To flex or not to flex? Is there a relationship between lumbar spine flexion during lifting and low back pain? A systematic review with meta-analysis.

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Abstract

Objective

To evaluate whether lumbar spine flexion during lifting is a risk factor for LBP onset/persistence, or a differentiator of people with and without LBP.

Design

Prognosis systematic review with meta-analysis.

Literature Search

Database search of Proquest, CINAHL, Medline and EMBASE until August 2018.

Study Selection Criteria

We included peer-reviewed articles, investigating lumbar spine position during lifting as a risk factor for LBP onset or persistence, or as a differentiator of people with and without LBP.

Data Synthesis

Lifting task comparison data were tabulated and summarised. For meta-analysis, we calculated an n-weighted pooled mean (SD) of the results for each of the LBP and no LBP groups. Where a study contained multiple comparisons (i.e. different lifting tasks that used various weights or directions), only one result for each study was included in the meta-analysis.

Results

Four studies (one longitudinal study and three cross-sectional studies) measured lumbar flexion with intra-lumbar angles and found no differences in peak lumbar spine flexion when lifting (longitudinal 1.5 degree (95%CI -0.7 to 3.7), p=0.19 and cross-sectional -0.9 (95%CI -2.5 to 0.7), p=0.29). Seven cross-sectional studies measured lumbar flexion with thoraco-pelvic angles and found people with LBP lifted with 6.0 degrees less lumbar flexion than people without LBP (95%CI -11.2 to -.89, p<0.01). Most (9 of 11) studies reported no between-group differences in lumbar flexion during lifting. The included studies were low quality.

Conclusion

There was low quality evidence that greater lumbar spine flexion during lifting was not a risk factor for LBP onset/persistence, nor a differentiator of people with and without LBP.

Key words

lift, manual handling, posture.

Introduction

Back pain is the leading cause of disability globally with 818,000 disability-adjusted life-years estimated to be lost annually due to work-related low back pain (LBP).[5,6,40,47] Lifting is a common risk factor for the development and exacerbation of LBP.[12,14,45,46]

There is a strong belief that lifting with a flexed lumbar spine has a causative role in lifting-related LBP,[16,38] and that lifting-related LBP is due to the combined angular (kinematic) position and load (kinetic force) on the lumbar spine.[1] As a result, workplace health and safety personnel and healthcare practitioners commonly advise that increased flexion (kyphotic curvature) of the lumbar spine should be avoided when lifting and risk of LBP can be reduced by lifting in a lumbar-neutral or a lordotic position. Lifting with a 'straight back' has become an accepted principle of occupational and public health world-wide.[23,31,45] Healthcare practitioners advocate the advice to lift with a straight back, and industry has adopted many practices to reduce lumbar flexion when lifting.[38] Critically, implementing lifting advice in healthcare and in workplaces has not been accompanied by reduced occupational LBP.[31]

Lifting advice has been extrapolated from cadaveric studies indicating the lumbar spine is susceptible to failure when repeatedly flexed, and is weaker when flexion and compression are combined.[2,19,29,36] However there is uncertainty about how transferable cadaveric findings are to real-life lifting situations. Another influence on lifting advice has been early in-vivo work that demonstrated higher lumbar intra-discal pressure during forward bending of the trunk or when a load was lifted.[37,49]

A limitation of the in-vivo studies was that they did not consider lumbar spine curvature during lifting and were conducted without comparing between groups with and without LBP. Spinal loads are similar when lifting with a flexed spine to lifting with a 'straight' lumbar spine.[18,25,44] While there is some evidence from epidemiology studies that high mechanical loads are a risk factor for LBP, those studies did not examine whether lumbar flexion during lifting was a risk factor.[12,13,22]

Therefore, we asked two questions in this systematic review:

1. Is lumbar spine flexion during lifting a risk factor for LBP onset/persistence?
2. Is lumbar spine flexion during lifting different in people with and without LBP?

Methods

The study protocol was prospectively registered in PROSPERO (CRD42017075661). The addition of a meta-analysis was the only alteration to the registered protocol. We became aware the data would be suitable for meta-analysis only after data extraction.

Eligibility Criteria

Included studies must have: (i) measured lumbar spine position with a marker set that identified two or more separate anatomic regional landmarks to allow calculation of lumbar spinal inclination relative to the vertical/horizontal, or lumbar spine angulation, or the calculation of inclination relative to the pelvis, (ii) measured lumbar spine position during natural/unconstrained lifting of an external load, (iii) provided results on lumbar spine position as a risk factor for LBP onset or persistence (longitudinal studies), or as a differentiator of people with and without LBP (cross-sectional studies), and (iv) been published in English language in a peer-reviewed journal (Table 1).

Information Sources and Study Selection

We searched the Proquest, CINAHL, Medline and EMBASE databases from inception to 21/08/18 (search strategy in Appendix 1). Potentially relevant articles were identified by title and abstract, full text articles were retrieved and checked against the selection criteria, and study characteristics were extracted. The reference lists of included articles were also searched. The search process and article screening were conducted by two authors independently (NS, LN) with assistance from a senior health faculty librarian. Any discrepancies were first discussed and if needed any disagreement was resolved by a third reviewer (PK).

Quality assessment

A modified Critical Appraisal Checklist (Appendix 2)[35] was used to assess and summarise quality at both individual study and domain levels. The basis for a study to be classified as either low, moderate or high quality depended on score across the 12 domains. In the context of this systematic review, we afforded more weight to domains eight (Has the measurement tool which was used for assessing lumbar kinematics been validated?) and nine (Were lumbar kinematics measured in a way that is equivalent to a known 'gold standard' for motion analysis?) than to the other 10 domains because they focused on assessing risks to internal validity (i.e. bias) as they assess aspects of measurement of the 'exposure' (lumbar spine kinematics). This quality assessment was performed by NS, LN, with PK available to resolve disagreements.

We used the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach[4] to assess the quality and summarise overall certainty of the body of

evidence included in our systematic review. The included studies were cross-sectional and non-randomised longitudinal studies; the GRADE guidelines for the assessment of quality of evidence indicate starting at 'low quality' for research using these study designs. The other criteria set by GRADE were then used to upgrade or downgrade certainty.

Data Extraction

The following data were extracted: (i) title, year, author, type of study, (ii) type and duration of intervention, number and characteristics of participants (gender, age, number, stage/time course of LBP, pain intensity, previous episodes, recruitment period, selection criteria, context), (iii) for all studies: method and measures of lumbar kinematics and their method of measurement; length of follow-up, loss to follow-up, and (iv) relevant results from each study. Data extraction was conducted by two authors independently (NS, LN) and later checked for similarity.

Data synthesis

One longitudinal study[32] combined data from people with no LBP and mild LBP-related disability because there were no differences in the movement characteristics of the people with no LBP and mild LBP at baseline. The combined no/mild LBP group was compared to a group with significantly disabling LBP; we preserved that contrast.

Two cross-sectional studies[33,34 21] reported a no LBP group and two pain subgroups. For meta-analysis, we combined the results of the pain subgroups. In two studies,[33,34] different lifting comparisons were recorded using the same cohort and therefore were pooled. Where necessary, we contacted authors[17,20,21,30,33] to clarify data. Some[21,33] provided additional data for meta-analysis. We estimated upper and lower lumbar sagittal plane degrees of flexion

149 from one study[20] by direct measurement of an enlarged version of the published graph of the
150 results, using the Adobe Acrobat measurement tool.
151
152 Lifting task comparisons were tabulated and summarised (Appendix 3). For meta-analysis,
153 we calculated an n-weighted pooled mean (SD) of the results for each of the LBP and no LBP
154 groups. Therefore, if a study contained multiple comparisons (i.e. different lifting tasks that
155 used various weights or directions),[24] the means and SD of those tests were pooled to create a
156 single result for each study for inclusion in the forest plot (see Appendix 4 for an example).
157
158 Meta-analysis was completed using Revman 5 software using a random effects model.[41] We
159 analysed lumbar angles for the upper and lower spinal regions separately, as these regions
160 may move differently.[33] Where a study's reported data were not suitable for the meta-analysis
161 and our request for the necessary detail from the authors was unanswered,[17] we excluded the
162 study from meta-analysis.
163
164 There were two main methods of measuring 'lumbar spine flexion' (see Appendix 5).
165 **Method 1:** applying markers or sensors on the skin overlying thoracic spine and pelvis
166 landmarks (thoraco-pelvic angles) (used in seven studies).[15,27,28,30,39,42,43] Where authors
167 included two or more different measures of lumbar spine position during lifting (e.g. both a
168 thoraco-pelvic angle and a measure of trunk inclination relative to the vertical), we used the
169 thoraco-pelvic angles for meta-analysis as they more accurately reflect lumbar flexion.[15,27]
170 **Method 2:** multiple markers or sensors placed on the skin overlying the lumbar spine region
171 (intra-lumbar angles) (used in five studies).[17,20,21,32-34]
172

We sub-grouped data for meta-analysis based on quality of the measurement method used to identify lumbar spine flexion (intra-lumbar being higher quality than thoraco-pelvic) and instead of weighting these studies in the meta-analysis, we presented them as separate subgroups. Heterogeneity was assessed using an I^2 statistic. As the longitudinal and cross-sectional studies are conceptually different, we also presented them as separate subgroups.

