant correlation coefficient (significance level)	Meta-analysis
	RMDQ= 10.5 (±5.3) FABQ-PA= 10.9 (± 5.3)					
Mazaheri, M. et al. (2014)	NSLBP (n= 40) Age= 34.4 (± 9.7) Sex= 60% female BMI= not reported VAS= 31.2 (±25.7) ODI= 25.5 (±6.7) TSK-17= 42.3 (±7.3) PCS= 20.1 (±11.9)	EOS (0) EOSD (1) Stance width= 'shoulder width'	Pain-related fear (TSK) Pain catastrophizing (PCS) Temporal precedence= before CoP measurement	Positional (SD of CoP displacement (AP & ML)) Dynamic (CoP velocity (TOT)) Frequency (Mean power frequency (AP & ML)) Non-linear (Sample entropy (TOT))	/	# MA 1.1 MA 2.1
Meinke, A. et al. (2022)	NSLBP (n= 27) Age= 35.0 (±25.5) Sex= 63% female BMI= not reported NRS= 2.6 (±1.3) ODI= not reported TSK-11= 20.0 (± 5.6)	ECS (1) Stance width= NS	Pain-related fear (TSK) Temporal precedence= not reported	Positional (CoP displacement (AP & ML)) Dynamic (CoP velocity (AP & ML))	TSK-11 x CoP velocity ML (ECS): r= 0.43 (p= 0.049)	* MA 1.2
Mikkonen, J. et al. (2022)	CLBP (n= 77) Age= 43.8 (41.1-46.5) Sex= 66% female BMI= 25.5 (24.6-26.5) NRS= 4.4 (4.0-4.9) RMDQ= 3.7 (2.9-4.5) TSK-17= 31.4 (29.5 - 33.2)	EOS (0) ECS, EOU (1) ECU (2) Stance width= 'as close together as possible without discomfort'	Pain-related fear (TSK) Temporal precedence= after CoP measurement	Positional (CoP area (95%)) Dynamic (CoP velocity (TOT))	TSK x CoP area (EOS): r= 0.22 ($p< 0.05$) TSK x CoP area (ECS): r= 0.18 ($p< 0.05$) TSK x CoP area (EOU): r= 0.22 ($p< 0.05$)	* MA 1.1 MA 1.2 MA 1.3
Rowley, K.M. et al. (2019)	RLBP (n= 19) Age= 23.5 (± 2.8) Sex= 63% female BMI= 23.6 (± 2.4) VAS= 0.4 (± 0.4) ODI= 12.0 (6.0-16.0) TSK-17= 31.3 (±6.5) FABQ-PA= 12.2 (±7.7) FABQ-W= 8.1 (±6.7) PCS= 5.0 (3.0-11.0)	EOS (0) Stance width= 'preferred stance width'	Pain-related fear (TSK, FABQ) Pain catastrophizing (PCS) Temporal precedence= not reported	Dynamic (CoP velocity (TOT))	/	#, § MA 1.1 MA 2.1
Shanbehzadeh, S. et al. (2018)	NSCLBP (n= 38) Age= 28.6 (±4.85) Sex= not reported BMI= not reported VAS= 1.6 (±1.0) ODI= 18.0 (±9.3) PASS-20= 31.6 (±15.8) TSK-17= 38.2	EOS (0) ECS, EOSD, EOSV (1) ECSV, ECSD, EOSVD (2) ECSVD (3) Stance width= 'toes and heels touching'	Pain-related fear (TSK, FABQ, PASS-20) Temporal precedence= not reported	Positional (CoP area (95%), CoP displacement (AP & ML)) Dynamic (CoP velocity (TOT))	/	#, § MA 1.1 MA 1.2 MA 1.4

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Table 2 (*continued*)

First author (publication year)	Sample characteristics	Postural task description (number of postural manipulations) and stance width	Pain-related psychological variable (questionnaire) and temporal precedence with center of pressure measurement	Center of pressure subcategory (specific variable)	Significant correlation coefficient (significance level)	Meta-analysis
	(±6.9) FABQ-PA= 15.0 (±5.8)					
Mean scores	Age= 34.4 (±7.7), Sex= 60.3% (±12.6%) female, BMI= 25.5 (±3.0), VAS/NRS= 3.1 (±1.5), ODI= 18.4 (±4.5), RMDQ= 6.9 (±2.9), TSK= 35.0 (±6.1), FABQ-PA= 10.6 (±2.6), FABQ-W= 9.9 (±3.1), PASS-20= 31.6 (±0.0), PCS= 11.6 (±7.7)					