Results

The search yielded 2,289 non-duplicate studies. We excluded 2,255 based on title and abstract. Thirteen papers from 12 independent studies with 697 participants met the inclusion criteria. Mitchell et al[33] and Mitchell et al[34] reported results from the same cohort, therefore, the results were combined. One longitudinal and 11 cross-sectional studies met the inclusion criteria (Figure 1). The characteristics of included studies are summarised in Table 2 and detailed in Appendix 3 including the descriptions of study populations.

Meta-analysis

Four studies (one longitudinal study and three cross-sectional studies) measured lumbar flexion with intra-lumbar angles. There were no differences in peak lumbar spine flexion when lifting (longitudinal 1.5 degree (95%CI -0.7 to 3.7), p=0.19 and cross-sectional -0.9 (95%CI -2.5 to 0.7), p=0.29) and no significant heterogeneity I^2 = 0% and 3% (Figure 2).

Seven cross-sectional studies measured lumbar flexion with thoraco-pelvic angles. People with LBP lifted with 6.0 degrees less lumbar flexion than people without LBP (95%CI -11.2 to -.89, p<0.01). There was substantial heterogeneity (Tau^2 p<0.01, I^2=76%). We did not undertake sensitivity analyses because results across studies were consistent. For description of the individual study results see Appendix 6.

198

199 **Quality Assessment**

200 The quality assessment information at both individual study and domain levels is summarised
201 in Table 3. The full detail is reported in Appendix 2 and 7 and informed the GRADE quality
202 assessment.

203

204 The methods of the 12 included studies were diverse, with disparate capture devices used to
205 measure lumbar spine position during lifting tasks, each with different measurement system
206 errors. Four studies measured lumbar spine flexion using a method that has been validated
207 against a known 'gold standard' for laboratory-based motion capture.[20,21,32-34] For this reason,
208 the quality in these studies is higher than in the other studies of this review. These four
209 studies and the study by Dideriksen et al,[17] all measured intra-lumbar angles but with varying
210 motion capture devices, lumbar marker positioning and validity of lumbar spine flexion
211 measurement.[17,20,21,32-34]

212

213 In seven studies, it was not possible to accurately estimate lumbar spine flexion (i.e. kyphosis
214 between L1 and L5) because marker or sensor locations were more indicative of trunk flexion
215 relative to the pelvis (thoraco-pelvic angles).[15,27-29,39,42,43] The study populations in these
216 studies were also poorly described generally including: an absence of recruitment
217 details,[27,28,42,43] ambiguous inclusion criteria of the LBP group[15,29] and also no disability
218 measures for the LBP group.[15,27,29,39] Sample sizes of studies in this review were of similar
219 size to many motion analysis studies but only five studies reported any type of power
220 calculation.[20,21,28,33,34,39] The quality for the individual included studies ranged from low to
221 high (Appendix 7).

222

Certainty of evidence: summary of GRADE results

We rated the overall quality of the body of evidence in the review as 'low', which GRADE suggest indicates that 'confidence in the effect estimate is limited and the true effect may be substantially different from the estimate of the effect'.

We judged *overall risk of bias* to be high, as most studies measured the lumbar spine during lifting using a marker set that indirectly captured lumbar curvature (by use of thoraco-pelvic angles) with inadequate validation of that type of measurement system, and the methodological quality of studies included in this systematic review was usually low. We judged *inconsistency* to be low for the cross-sectional and longitudinal intra-lumbar results due to low statistical heterogeneity in their meta-analyses. Among the cross-sectional studies that reported thoraco-pelvic angles, there was significant statistical heterogeneity (I^2 = 76%, P = 0.001) in that meta-analysis (indicating inconsistency of the effect size). No included study, of any type, showed an unequivocal effect for lifting with a more flexed lumbar position being associated with LBP. There was little *indirectness*, beyond the previously mentioned use of thoraco-pelvic angles. For *imprecision*, we noted that the four of 15 results from the meta-analysis, that favoured the LBP group to be more flexed all had 95% confidence intervals that substantially crossed zero, indicating considerable uncertainty in the estimate. Sample sizes were small in comparison to most trials of treatment effect but are common for biomechanical studies, as the use of repeated measures (repetitions of lifts) increases statistical power. We judged *publication bias* as unlikely**,** given no apparent unequivocal evidence of an association between LBP and lumbar flexion during lifting.

Discussion

We found low quality evidence of no longitudinal relationship between greater lumbar spine flexion during lifting and LBP onset or persistence. There was also low quality evidence of no cross-sectional relationship between greater lumbar spine flexion during lifting and LBP. Only two of 43 comparisons reported greater lumbar flexion in people with LBP: one cross sectional study that measured intra-lumbar angles and found greater upper lumbar spine flexion of four degrees in the LBP group, but less lower lumbar spine flexion,[20] and one other study,[15] with a high risk of bias (i.e. less accurate measure of lumbar spine flexion) but in only one of five between group comparisons.

There is no credible in-vivo evidence to support the dogma[10,11,38] that lumbar spine flexion should be minimized when lifting to prevent LBP onset, persistence or recurrence. More comparisons found those with LBP used *less* lumbar flexion when lifting, although this may have been in response to advice following their LBP onset or a response to pain itself.

While there is evidence that load on the lumbar spine may be a risk factor in both the onset and persistence of LBP,[12,48] the risk relationship between lumbar flexion and LBP is not demonstrated by the current body of in-vivo research in this area. Recent biomechanical studies in pain-free populations do not support an increase in disc pressure, compression or shear strain in flexed versus straight back lifting.[18,25,44] Previous studies do not support current lifting advice translating to reductions in lifting-related LBP.[31,46] Therefore, advice to minimize lumbar spine flexion during lifting to reduce the risk of LBP is currently difficult to justify.

Increased exposure to forward trunk inclination (bending) and lifting have separately been associated with LBP in other reviews.[12,22] Greater exposure to forward trunk inclination in

the workplace, and lifting frequencies of greater than 25 lifts/day or regularly lifting over 25kgs, were associated with increased risk of LBP. Importantly, no study in either of these reviews, measured lumbar position or trunk position during lifting. The studies in these reviews used self-report questionnaire and video observation of unknown validity and reliability to analyze time spent in various degrees of trunk inclination (bending at work) or lifting exposures. Critically, to date no study that has directly measured the lumbar spine during lifting, has found a relationship between LBP and greater lumbar flexion.

The groups with LBP included in this review, were mostly people who were mildly disabled by LBP, with low mean LBP intensity at the time of testing. No study specified lifting-related pain as an inclusion criterion for the LBP group. Participants in the studies lifted weights between a pen and a 12 kg box, representing less than the maximal advised loads for manual workers of up to 23kg.[26] While all of these factors may have influenced the results of these studies, within the included studies, higher levels of pain, disability or the weight lifted did not result in a finding of more lumbar flexion. Nonetheless, we cannot exclude that if future studies only included participants with higher levels of pain, LBP that was specific to lifting, and required them to lift greater weight, a difference between groups may be observed.

Using the GRADE criteria, we rated the overall quality of the body of evidence in the review as ‘low’ but acknowledge that the risk of bias in the included studies could have been adequate reason to further downgrade this body of evidence from low quality to very low quality. We endeavoured to answer the question, ‘is lumbar flexion during lifting associated with LBP?’ and given the consistency of findings in the meta-analyses, which universally found no unequivocal evidence in any study that LBP is associated with a more flexed lumbar spine during lifting, it is unlikely that future research of similar quality would

297 contradict our results. Because the results were so consistent, we believe a GRADE score of
298 'very low' quality of evidence, representing 'very little confidence in the effect estimate', is
299 not justified.
300
301 Among the cross-sectional studies that measured lumbar flexion with thoraco-pelvic angles,
302 there was significant statistical heterogeneity. This is likely due to the clinical diversity (e.g.
303 study populations) and methodological diversity (e.g. measurement approaches) across these
304 studies. Such diversity is common in epidemiological (non-randomised) studies. While we
305 chose to retain the pooled estimate as a broad summary estimate, the point estimate for
306 lumbar flexion from cross-sectional thoraco-pelvic angles should be interpreted with caution.
307
308 There is a lack of high-quality studies in people with and without LBP, that have measured
309 lumbar spine flexion during lifting, using measures that have been validated against a gold
310 standard for motion analysis. Other variables that can be reported from measurement of
311 lumbar kinematics during lifting, such as time spent in peak flexion, effect of fatigue on
312 lumbar kinematics and other aspects of movement variability were not captured by this
313 review or simply were not reported in studies of people with and without LBP. There is also a
314 paucity of longitudinal studies. Therefore, future high-quality work in this area may be
315 warranted to definitively establish whether lumbar kinematics during lifting is a factor of
316 concern, especially as this topic is so controversial.
317
318 The sample sizes were generally small and usually without an adequate power analysis. Only
319 three studies,[20,28,33,34] reported the core components of a sample size calculation: the size of
320 the difference they were powering to detect, alpha level (p-value), variance and confidence
321 level required. Despite these methodological considerations, the similarity of findings across

the included studies strengthens the argument that there is no consistent evidence of greater peak lumbar flexion during lifting in people with LBP compared to those without LBP. While almost all the findings indicated no greater flexion during lifting in the LBP group, two studies consistently demonstrated *less* lumbar flexion in the LBP group.

Because non-statistically significant findings are less likely to be published, it is unlikely that unpublished studies would change the results of our systematic review. Only two comparisons from all the included studies indicated that the LBP group displayed greater peak lumbar flexion when lifting. Although the thoraco-pelvic measures suggested that the LBP group used less lumbar flexion when lifting, we consider that type of measurement a less precise measure of lumbar flexion.

Clinical implications

Recent research supports that people with and without LBP, clinicians and occupational health advisors commonly believe that lifting with a flexed lumbar spine is a risk factor for LBP.[10,11,38] This has led to the current common advice by health professionals and the occupational health industry to warn people about the risk of pain and injury to their back if they lift with a flexed back.[46] This advice is being provided in spite of an absence of in-vivo kinematic evidence. Given the strong evidence that LBP is influenced by various biopsychosocial factors,[3,6] including negative LBP beliefs and fear of movement,[7-9] persisting with the current advice to avoid lumbar flexion during lifting due to an increase risk of LBP is not justified.

Limitations

Only 12 studies met the inclusion criteria. Our results are at risk of publication bias because we did not include studies published in languages other than English. No study incorporated lifts over 12kgs. Therefore our results may not apply to heavy lifting. All of the studies in our review were conducted in a laboratory. It is unknown if lifting kinematics in the laboratory accurately reflect lifting kinematics in the workplace or in other activities of daily living. Field-based data capture of lumbar kinematics during repeated lifting in people engaged in manual work is required to answer this question. We only considered lumbar position, and not the load on the lumbar spine.

Conclusions

There is currently no credible longitudinal or cross-sectional evidence to suggest that a more flexed lumbar spine during lifting is a risk factor for LBP onset or persistence, or a differentiator of people with and without LBP.

Key Points

Findings – There was no prospective association between lumbar spine flexion when lifting and the development of significantly disabling LBP. There was no difference in peak lumbar flexion during lifting, between people with and without LBP.

Implications - Current advice to avoid lumbar flexion during lifting to reduce LBP risk is not evidence-based.

Caution – There was only one longitudinal study included and it only captured lifts of low load. No study incorporated lifts of over 12kgs.

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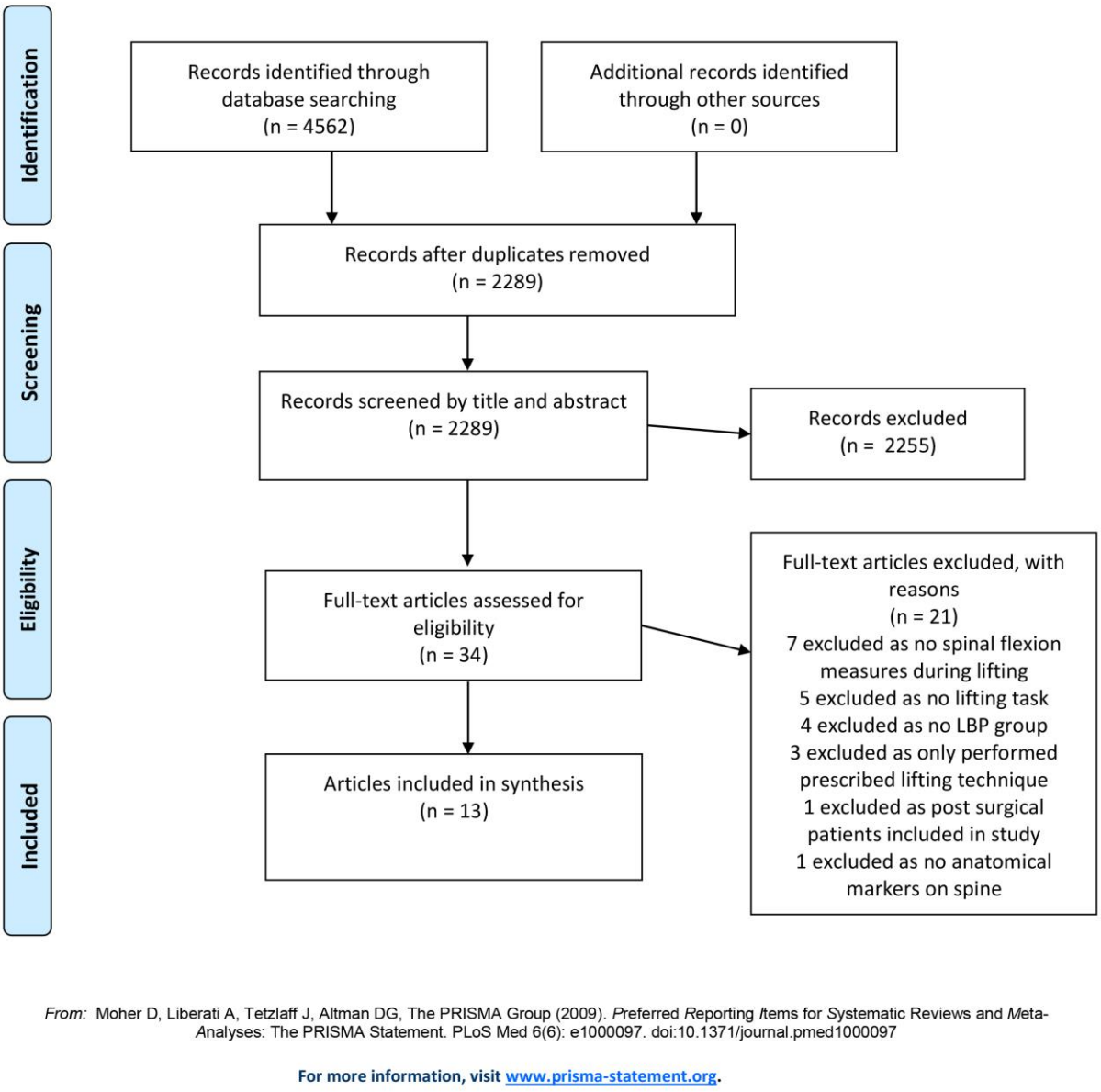
549 **Figures**

550



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552 **Figure 1: PRISMA flow diagram of article screening process as at 21/8/18**

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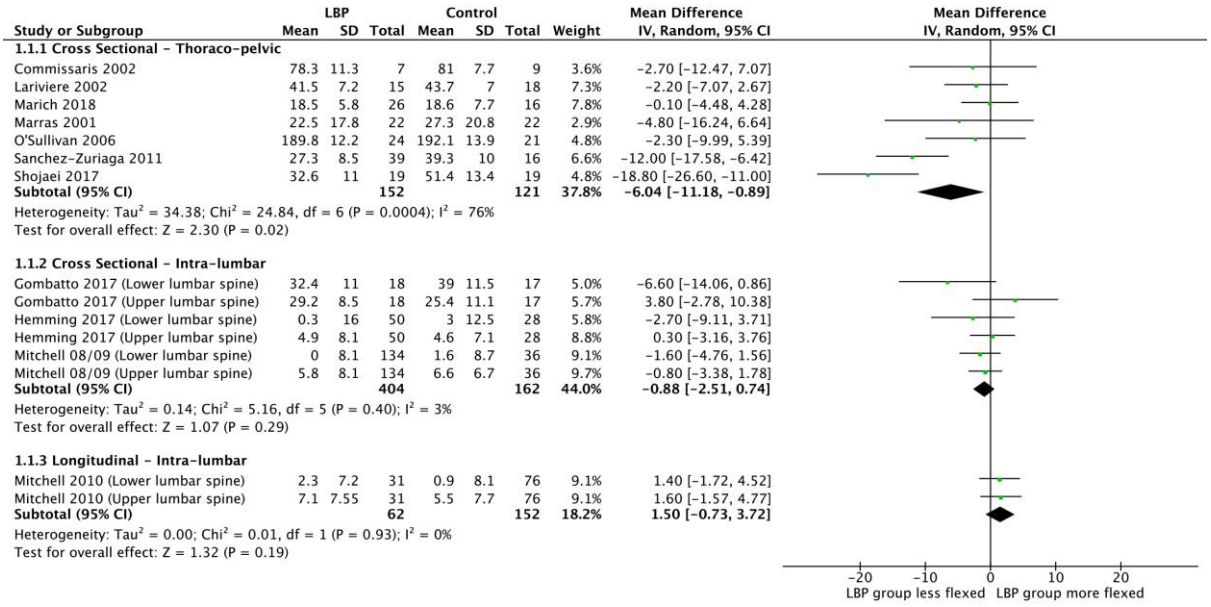


554

555 **Figure 2: Meta-analysis of studies comparing lumbar flexion during lifting in people**