Abbreviations: LBP= low back pain, CLBP= chronic low back pain, NSLBP: non-specific low back pain, RNSLBP= recurrent non-specific low back pain, RLBP= recurrent low back pain, NSCLBP= non-specific chronic low back pain, BMI= body mass index, VAS= visual analogue scale, NRS= numeric rating scale, ODI= oswestry disability index, RMDQ= roland morris disability questionnaire, TSK= tampa scale for kinesiophobia, FABQ= fear avoidance beliefs questionnaire, FABQ-PA= fear avoidance beliefs questionnaire physical activity subscale, FABQ-W= fear avoidance beliefs questionnaire work subscale, PCS= pain catastrophizing scale, PASS-20= pain anxiety symptoms scale, EOS= standing on stable support surface with eyes open, ECS= standing on stable support surface with eyes closed, EOU= standing on unstable support with eyes open, EOSV= standing on stable support surface with eyes open and muscle vibration, EOSD= standing on stable support surface with eyes open while performing a dual task, ECU= standing on unstable support with eyes closed, ECSV= standing on stable support surface with eyes closed and muscle vibration, ECSD= standing on stable support surface with eyes closed while performing a dual task, EOSVD= standing on stable support surface with eyes open and muscle vibration while performing a dual task, ECUV= standing on unstable support surface with eyes closed and muscle vibration, ECSVD= standing on stable support surface with eyes closed and muscle vibration while performing a dual task, CoP= center of pressure, AP= anteroposterior, ML= mediolateral, TOT= total, SD= standard deviations, MA= meta-analysis, *= reported correlation coefficients in article, #= non-published correlation coefficients obtained through author contact, §= additional non-published data obtained through author contact

0.13) (11 studies, n = 590) [8,15,23,50,51,53,55,57,59,60,62] was found between pain-related fear and CoP variables during standing on a stable support surface with eyes closed (see Fig. 3b). Sub-analyses for dynamic CoP variables yielded a significant pooled correlation coefficient of 0.10 (95% CI= 0.01, 0.18) (nine studies, n = 551) [8,23,50,51,53,57,59,60,62]. No significant pooled correlation coefficient was found for positional CoP variables (11 studies, n = 590; pooled r = 0.04, 95% CI= −0.04, 0.12) [8,15,23,50,51,53,55,57,59,60,62]. The certainty of evidence for all pooled correlation coefficients was very low.

3.4.1.3. Pain-related fear and linear CoP with two postural manipulations. A non-significant pooled correlation coefficient of 0.04 (95% CI= −0.06, 0.13) (seven studies, n = 424) [8,15,50,51,53,55,60] was found between pain-related fear and CoP variables during standing on an unstable support surface with eyes closed (see Fig. 3c). Sub-analyses yielded non-significant pooled correlation coefficients of 0.05 (95% CI= −0.05, 0.14) and 0.07 (95% CI= −0.03, 0.17) for respectively positional (seven studies, n = 424) [8,15,50,51,53,55,60], and dynamic (five studies, n = 388) [8,50,51,53,60] CoP variables. The certainty of evidence for all pooled correlation coefficients was very low.

A non-significant pooled correlation coefficient of 0.06 (95% CI= −0.10, 0.22) (six studies, n = 153) [8,15,54–56,62] was found between pain-related fear and CoP variables during standing on a stable support surface with eyes closed and muscle vibration (see Fig. 3d). Sub-analyses yielded a non-significant pooled correlation coefficient of 0.06 (95% CI= −0.10, 0.22) for positional CoP variables (six studies, n = 153) [8,15,54–56,62]. The certainty of evidence for all pooled correlation coefficients was very low.