556 **with and without LBP.**

557 Legend: Means and standard deviations (SD) are in degrees and have been rounded to the

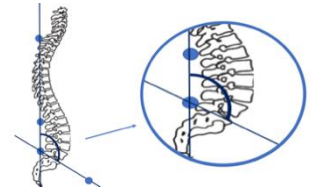
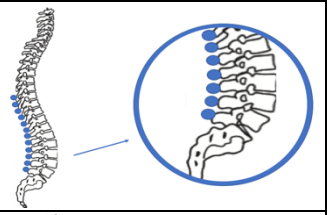
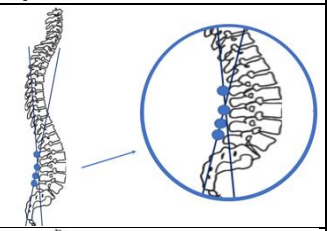
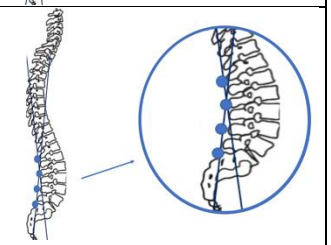
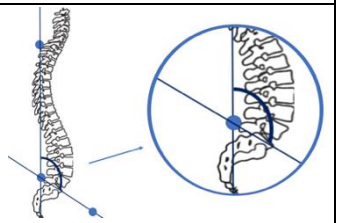
558 nearest 0.1. Negative values, reported in Mitchell et al for greater lumbar flexion, have been

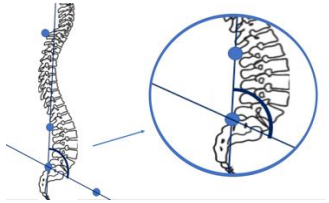
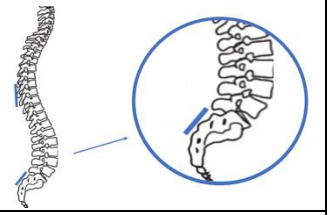
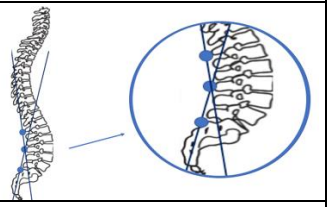
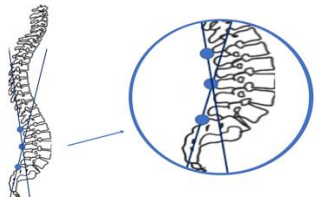
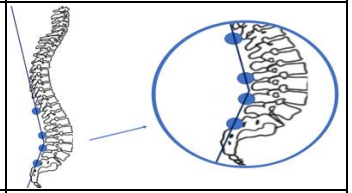
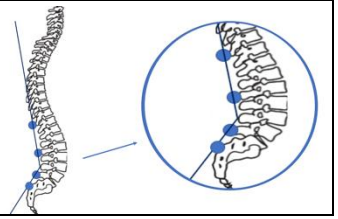
559 reversed for uniformity in this forest plot.

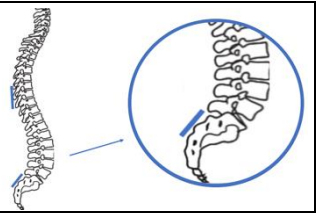
Table 1: Inclusion and exclusion criteria for screening process

Inclusion criteria
1. Must measure lumbar spine using any type of marker set that identifies two or more separate anatomic regional landmarks that allow: a) the calculation of spinal inclination (lumbar region inclination, even though it may not be possible to differentiate hip from lumbar or lumbar from thoracic contribution), or b) the calculation of the lumbar spine relative to the pelvis (lumbar spine angulation or inclination, either 2 segments or more). So, either there needed to be a measurement of spine inclination relative to the vertical/horizontal or that the spine is flexing relative to the pelvis or hips.
2. Must have a LBP group or look at LBP in some way as a result of lifting.
3. Participants must have an external load that they were handling during the measurement period. This includes any external load. There were no upper or lower load limits on the weight of the external load participants lifted.
4. Must inform the question: What evidence is there that the position of the lumbar spine during lifting is either: a) a risk factor for pain onset or pain persistence (longitudinal studies), or b) a differentiator of people with and without pain (cross-sectional)
Exclusion criteria
Studies with no, or only one, marker on the spine or self-report measures of lumbar spine position.
Specific back pain, radiculopathy, nerve root irritation, spinal stenosis, rheumatologic/ inflammatory (e.g. RA) or neurological conditions (e.g. MS)
Functional tasks in any sport other than weight-lifting
Only examined prescribed lifting techniques, and not the voluntary, automatic lifting technique of the participant
Participants were educated by the study investigators on how to lift before the measurements were taken
Not samples that included participants who were pregnant, had a lower-limb amputation or severe lower limb arthritis
Studies published in any language other than English
Studies published in any form other than a full peer-reviewed article
Studies that involved participants under 18 years of age

Table 2. Characteristics of the included studies

Study (Author/Year) Design Sample source	**Sample Size % Females Age and BMI**	**LBP at time of testing (yes/no) Level of pain in LBP group Disability in LBP group**	**Measurement device Lx spine marker/sensor placement Lifted object**	**Schematic of Lx spine markers/sensors**
Commissaris et al. 2002 Cross-sectional Post-pregnancy exercise class	n = 16 (LBP 7 vs Control 9) 100% female LBP - Age 33.4(3.6)*, BMI 22.3(3.0) Control - Age 34(3.4), BMI 22.9(2.9)	Yes Baseline VAS median pain - 2.7(0.2-9.8) Disability Rating Index Median - 2.9 (1.0-6.9)	Two-camera opto-electronic system C7, T12, L5, ASIS and Greater Trochanter 8.3kg box	
Dideriksen et al. 2014 Cross-sectional Pain clinic, GPs or via advertising	n = 34 (LBP 17 vs Control 17) LBP 59% Control 53% female LBP - Age 32.5(9.6), BMI 23.6 Control - Age 29.7(7.3), BMI 22.5	Yes Baseline NRS - 1.8(1.5) ODI - 14.2%(7.2)	Epionics SPINE 12 angle sensors (25 mm) along the spine starting at PSIS 5kg box	
Gombatto et al. 2017 Cross-sectional Orthopaedic clinic	n = 35 (LBP 18 vs Control 17) LBP 61% Control 59% female LBP - Age 28.1(13.1), BMI 24.4(2.9) Control - Age 25.6(8.7), BMI 25.2(3.5)	Yes Baseline NRS - 2.1(1.9) Modified ODI – 18%(12.7)	**Nine-camera 3D Vicon L1, L3, L4 and L5 Light digital metronome	
Hemming et al. 2017 Cross-sectional University Health Boards	n = 78 (LBP 50 vs Control 28) LBP 50% Control 52% female LBP - Age 42.2(10.5), BMI 22.2(4.2) Control - Age 38.5(11.2), BMI 21.5(4.1)	Yes Baseline VAS - 4.5(1.4) ODI – 22%(11.28)	**Eight-camera 3D Vicon T12, L2, L4 and PSIS Pen and 2.5kg box	
Lariviere et al. 2002 Cross-sectional Unknown	n = 33 (LBP 15 vs Control 18) 0% female LBP - Age 39(3), BMI 23.2(2.3) Control - Age 40(4), BMI 24.2(2.6)	Yes Lifting VAS - 2.6(2.7) Unknown	Five-camera 2D motion capture C7, L5 and mid-point pelvic crest 12kg box	

Marich et al. 2018 Cross-sectional Advertisements	n = 42 (LBP 26 vs Control 28) LBP 58% Control 63% female LBP - Age 38.5(12.3), BMI 24.0(2.6) Control - Age 37.4(11.0), BMI 23.6(2.4)	Yes Baseline NRS - 3.0(1.0) Modified ODI - 24.2%(12.8)	Eight-camera 3D Vicon T12 and S1 Lightweight box	
Marras et al. 2001 Cross-sectional Orthopedic clinic	n = 44 (LBP 22 vs Control 22) 45% female LBP - Age 39.0(10.1), BMI 31.3 Control - 36.4(11.1), BMI 25.4	Yes Baseline NRS - 4.8 Unknown	Lumbar motion monitor (Triaxial electro-goniometer) Thoracic spine and sacrum 4.5, 6.8, 9.1, and 11.4kg weights	
Mitchell et al. 2008/09 Cross-sectional University Nursing Programs	n = 170 (LBP 134 vs Control 36) 100% female LBP - Age 22.7(4.5), BMI 23.2(3.9) Control - Age 21.7(3.5), BMI 21.9(2.8)	Unknown < 3/10 VAS pre-testing ODI - 14.6%(7.7)	**3-Space® Fastrak™ T12, L3 and S2 Pen, pillow and 5kg box	
Mitchell et al. 2010 Longitudinal University Nursing Programs	n = 107 (LBP 31 vs Control 76) 100% female LBP - Age 21.7(4.5) Control - Age 21.7(3.7)	Unknown Unknown Significant (definition in article)	**3-Space® Fastrak™ T12, L3 and S2 Pen, pillow and 5kg box	
O'Sullivan et al. 2006 Cross-sectional Industrial workers	n = 45 (LBP 24 vs Control 21) 0% female LBP - Age 38.7(9.2), BMI 26.43(2.8) Control - 38.2(9.3), BMI 25.0(3.3)	Unknown < 3/10 VAS pre-testing Unknown	Canon Digital IXUS V camera T10, L2, L4 and S2 12kg box	
Sanchez-Zuriaga et al. 2011 Cross-sectional Unknown	n = 55 (LBP 39 vs Control 16) Unknown LBP - Age 45(11), BMI 24.9(3.0) Control - Age 39(11), BMI 25.0(4.0)	Unknown Unknown ODI - 33.7%(13.2)	Four camera 3D video Pulnix TM-6740CL T12, L3, L5 and Sacrum Empty, 5kg and 10kg box	

Shojaei et al. 2017 Cross-sectional Unknown	n = 38 (LBP 19 vs Control 19) 100% female LBP - Age 58(9), BMI 27.5(4.6) Control - Age 56(9), BMI 25.7(4.1)	Unknown Pain intensity 3.84(2.0) on WBPI Roland Morris 6.1(4.5)	Two Xsens Technologies IMU's T10 and S1 4.5kg weight	

Legend:
Lx=Lumbar spine, LBP=Low Back Pain, BMI=Body Mass Index, ASIS=Anterior Superior Iliac Spine , PSIS=Posterior Superior Iliac Spine, *Mean (standard deviation) unless median stated (range), **Gold standard measure for lumbar spine motion analysis
VAS=Visual Analogue Scale (0-10), ODI=Oswestry Disability Index (%), NRS=Numerical Pain Rating Scale (0-10), WBPI=Wisconsin Brief Pain Inventory (0-10) and Roland Morris=Roland Morris Disability Questionnaire (0-24)

Table 3: Domain level quality score

Critical appraisal domains	Percentage of studies scoring yes
1. Were the people with LBP (or with persistent LBP) and those people without LBP (or without persistent LBP) comparable in their current characteristics other than regarding their lumbar spine position?	83%
2. Were cases (people with LBP) and controls (people without LBP) matched appropriately on previous exposures that might influence the presence of LBP?	58%
3. Were the same criteria used for identifying cases and controls?	67%
4. Was pain vs no pain measured in a valid and reliable way?	75%
5. Was pain vs no pain measured in the same way for cases and controls?	75%
6. Were confounding factors identified?	92%
7. Were confounding factors dealt with appropriately?	75%
8. Has the measurement tool which was used for assessing lumbar kinematics been validated?	83%
9. Were lumbar kinematics measured in a way that is equivalent to a known 'gold standard' for motion analysis?	33%
10. Were lumbar kinematics assessed in a reliable way?	83%
11. Was the exposure period of interest long enough to be meaningful?	100%
12. Was appropriate statistical analysis used?	92%

Appendix 1: Search strategy

The search involved the use of both keyword searching in the title and abstract fields as well as subject heading searching across the four concepts of the search strategy.

REGION lumbar or lumbopelvic or spinopelvic or thoracolumbar or “lumbar vertebrae” or back or spinal or spine or lumbosacral or “lumbosacral region” or “lumbar spine” or trunk

TOPIC OF INTEREST (Spinal position) posture or “range of mo*” or “biomechanical phenom*” or “lumbar flexion” or flex* or bend* or “joint position” or “lumbar posture” or “lumbar position” or lordosis or kyphosis or biomechanics or kinematics or “trunk kinematics”

TASK load* or mov* or lift* or carry or “manual handl*” or handl* or “functional tasks”

OUTCOME “nonspecific low back pain” or “low* back pain” or “chronic low back pain” or “low* back ache” or backache or “low back syndrome” or lumbago or LBP or CLBP or NSLBP or NSCLBP or discomfort or “back discomfort” or “lumbar pain” or “spin* pain”

The four search concepts were then combined (#1 AND #2 AND #3 AND #4) before limits were applied.

Limits
- Peer reviewed/Article
- English language
- Adult
- Human

Medline Example

1. (lumbar or lumbopelvic or spinopelvic or thoracolumbar or "lumbar vertebrae" or back or spinal or spine or lumbosacral or "lumbosacral region" or "lumbar spine" or trunk).tw.

or

Lumbar Vertebrae/
Thoracic Vertebrae/
Back/
Spine/
Lumbosacral Region/

---

2. posture or "range of mo*" or "biomechanical phenomena" or "lumbar flexion" or flex* or bend* or "joint position" or "lumbar posture" or "lumbar position" or lordosis or kyphosis or biomechanics or kinematics or "trunk kinematics").tw.

or

Posture/
"Range of Motion, Articular"/
Biomechanical Phenomena/
Lordosis/
Kyphosis/

---

3. ("nonspecific low back pain" or "low* back pain" or discomfort or "back discomfort" or "lumbar pain" or "spin* pain" or "chronic low back pain" or "low* back ache" or backache or "low back syndrome" or lumbago or LBP or CLBP or NSLBP or NSCLBP).tw.

or

Low Back Pain/
Back Pain/

---

4. (load* or lift* or carr* or "manual handl*" or handl* or mov* or "functional tasks").tw.

or

Lifting/

Then 1. and 2. and 3. and 4.

*The search was then limited to Adults, Human, Peer review/article and English.

Appendix 2: Adapted critical appraisal checklist*

Reviewer _____ Date_____

Author_____ Year_____ Record Number_____

	Yes	No	Unclear	Not applicable
1. Were the people with LBP (or with persistent LBP) and those people without LBP (or without persistent LBP) comparable in their current characteristics other than regarding their lumbar spine position? N.B. Hereafter, 'people with LBP' also refers to 'people with persistent LBP' and 'people without LBP' also refers to 'people without persistent LBP' if the research question is about LBP persistence.	☐	☐	☐	☐
2. Were cases (people with LBP) and controls (people without LBP) matched appropriately on previous exposures that might influence the presence of LBP?	☐	☐	☐	☐
3. Were the same criteria used for identification of cases and controls?	☐	☐	☐	☐
4. Was pain vs no pain measured in a valid and reliable way? In cross-sectional studies, this would have been the exposure and in longitudinal studies, would have been the outcome.	☐	☐	☐	☐
5. Was pain vs no pain measured in the same way for cases and controls? In cross-sectional studies, this would have been the exposure and in longitudinal studies, would have been the outcome.	☐	☐	☐	☐
6. Were confounding factors identified?	☐	☐	☐	☐
7. Were confounding factors dealt with appropriately?	☐	☐	☐	☐
8. Has the measurement tool which was used for assessing lumbar kinematics been validated? In cross-sectional studies, this would have been the outcome and in longitudinal studies, would have been the exposure.	☐	☐	☐	☐
9. Were lumbar kinematics measured in a way that is equivalent to a known 'gold standard' for motion analysis?	☐	☐	☐	☐

In cross-sectional studies, this would have been the outcome and in longitudinal studies, would have been the exposure.				
10. Were lumbar kinematics assessed in a reliable way? In cross-sectional studies, this would have been the outcome and in longitudinal studies, would have been the exposure.	☐	☐	☐	☐
11. Was the exposure period of interest long enough to be meaningful?	☐	☐	☐	☐
12. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

_____

_____

_____

*Adapted with permission from the Joanna Briggs Institute.

Explanation of critical appraisal checklist items

How to cite the original critical appraisal tool: Critical Appraisal Checklist for Case Control Studies. Joanna Briggs Institute Reviewers' Manual: 2016 edition. Australia: The Joanna Briggs Institute, University of Adelaide, Australia; 2016.

Critical Appraisal Tool

1. Were the people with LBP (or with persistent LBP) and those people without LBP (or without persistent LBP) comparable other than regarding their lumbar spine position during lifting?

In a case control study, the control group should be representative of the source population that produced the cases. This is usually done by individual matching; wherein controls are selected for each case on the basis of similarity with respect to certain characteristics other than the exposure of interest (lumbar spine position). Frequency or group matching is an alternative method. Selection bias may result if the groups are not comparable.

Similarly, in a cohort study, it is important that the people with and without the variable of interest (particular lumbar spine positions during lifting) were comparable in other ways.

2. Were cases and controls matched appropriately?

As in item 1, the study should include clear definitions of the source population. Sources from which cases and controls were recruited should be carefully looked at. Study participants may be selected from the target population, the source population, or from a pool of eligible participants (such as in hospital-based case-control studies). It is important that the people with and without the variable of interest (particular lumbar spine positions during lifting) were not only similar in their current characteristics (item 1) but also similar on previous exposures that may influence the presence of LBP.

3. Were the same criteria used for identification of cases and controls?
It is useful to determine if patients were included in the study based on either a specified diagnosis or definition. This is more likely to decrease the risk of bias. Characteristics are another useful approach to matching groups, and studies that did not use specified definitions should provide evidence on matching by key characteristics. A case should be defined clearly. It is also important that controls must fulfil all the eligibility criteria defined for the cases except for those relating to lumbar spine position during lifting.

4. Was pain vs no pain measured in a valid and reliable way?
The study should clearly describe the method of measurement of low back pain. A judgement can then be made about whether this method has acceptable validity and reliability, based either on references in the paper or on other available knowledge.

5. Was pain vs no pain measured in the same way for cases and controls?
Assessment of this exposure or outcome should have been carried out according to the same procedures or protocols for both cases and controls.

6. Were confounding factors identified?
Confounding has occurred where the estimated exposure effect is biased by the presence of some difference between the comparison groups (apart from the exposure of interest). Typical confounders include baseline characteristics, prognostic factors, or co-interventions. A confounder is a difference between the comparison groups and it influences the direction of the study results. In this context, a high-quality study will identify potential confounders and measure them (where possible).