3.4.1.4. Pain-related fear and linear CoP with three postural manipulations. A non-significant pooled correlation coefficient of − 0.04 (95% CI= −0.22, 0.14) (five studies, n = 115) [8,15,54–56] was found between pain-related fear and CoP variables during standing on an unstable support surface with eyes closed and muscle vibration (see Fig. 3e). No sub-analyses were executed because all included CoP variables were positional. The certainty of evidence for the pooled correlation coefficient was very low.

3.4.2. Pain catastrophizing

3.4.2.1. Pain catastrophizing and linear CoP without postural manipulations. A non-significant pooled correlation coefficient of 0.28 (95% CI= −0.10, 0.67) (three studies, n = 87) [52,58,61] was found between pain catastrophizing and CoP variables during standing on a stable support surface with eyes open (see Fig. 3f). Sub-analyses yielded a non-significant pooled correlation coefficient of 0.29 for dynamic CoP variables (95% CI= −0.15, 0.74) (three studies, n = 87) [52,58,61]. The certainty of evidence for all pooled correlation coefficients was very low.

Due to heterogeneity in the non-linear CoP variables [8,50,51,58], and a lack of studies using particular postural tasks [58,60,62], meta-analyses for these variables were not performed. All correlations of individual studies are reported in Appendix 6.

3.5. Moderation and sensitivity analyses

Two meta-analyses showed statistical heterogeneity greater than 30%, for which we planned to perform moderation and sensitivity analyses. However, because these meta-analyses contained only three studies, moderation and sensitivity analyses could not be conducted.

4. Discussion

4.1. Study findings

This systematic review investigated the associations between pain-

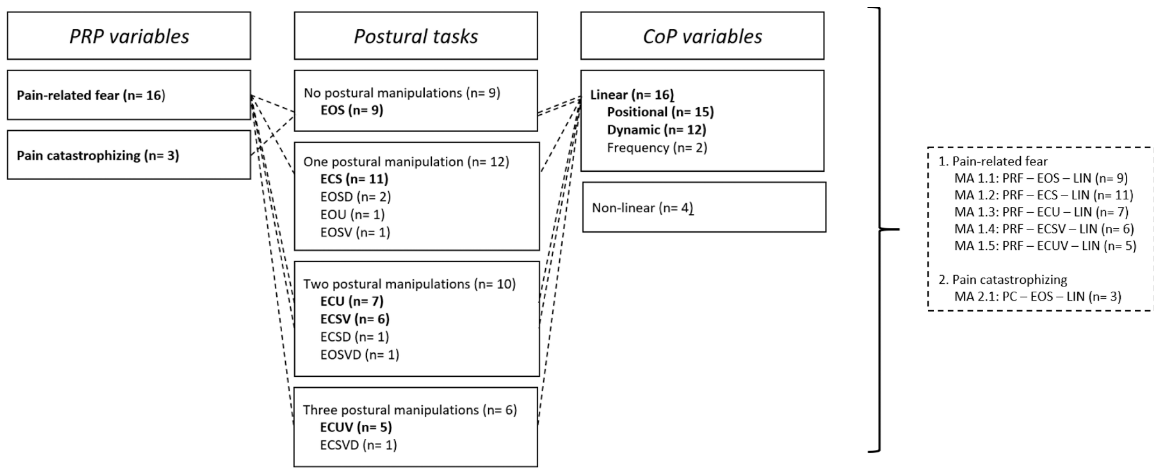


Fig. 2. Data clustering and performed meta-analyses. Fig. 2 displays the different data clusters with their subgroups, the number of studies reporting these data, and the conducted meta-analyses. Abbreviations: PRP= pain-related psychological, CoP= center of pressure, EOS= standing on stable surface with eyes open, ECS= -standing on stable surface with eyes closed, EOSD= standing on stable surface with eyes open while performing a dual task, EOU= standing on unstable surface with eyes open, EOSV= standing on stable surface with eyes open and muscle vibration, ECU= standing on unstable surface with eyes closed, ECSV= standing on stable surface with eyes closed and muscle vibration, ECSD= standing on stable surface with eyes closed while performing a dual task, EOSVD= standing on stable surface with eyes open and muscle vibration while performing a dual task, ECUV= standing on unstable surface with eyes closed and muscle vibration, ECSVD= standing on stable surface with eyes closed and muscle vibration while performing a dual task, MA= meta-analysis, PRF= pain-related fear, LIN= linear, PC= pain catastrophizing, dotted lines indicate conducted meta-analyses, n = number of articles reporting the variable.

related psychological variables and CoP variables during static bipedal standing in individuals with LBP. The findings of the meta-analyses indicated weak, overall non-significant, associations of very low certainty of evidence. This was not in line with our hypothesis, as we assumed to find negative correlations implying that increased levels of negative pain-related psychological variables would result in decreased CoP motion. Moreover, and contrary to our hypotheses, pooled correlation coefficients were not stronger during more difficult postural tasks.