7. Were confounding factors dealt with appropriately?
Strategies to deal with effects of confounding factors may be dealt with within the study design or in data analysis. By matching or stratifying sampling of participants, effects of confounding factors can be adjusted for. When dealing with adjustment in data analysis, it is important to assess the statistics used in the study. Most will be some form of multivariate regression analysis to account for the confounding factors measured. Look out for description of statistical methods as regression methods such as logistic regression are usually employed to deal with confounding factors variables of interest.

8. Has the measurement tool used for assessing outcomes (lumbar kinematics) been validated?
Determine whether the measurement tools used were validated instruments (was a validation study referenced in the paper or conducted as part of that research) and whether those measurements were conducted in a uniform way across all participants.

9. Were lumbar kinematics measured in a way that was equivalent to a known 'gold standard' for motion analysis?
Assessing validity requires that a 'gold standard' is available to which the measure has been compared. In this context, the validity of lumbar spine position measurement should have been previously compared to the 'gold standard' (i.e. functional MRI or similar) or must have incorporated a 3D capture of the position of the lumbar spine which has measured two or more segments within the lumbar spine.

10. Were lumbar kinematics assessed in a reliable way?
Reliability refers to the processes included in an epidemiological study to check repeatability of the measurements of interest. These usually include intra-observer reliability and inter-observer reliability. Was a reliability study previously published or was this conducted as part of this research and was the level of reliability acceptable?

11. Was the exposure period of interest long enough to be meaningful?
It is particularly important in a case-control study that the exposure time was sufficient enough to show an association between the exposure and the outcome. It may be that the exposure period may be too short or too long to influence the outcome.

12. Was appropriate statistical analysis used?
It is important to assess the appropriateness and transparency of the analytical strategy used.