Although pain-related psychological variables were subdivided into pain-related fear and pain-catastrophizing based on distinctive underlying mechanisms, results of both meta-analyses could not be compared due to the high statistical heterogeneity in the meta-analyses regarding pain catastrophizing. More research is needed to determine whether the discrepancies in findings between pain-related fear and pain catastrophizing are actually due to distinctive underlying mechanisms.

Potentially, the use of generic (non-task-specific) questionnaires to measure pain-related psychological variables could explain the weak and mainly non-significant findings. Matheve et al. (2019) highlighted the importance of using task-specific measures when assessing the association between pain-related fear and movement patterns in individuals with LBP. They showed that individuals with LBP might be fearful of particular activities, without achieving a high score on generic questionnaires, such as the TSK or FABQ [63]. Therefore, instead of solely relying on total scores of generic questionnaires, De Baets et al. [64] recommended to use a person-centered approach that evaluates an individual's pain-related cognitions and emotions regarding particular tasks, taking into account motivational and contextual factors [64]. In accordance with these findings, Meinke et al. (2022) found weak to strong positive associations between directional fear questions (e.g., 'I could harm my back if I bend forward') and postural sway [59]. Moreover, although some studies reported scores exceeding the cut-off scores of the pain-related psychological questionnaires, the majority of the studies reported values below the cut-off scores, indicating the absence of highly present negative pain-related psychological variables [65–67]. This may have affected our findings, thus results of the meta-analyses should be interpreted in this context.

Furthermore, the static bipedal standing tasks investigated in our meta-analyses might have not been sufficiently challenging or threatening to alter CoP motion and consequently its association with pain-related psychological variables. Da Silva et al. (2018) investigated CoP motion in people with chronic LBP during different tasks and concluded that the most difficult postural tasks (e.g., semi-tandem stance and unipedal stance) were the most sensitive to alterations in CoP motion [23]. Similarly, Van Daele et al. (2010) only found a difference in the effect of a cognitive dual tasks on CoP motion between patients with and without LBP in the most difficult postural task [68]. The assumption that task difficulty also affects the correlation between pain-related psychological variables and CoP variables is substantiated by Kahraman et al. (2018), who only observed moderate to strong negative correlations between fear of movement and postural sway during a dynamic task (i.e., testing limits of stability), but not during static bipedal nor unipedal standing [69]. Moreover, static bipedal standing of short duration may not typically provoke fear of pain or be perceived as a threatening postural task in individuals with LBP. Therefore, the included tasks may be less influenced by pain-related fear compared to more pain- or fear-provoking postures or movements. For example, a recent meta-analysis from Ippersiel et al. (2022) demonstrated associations between pain-related threat and guarded motor behavior during flexion-based tasks, but not consistently during for example gait and extension-based tasks [18].

Postural threats and emotions are known to affect postural control, even in healthy individuals [70,71]. For example, CoP motion decreases when healthy individuals are standing on an elevated platform in comparison with standing on a ground-level platform, although the biomechanical requirements for maintaining balance remain the same [72]. This might be explained by the 'integrated model of anxiety and postural control', which states that threat assessment is critically linked to every aspect of postural control at multiple levels in the brain (e.g., amygdala, sensory cortex, motor cortex) [73]. It might be likely that the postural tasks included in this review were not threat-inducing nor demanding enough to evoke alterations in CoP motion, particularly in the relatively young [74] and minimally disabled [75] cohorts that are included in the meta-analyses. The importance of disability in context of motor behaviour is highlighted in a recent meta-analysis of Nzamba et al. (2023) who found negative associations between disability and spinal movement in individuals with LBP [76], and Shanbehzadeh et al. (2022) who showed that higher levels of disability may also be related to poorer postural control [22].

Table 3
QUIPS risk of bias assessment.

Reference	Study participation	Study attrition	Prognostic factor measurement	Outcome measurement	Study confounding	Statistical analysis and reporting	Overall
[50]	Low	Low	Low	Low	High	High	High
[51]	Moderate	High	Low	Low	High	High	High
[47]	High	Low	Low	Low	High	High	High
[23]	Low	High	Low	Low	Moderate	Low	High
[52]	High	Low	Low	Low	High	High	High
[53]	High	Low	High	Low	High	High	High
[54]	Low	Low	Moderate	Low	High	Moderate	High
[56]	Moderate	Low	Moderate	Low	High	High	High
[55]	High	Low	Low	Low	High	High	High
[8]	High	Low	Low	Moderate	High	High	High
[57]	High	High	Low	Moderate	Moderate	Low	High
[58]	Moderate	Low	Low	Low	High	High	High
[59]	High	Low	Low	Low	Moderate	Low	High
[60]	Low	Low	Low	Low	Low	Low	Low
[61]	Moderate	Low	Low	Low	High	High	High
[62]	Moderate	Low	Low	Low	High	High	High

Table 4
Results of performed meta-analyses.

Performed meta-analyses	Number of studies	Number of participants	Pooled r	95% CI	I^2	GRADE
1. Pain-related fear						
No postural manipulation						
MA 1.1: Standing on a stable support surface with eyes open	9	303	0.07	[− 0.04, 0.18]	0%	Very low
MA 1.1.1: Positional CoP	8	284	0.14	[0.03, 0.26]	0%	Very low
MA 1.1.2: Dynamic CoP	9	303	0.05	[− 0.07, 0.16]	0%	Very low
One postural manipulation						
MA 1.2: Standing on a stable support surface with eyes closed	11	590	0.05	[− 0.03, 0.13]	0%	Very low
MA 1.2.1: Positional CoP	11	590	0.04	[− 0.04, 0.12]	0%	Very low
MA 1.2.2: Dynamic CoP	9	551	0.10	[0.01, 0.18]	0%	Very low
Two postural manipulations						
MA 1.3: Standing on an unstable support surface with eyes closed	7	424	0.04	[− 0.06, 0.13]	0%	Very low
MA 1.3.1: Positional CoP	7	424	0.05	[− 0.05, 0.14]	0%	Very low
MA 1.3.2: Dynamic CoP	5	388	0.07	[− 0.03, 0.17]	0%	Very low
MA 1.4: Standing on a stable support surface with eyes closed during muscle vibration	6	153	0.06	[− 0.10, 0.22]	0%	Very low
MA 1.4.1: Positional CoP	5	153	0.06	[− 0.10, 0.22]	0%	Very low
Three postural manipulations						
MA 1.5: Standing on an unstable support surface with eyes closed during muscle vibration	5	115	-0.04	[− 0.22, 0.14]	0%	Very low
2. Pain catastrophizing						
No postural manipulations						
MA 2.1: Standing on a stable support surface with eyes open	3	87	0.28	[− 0.10, 0.67]	72.67%	Very low
MA 2.1.1: Dynamic CoP	3	87	0.29	[− 0.15, 0.74]	79.5%	Very low

Abbreviations: CI= confidence interval, MA= meta-analysis, CoP, center of pressure, I^2= statistical heterogeneity, GRADE= Grading of Recommendations, Assessment, Development, and Evaluations

Another possible explanation for the weak and mainly non-significant correlations might be the divergence in presentation of motor control alterations (including postural strategies) in patients with LBP [77]. As the divergence in motor control strategies (ranging from ‘tight’ to ‘loose’ motor control) is often overlooked in research, results may be conflicting. Subgrouping patients with LBP based on their motor control strategy might yield stronger associations between pain-related psychological and CoP variables in individuals with LBP.