Study (1st author and year)	n, sex, age and BMI	Sample source (LBP and NoLBP definition)	Pain information • Level of pain • Duration • Type: (symptom pattern, diagnosis, +/- leg pain), • Pain/Activity limitation: Back pain at time of testing? (yes/no)	Measurement device and region measured	Author's name for lumbar spine measures	Lumbar lifting kinematic outcome (Dependant variable)	Lifting Task	Relevant Findings	Reviewer Comments	Pain group more flexed/ extended/ no difference in lumbar spine during lifting
Commissaris 2002	n = 16 7 LBP 9 Controls LBP: Mean Age- 33.4 (3.6) females - 100% Mean BMI - 22.3 (3.0) Control: Mean Age - 34 (3.4) Females - 100% Mean BMI - 22.9 (2.9)	All subjects were recruited from an ordinary postpregnancy exercise class. LBP: a delivery within 1 year before study and ongoing back and/or pelvic pain. LBP group displayed a positive pain drawing in the low back and/or pelvic region. No exclusion criteria were applied. Control: a delivery within 1 year before study and no ongoing back and/or pelvic pain. No exclusion criteria were applied.	Baseline Median pain LBP group VAS 27mm (range 2 - 98mm) Control 0mm on VAS Pain Duration - Unknown. LBP group did have pain at time of testing. Median Disability Rating Index 29mm (0 - 100mm)	A 2-camera opto-electronic system recorded the positions of 14 passive light-reflecting markers. Thirteen hemispherical markers (diameter, 20mm) were attached to anatomic landmarks on the left side of the body, except for 3 markers that were put on the spinal column. (3) The spinous process of the seventh cervical vertebra; (4) the spinous process of the 12th thoracic vertebra; (5) the spinous process of the fifth lumbar vertebra; (6) the ASIS; therefore lumbosacral joint angle defined as the junction of the projection of one link onto another link 3– 4 and 5– 6.	Lumbosacral angle, Lumbar spine angle and trunk inclination.	The angular ROM was defined as the difference between the baseline angle and the absolute peak angle reached at any instant between the onset of the downward and end of the upward phases of the lifting task. Lift-off angle are the values at the instant of box lift-off.	Floor to chest symmetrical lift of a box (360 x 360 x 250mm) weighing 8.3kg with both hands. The movement was repeated 7 times.	Compared utilising independent sample t tests and Levene test for equality of variances. **Box lift off lumbosacral angle 78.3 ± 11.3 LBP 81.0 ± 7.7 Controls.** **This data was utilised for Meta-Analysis.** Lumbosacral ROM during lifting 20.3 ± 8.5 LBP 18.8 ± 4.3 Controls. Lift off lumbar spine angle 126.3 (16.8) LBP 109.0 (12.3) Controls. Lumbar spine flexion ROM during lifting 52.9 ± 15.5 LBP 43.8 ± 9.5 Controls. Trunk inclination at box lift off 37.8 (5.0) LBP 33 (10.8) Controls.	The finding of increased lumbar flexion in this study at box lift off are questionbale given the lumbar spine was defined by a backward pelvic tilt relative to the trunk and a pelvic marker was on the greater trochanter.	More flexed presented in one kinematic comparison relating to the lumbar spine. All other lumbar spine kinematic findings not different. (1 of 5 comparisons more flexed)
Okderiksen 2014	n = 34 17 in each group LBP: Mean Age - 32.5 (9.6) Females - 59% Weight - 74.3 (12.8) kg Height - 1.77 (0.1)m Control: Mean Age - 29.7 (7.3) Females - 53% Weight - 69.2 (14.0) kg Height - 1.75 (0.1) m	Pain clinic, general practitioners or general advertising. LBP: Chronic non-specific LBP > 3 months with periods of symptom aggravation and remission in the last six months. Each episode of LBP should have lasted at least one week with sufficient intensity to limit function. Control: Age / gender matched pain free participants with no relevant history of back or lower limb pain or injury that limited their function and/or required treatment from a health professional.	Pain Duration - Mean 34.2 (29.3) months. LBP group did have pain at time of testing. Oswestry Disability Index 14.2% (7.2). Mean current pain pre lifting 1.8 (1.5). Pain increased during performance to mean 2.5 (2.6). Controls reported no pain at rest or throughout the repetitive lifting task. Also reported average pain intensity 3.1 (2.2)	Epionics SPINE (Epionics Medical GmbH, Potsdam, Germany). The SPINE system was composed of two strips, both equipped with 12 angle sensors per strip. Sensor strips were placed 5 cm laterally to the spine by means of adhesive bandages. The most caudal sensor was aligned with subject's posterior superior iliac spine. Recorded data from this sensor was referred to as spinal angle #1, while data from consecutively more cranial sensors was referred to as spinal angle #2–12.	Spinal angles	Angular offset and within-group variance of the angular offset trajectory and magnitude.	Participants repetitively moved a box (40 x 20 x 30 cm) with hole-shaped handles, loaded with a weight of 5 kg, between two shelves placed approximately at knee (lateral epicondyle of femur with the knee extended) and shoulder (position of the clavicle while standing) height. The task was repeated 22 times. The first and last lifts were removed from analysis.	There was no significant difference between the angular offset (mean angle for each sensor throughout entire task; average p-value = 0.54, lowest p-value = 0.18 for sensor #2) or the within-group variance of the angular offset across the 12 sensors for the two groups (p = 0.27). The variability of the task-related angular trajectory was several magnitudes larger than the accessory angular trajectory, and was highest for the most caudal sensors. There was no difference in the magnitude of the task-related an- gles between the LBP and the control groups, indicating that the occurrence of back pain did not modify the execution of the task mechanically. Furthermore, there was little difference in the magnitude of the accessory angles between the LBP and the control group (only significantly different for accessory angles at sensor #2; p = 0.048.	Although the range and variability of the angular trajectories did not differ, using RQA, The authors found that the structure of the variability was more deterministic (less random) for the LBP group.	No difference in lifting angles or variance of lifting spinal angles.
Gombatto 2017	n = 35 LBP n = 18 Control n = 17 LBP: Mean age 28.1 (13.1) Mean BMI 24.4 (2.9) 61% Female Control: Mean age 25.6 (8.7) Mean BMI 25.2 (3.5) 59% Female	LBP group recruited from orthopaedic clinics. Controls recruited from college campus and surrounding community. LBP: Primary complaint of LBP which they sought physical therapy for. Control: No history of LBP.	Median pain VAS 29mm (Range 60mm) Median duration 1.5 years (Range 30 years) Mean pain last 7 days NRS 3.7 (2.4) Mean current pain 2.1 (1.9) Modified ODI 18% (12.7) Yes for pain at time of testing 3 participants increased pain during pick up.	Nine camera 3D Vicon system was utilised. Upper lumbar spine - Markers bilaterally 4cm lateral to L1 and spinous process L3. Lower lumbar spine - Markers bilaterally 4cm lateral to L4 and spinous process L5.	Upper Lumbar and Lower Lumbar	Angular excursion (range of movement ie max ext to max flex)	Lift a small digital metronome of negligible weight from the floor. Lift completed three times.	**LBP 29.2(8.5) vs Control 25.4(11.1)** **This data was utilised for Meta-Analysis (upper lumbar)** **LBP 32.4(11) vs Control 39(11.5)** **This data was utilised for Meta-Analysis (lower lumbar)** Mixed model ANOVA tests. Adobe measurement tool used to derive mean (SD).	In the sagittal plane, there was a significant group by lumbar region interaction effect (P < 0.05). Subjects in the LBP group displayed greater movement in the upper lumbar region (4 deg) and less in the lower lumbar region (6 deg) than control subjects.	Upper lumbar more flexed lower lumbar less flexed. (No differences in 0 of 2 comparisons for Meta-Analysis)
Hemming 2017	n = 96 50 LBP (AEP 23 and FP 27) 28 Controls LBP: Mean Age - AEP 43.7 (11.2) FP Group 41 (10.0) Females - AEP Group 82% FP Group 22% Mean - BMI - AEP 20.8 (4.9) FP 23.4 (3.5) Control: Mean Age - 38.5 (11.2) Females - 52% Mean BMI - 21.5 (4.1)	LBP group recruited from physiotherapy waiting lists in Cardiff and Vale University Health Board. Unknown where controls were recruited from. LBP: Aged 18–65 years, chronic LBP, pain in the lumbar and/or buttock region. Clear mechanical basis of the disorder aligned with specific aggravating and easing postures and movements, with distinct symptom relief observed during movement conducted in the opposing direction of reported pain provocation (assessed subjectively and objectively). Clinical diagnosis of specific MCI—*either FP or AEP.* Control: Not discussed in text. Table indicates no current LBP or history of LBP.	Pain duration - Range (3 months to 10+ years) LBP group did have pain at the time of testing. Oswestry Disability - AEP group 22.5 (11.6) FP group 21.6 (10.0) Baseline VAS - AEP group 4.6 (1.4) FP group 4.5 (1.4)	Eight-camera Vicon motion analysis system. Retro-reflective markers over the following anatomical positions: spinous processes of the 7th cervical, 2nd, 4th, 6th, 8th, 10th and 12th thoracic and 2nd and 4th lumbar vertebrae, manu- brium sterni (superior border) and bilaterally on the ante- rior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), iliac crest (mid-crest, vertically aligned with the greater trochanter) acromioclavicular joint, ulna styloid process, 10 cm lateral of the 12th thoracic spinous process, lateral knee joint line, and the lateral malleoli creating a full body model.	Upper Lumbar and Lower Lumbar	The change in orientation between the lines interconnecting the adjacent markers was used to define each spinal region curvature in degrees. This was calculated by summing all angular changes within each region: lower lumbar (S1– L3); upper lumbar (L3–T12); lower thoracic (T12–T6); and upper thoracic (T6–C7) (Fig. 3). The mid-point spinal curvature of the subjects' total range of movement was determined for each task. This was calculated as follows: (maximum flexion sagittal spinal angle + maximum extension sagittal spinal angle)/2.	1. 2.5kg box lift from plinth (NB Box not directly in front of participant) 2. 2.5kg box replace back on other side of plinth 3. Pen lift from floor 4. Pen replace to floor	Peak flexion angle (Below data was obtained from request to author) Negative values signify extension **Upper lumbar comparisons** **1. Box Lift AEP -3.7 (5.4) FP 2.5 (8.8) Controls -2.1 (7.4)** **2. Box Replace AEP -6.5 (9.8) FP 1.2 (8.1) Control -4.3 (7.3)** **3. Pen lift AEP 7.9 (7.5) FP 13.4 (7.2) Controls 12.1 (6.7)** **4. Pen replace AEP 9.0 (7.6) FP 14.2 (7.8) Controls 12.9 (7.2)** **This data were pooled for Meta-Analysis (upper lumbar)** **Lower lumbar comparisons** **1. Box Lift AEP -6.2 (17.7) FP 12.7 (13.4) Controls -6.5 (10.2)** **2. Box Replace AEP -13.3 (15.7) FP 16.7 (13.1) Control -11.1 (9.9)** **3. Pen lift AEP 9.8 (16.3) FP 14.2 (16.2) Controls 14.6 (14.6)** **4. Pen replace AEP 11.0 (17.1) FP 16.6 (19.3) Controls 15.3 (15.3)** **This data were pooled for Meta-Analysis (lower lumbar)** NB. *n*-weighted pooled mean used to combine FP and AEP groups so pain vs control	Analyses identified differences primarily in the lower thoracic and upper lumbar spinal regions between the FP and AEP group and the FP and control group. In both instances, the FP group consistently operated in greater thoraco-lumbar spinal flexion. No between group significant differences were observed in the upper thoracic or lower lumbar regions during any task. Gender could be a large confounding factor not accounted for in this study.	No differences between pain vs control (0 of 8) comparisons. Differences only between fp vs aep vs control for upper lumbar spine position.
Lariviere 2002	n = 33 15 LBP 18 Controls LBP: Mean Age - 39 (3) Females - 0% Mean - BMI - 23.2 (2.3) Control: Mean Age - 40(4) Females - 0% Mean BMI - 24.2 (2.6)	Recruitment method not stated. LBP: lumbar/lumbosacral pain with or without proximal radicular pain (limited distally to the knees); and presence of chronic pain defined as a daily or almost daily pain for at least three months. Control: no back pain in the preceding year and no back pain exceeding one week at any time previously; never lost one day of work because of back pain; and never consulted for a back problem. Not known where recruited from.	LBP group VAS 2.6 cm (2.5) and 2.7 (2.9) for the symmetric and asymmetric tasks, respectively. LBP group did have pain during testing. From inclusion criteria duration > 3 months.	Briefly, five video cameras were used to collect, at 60 Hz, the bi-dimensional (2D) position of the 27 reflective markers. Change in lumbar vertebral angle from upright standing was calculated using the position of skin markers located (1) at the middle point between the posterosuperior iliac spine (PSIS) and the anterosuperior iliac spine (ASIS) on the lateral sides of the trunk, (2) on the L5 spinous process and (3) on the C7 spinous process. A postural index (PI) was computed to quantify lifting technique. The PI quantifies the extent to which the posture adopted deviates from a stooped (knee straight, trunk flexed) posture. Trunk flexion relative to the vertical was calculated from estimated L5/S1 and C7/T1 joint centers.	Lumbar vertebral angle, postural index (PI) and trunk flexion angle.	Change in lumbar vertebral angle from upright standing, PI and peak trunk flexion angle from the vertical were calculated for both lifting and lowering.	Symmetric and asymmetric lifting tasks with a A 12kg box. From floor height to height of greater trochanter or shelf 90 degrees right then placed back on the floor.	None of the postural variables showed a group difference. Compared using two way repeated measures ANOVA. **Change in vertebral angle (lifting symmetrical task) LBP 42 (7) vs Control 46 (7)** **Change in vertebral angle (lowering symmetrical task) LBP 41 (9) vs Control 43 (7)** **Change in vertebral angle (lifting asymmetrical task) LBP 41 (7) vs Control 44 (7)** **Change in vertebral angle (lowering asymmetrical task) LBP 42 (6) vs Control 44 (6)** **This data were pooled for Meta-Analysis** Peak trunk flexion from the vertical (lifting symmetrical task) LBP 91 (20) vs Control 87 (22) Peak trunk flexion from the vertical (lowering symmetrical task) LBP 91 (22) vs Control 85 (24) Peak trunk flexion from the vertical (lifting asymmetrical task) LBP 91 (19) vs Control 89 (22) Peak trunk flexion from the vertical (lowering asymmetrical task) LBP 93 (21) vs Control 89 (23)	The moderate nature of the back pain perceived by the CLBP patients may explain why no significant postural shifts were detected relative to controls.	no difference in lumbar vertebral angle, trunk flexion angle or PI between groups. No differences in lumbar vertebral angle or trunk inclination (0 of 8) comparisons.
Marich 2018	n = 42 LBP n = 26 Control n = 16 LBP: Mean age 38.5 (12.3) Mean BMI 24.0 (2.6) 58% Female Control: Mean age 37.4 (11.0) Mean BMI 23.6 (2.4) 63% Female	LBP group recruited through advertisements. Control group matched to LBP group but uncertainty as to recruitment. LBP: Symptoms that resulted in seeking a medical/health care intervention (eg, physician, chiropractor, or physical therapist) or altered performance of work, school, daily functional, or physical activity for 3 or more consecutive days. LBP condition for >12 months and present > half of the days of the year. Control: No history of LBP.	Mean current pain NRS 3.0 (1.0) Average pain preceding 7 days 3.4 (0.8) Modified low back disability questionnaire 24.2% (12.8) Yes for pain at time of testing Mean pain duration 13.7 (7.5) years 11/26 LBP participants experienced increased pain with the lifting trials.	An 8 camera 3D Vicon motion capture device was utilised to capture upper and lower lumbar spine movement. Markers on T12 and S1 defined the lumbar spine.	Lumbar spine	Maximal lumbar excursion	A lightweight container 20 x 30 x 12cm was lifted 3 x prior to training and 3 x post lumbar specific training. The container was lifted from a height equal to the participants shank length and a horizontal distance equal to half the participant trunk length	**Maximal lumbar excursion LBP group 18.5 (5.8) vs Controls 18.6 (7.7) P = .93** **This data was utilised for Meta-Analysis** NB. For the first 50% of total movement time lumbar excursion was significantly greater in the LBP group. 11.2 (5.0) vs 7.1 (2.7) P = .005 Independent group t tests	No differences in maximal lumbar excursion between LBP and controls. Difference in first 50% of downward trunk movement where LBP group displayed greater lumbar excursion in the early phase. This was corrected following intervention which improved 10/11 participants pain with pick up task post intervention.	Maximal lumbar excursion in normal lift pre intervention no differences between groups (0 of 1 comparisons).