4.2. Considerations

Some considerations should be taken into account. Overall, the number of included studies in the meta-analyses was limited. The certainty of evidence of the meta-analyses was very low, and planned moderation analyses could not be performed. Thus, future studies accounting for the limitations of the current literature could reveal different findings. Moreover, we used unpublished data obtained through author contact. As these data have not been peer-reviewed, their quality is not guaranteed. We compensated for this by scoring high risk of bias for statistical analyses and reporting. Nevertheless, we believe that the data obtained through author contact added considerable value by enlarging the body of evidence. Furthermore, even though methodological heterogeneity in terms of postural tasks (i.e., only static bipedal standing tasks) and outcomes (i.e., only measures of CoP) was limited, the included studies still varied regarding stance width, verbal instructions, the number of trial repetitions, data acquisition duration, and sampling frequency, possibly impacting postural control measurement [44]. In addition, different outcome measurements regarding CoP variables (e.g. sway, area) and pain-related psychological questionnaires were used, which increased the methodological heterogeneity. Finally, the type and duration of LBP complaints has not been accounted for. Although recent evidence indicated no differences in terms of postural control between acute, subacute and chronic low back pain [42], research suggests that the duration or intensity of complaints might affect the interaction between postural control and pain-related psychological variables as fear and avoidance behaviors were identified as predisposing factors for long-term consequences on motor behaviors [78].

4.3. Future directions

The evidence provided in this study is too preliminary to transfer directly into clinical practice. However, based on our findings, we recommend future studies to explore more challenging (in terms of

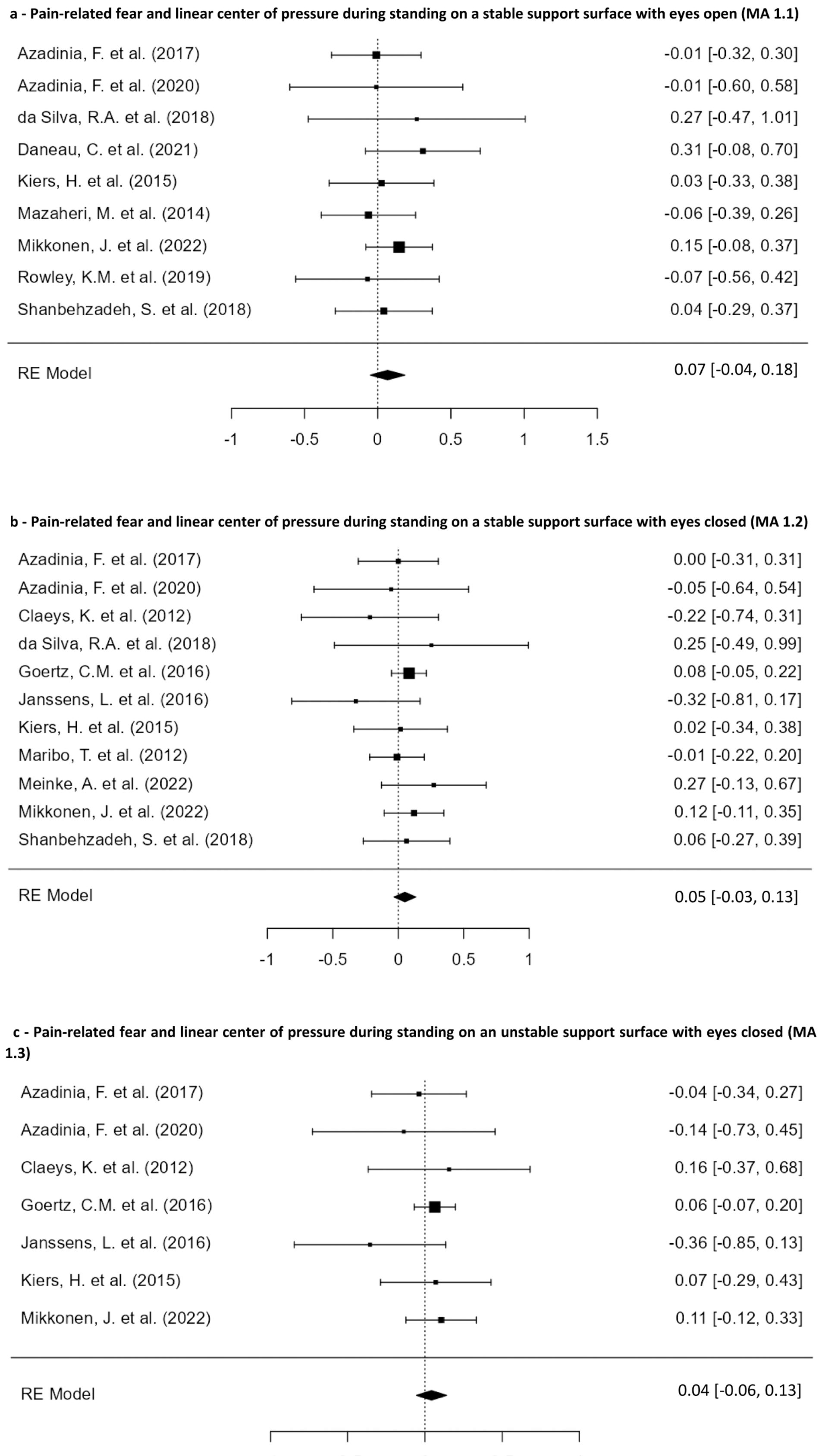
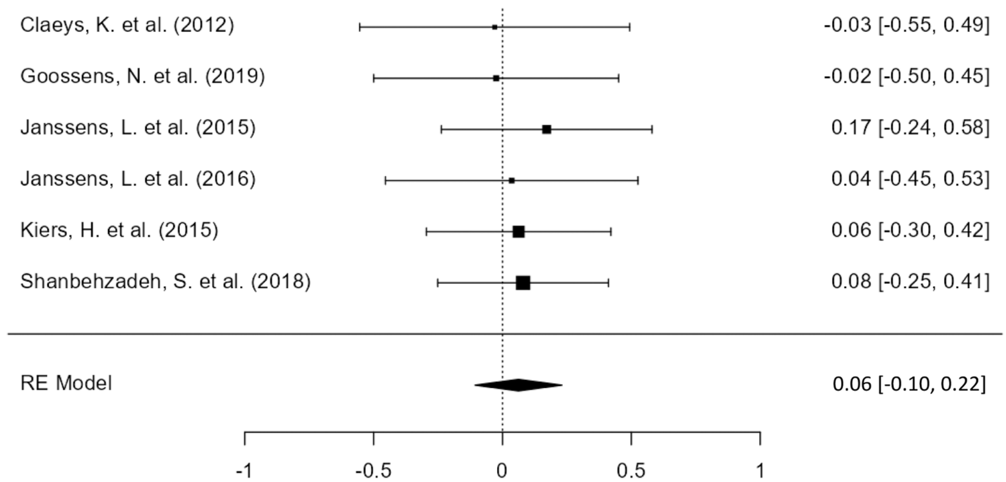
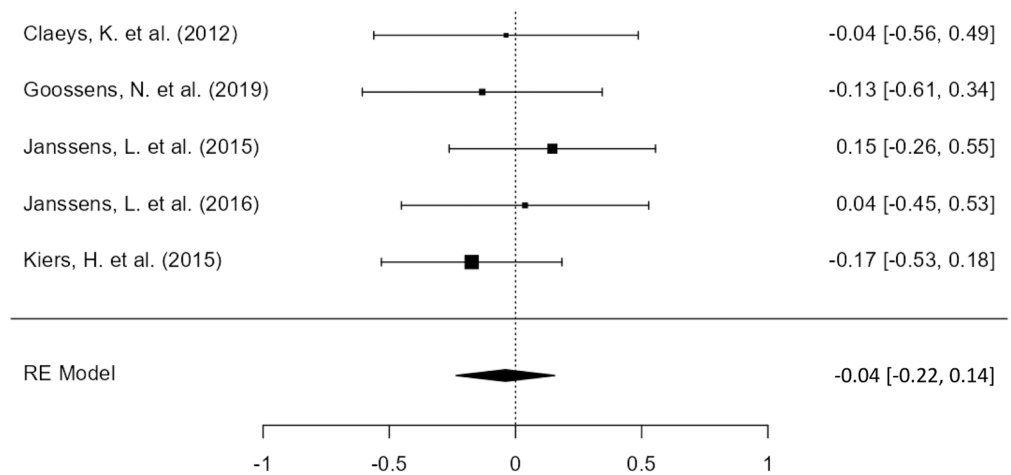


Fig. 3. Forest plots of main meta-analyses. Fig. 3 displays the forest plots of the main meta-analyses. Forest plots of the sub-analyses are added in the Appendices.,.

d - Pain-related fear and linear center of pressure during standing on a stable support surface with eyes closed and muscle vibration (MA 1.4)



e - Pain-related fear and linear center of pressure during standing on an unstable support surface with eyes closed and muscle vibration (MA 1.5)



f - Pain catastrophizing and linear center of pressure during standing on a stable support surface with eyes open (MA 2.1)

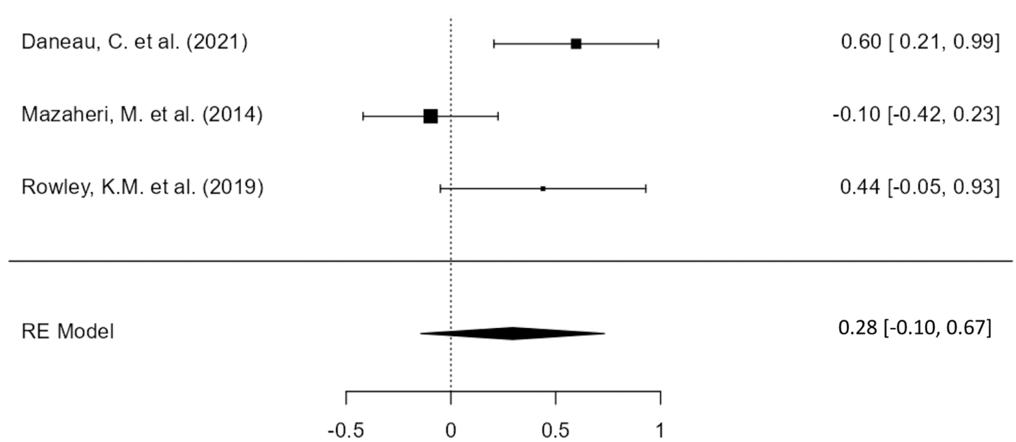


Fig. 3. (*continued*).

sensorimotor demands) and/or threat-inducing (in terms of perceived danger or damage) postural tasks, as they may have stronger effects on the association between pain-related psychological variables and CoP variables. Furthermore, adding task-specific measures of pain-related psychological variables might increase our insight. In line with this, tailoring the postural task to each patient by taking into account their individually feared tasks, might add useful knowledge. Also, adding kinematic and electromyographic measures to evaluate postural control might help us to gain more insight into the specific postural strategies (e.g., loose versus tight) and the associations between pain-related psychological variables and motor control. Given the heterogeneity of LBP, we recommend to distinguish subgroups based on the clinical presentation of LBP (e.g., specific versus non-specific LBP, acute versus chronic LBP) to examine whether this affects the correlation between pain-related psychological variables and CoP variables. Finally, longitudinal studies are needed to gain more knowledge about the causality between pain-related psychological variables and postural control in patients with LBP.

5. Conclusion

In summary, this systematic review and meta-analysis assessed whether pain-related psychological variables are associated with postural control during static bipedal standing in individuals with LBP, during different postural tasks.

Meta-analyses regarding pain-related fear and CoP variables resulted in weak associations during static bipedal standing regardless of the task conditions. Additionally, weak (close to moderate) associations were found between pain catastrophizing and CoP variables during standing on a stable support surface with eyes open.

These findings do not support the idea of a strong relationship between pain-related psychological variables and postural control strategies in individuals with LBP. However, given the very low certainty of evidence and methodological limitations, it is difficult to draw conclusions and it is conceivable that further research, accounting for current study limitations, may lead to different conclusions.

CRediT authorship contribution statement

Sofie Van Wesemael: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Katleen Bogaerts:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **Liesbet De Baets:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **Nina Goossens:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **Elke Vlemincx:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Charlotte Amerijckx:** Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing. **Suniya Sohail:** Validation, Investigation, Writing – review & editing. **Thomas Matheve:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision. **Lotte Janssens:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2023.10.013.

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