Marras 2001	n = 44 22 LBP 22 Controls LBP: Mean Age - 39.0 (10.1) Females - 45% Mean BMI - 31.37 Control: Mean Age - 36.4 (11.1) Females - 45% Mean BMI - 25.4	Recruited from the orthopedic practice of one of the authors. LBP: No explanation of inclusion/exclusion criteria. Table 2 of study summarises characteristics of LBP group. Control: Age and gender matched to LBP group. Must have been asymptomatic in previous year.	LBP group did have pain at time of testing 4.8/10 (assumed on NPRS 0 - 10) Median duration of current LBP episode 6.5 weeks. 50% of LBP participants had a previous history of LBP prio to this current episode. All LBP participants had at least 50% of their pain experienced in the back vs referred into the leg. ie no participant with dominant leg pain presentation.	Trunk kinematics were measured with a lumbar motion monitor (LMM) which is essentially a triaxial torso electro-goniometer. The LMM attaches to the thoracic spine via a chest harness, and to the pelvis at the level of the sacrum with a pelvic harness. The unit weighs approximately 1.4 kg and does not restrict lumbar motion.	Trunk	Sagittal trunk position (°): LBP 22.56 ± 17.87 Controls 27.31 ± 20.84 P < .05. Repeated measures ANOVA used for load variables, no explanation of how kinematics variables were analysed.	Four weights weighing 4.5, 6.8, 9.1, and 11.4 kg, respectively, were lifted under free-dynamic sagittally symmetric conditions, each starting from six lift origins.	Kinematic analyses indicated that the participants with LBP significantly reduced their trunk and hip kinematics in terms of sagittal position and velocity, as compared with the asymptomatic group. **Sagittal trunk position (°) LBP 22.56 ± 17.87 Controls 27.31 ± 20.84 P < .05.** **This data was utilised for Meta-Analysis.**	No indication if this number was peak or change in trunk position or how it was calculated. Assumed mean peak ROM from standing over all lifts but unknown. Increased BMI is a significant confounder in this study's results which isn't accounted for.	Pain group less trunk flexion when lifting. No difference in (0 of 1 comparisons in Meta-Analysis)
Mitchell 2008	n = 170 No LBP n = 36 Minor LBP n = 81 Significant LBP n = 53. No LBP: Mean Age - 21.7 (3.5) Females - 100% Mean BMI - 21.9 (2.8) Minor LBP: Mean Age - 22.0 (4.2) Females - 100% Mean BMI - 23.3 (4.3) Significant LBP: Mean Age - 23.9 (5.1) Females - 100% Mean BMI - 23.1 (3.4)	Female undergraduate nursing students recruited via personal invitation from two university nursing programs. Group selection based on 4 criteria. 1. Worst ever LBP on VAS > 4/10 2. > 1 week duration in last 12 months 3. Required treatment, meds or activity limitation in the last 12 months. 4. > 20% disability on ODI No LBP: No history of LBP. 0/10 lifetime highest LBP. No annual history. Minor LBP: Some LBP in pervious 12 months but didn't meet significant LBP criteria Significant LBP: Scored above cut off in 3/4 criteria	Subjects who had LBP which limited their performance of the test procedures (pain greater than 3 out of 10 on a VAS at the time of testing) were excluded. Uncertainty as to level of LBP at time of testing. No LBP: No history of LBP. 0/10 lifetime highest LBP. No annual history. Minor LBP: Mean lifetime highest LBP on VAS 3.9 (2.3) Annual LBP duration range (1-7 days) ODI 10.4 (6.6) Significant LBP: Mean lifetime highest LBP on VAS 6.6 (1.6) Annual LBP duration range (8-30 days) ODI 21.2 (9.2)	Sensors were placed over T12, L3 and S2 using 3-Space® Fastrak™. Upper Lumbar (T12-L3),Lower Lumbar (L3-S2) and Total lumbar angles (T12-S2) were calculated.	Regional Lumbar spine (ULx and LLx) and Total lumbar.	The mean peak sagittal angles were calculated for the lifting tasks. The customised analysis software determined peak sagittal flexion angle reached between the manually tagged start and finish of the task. Range of motion from the reference position of usual standing to the peak angle in each functional task also calculated to compare relative motion between LLx and ULx regions during these tasks.	1. Pen lift. This test was performed once. 2. 5 kg Box lift. This and subsequent tasks were repeated three times. 3. Pillow transfer (asymmetrical lift). 4. 5 kg Box transfer (asymmetrical lift).	Low back pain did not modify regional differences in any lumbar spine angle or range of motion before or after adjustment for BMI. Repeated measures ANCOVA utilised for each posture or task. **Mean peak sagittal angle (Below data was obtained from author request)** **A more negative value signifies more flexed (Therefore reversed for Meta-Analysis to align with other studies where more flexed was a more positive value)** **In these data mild and significant LBP were re-coded at the individual patient level as any LBP.** **Upper Lumbar Comparisons** **Pen lift LBP -12.57 (6.53) vs Control -12.14 (5.64)** **5kg box lift LBP -8.27 (8.82) vs Control -9.15 (7.06)** **Pillow transfer LBP -4.47 (8.64) vs Control -5.75 (7.01)** **5kg box transfer LBP 2.03 (8.57) vs Control 0.42 (7.44)** **This data were pooled for Meta-Analysis (upper lumbar)** **Lower Lumbar Comparisons** **Pen lift LBP -7.93 (6.99) vs Control -8.55 (8.21)** **5kg box lift LBP -5.12 (8.26) vs Control -6.10 (9.06)** **Pillow transfer LBP 3.92 (8.39) vs Control 1.83 (8.98)** **5kg box transfer LBP 9.04 (8.93) vs Control 6.06 (8.72)** **This data were pooled for Meta-Analysis (lower lumbar)** **NB. Four lifting comparisons of Total lumbar angle also showed no differences between groups**	Did not present any raw data comparing groups as there were no differences.	No differences (0 of 12 comparisons) in regional lumbar position pain vs control.
Mitchell 2009	As in 2008 Paper for all boxes that are left blank				Lower Lumbar Spine	Mean peak sagittal angles and how far subjects held their LLx spine from their maximal end of range flexion angle during different lifting tasks (referred to as proximity to end of range).			Differences in this study are very small but some are statistically significant. Type 1 error? There seems to be a pattern where the significant LBP groups demonstrate a lifting technique that is consistently further from EOR lx flexion but around 2 degrees is not clinically meaningful.	7 of 24 comparisons showed a difference between groups for lower lumbar position when lifting. Significant LBP group tended to be further from their EOR lumbar position when lifting. NB. The data from this study contributed to the findings above and found no differences when combining pain groups vs control group (0 of 12 comparison) for mean peak sagittal angle.
Mitchell 2010 (longitudinal)	n = 117 initially (No/Mild LBP) 100% females n = 107 at 12 month follow up No/Mild LBP group n = 76 Significant LBP group n = 31 No/Mild LBP: Mean age 21.7 (3.7) 23.7% had a BMI over 25kg/m2 Significant LBP: Mean age 21.7 (4.5) 32.3% had a BMI over 25kg/m2	Female nursing students without significant LBP at baseline recruited via personal invitation from two undergraduate university nursing programs. Group inclusion as in 2008/2009. 3 out of 4 criteria cut off for development of significant LBP	No additional pain data.	As in 2008 and 2009	Regional Lumbar spine (Upper lumbar and Lower Lumbar)	As in 08	As in 08 except only for upper and lower lumbar.	10 lost to follow up (n = 107 at 12 months). 31 nursing students went on to develop Significant LBP in the 12 months post baseline. No significant differences in upper or lower lumbar spine position with any lifting task between groups. Control group = no/mild LBP and LBP group = group with significantly disabling LBP. Univariate differences were tested using binomial logistic regression. **A more negative value signifies more flexed (Therefore reversed for Meta-Analysis to align with other studies where more flexed was a more positive value)** **Upper Lumbar Comparisons** **Pen lift LBP -13.5 (5.50) vs Control -12.10 (6.30)** **5kg box lift LBP -10.50 (8.20) vs Control -8.10 (8.10)** **Pillow transfer LBP -5.40 (7.80) vs Control -4.20 (8.30)** **5kg box transfer LBP 0.90 (8.70) vs Control 2.30 (8.20)** **This data were pooled for Meta-Analysis (upper lumbar)** **Lower Lumbar Comparisons** **Pen lift LBP -8.90 (6.50) vs Control -8.50 (7.10)** **5kg box lift LBP -7.00 (8.00) vs Control -5.80 (7.70)** **Pillow transfer LBP 0.70 (7.10) vs Control 3.10 (8.40)** **5kg box transfer LBP 5.90 (7.30) vs Control 7.40 (9.20)** **This data were pooled for Meta-Analysis (lower lumbar)**	Mean peak regional lumbar spine lift position did not predict new onset significant LBP at 12 months.	No difference in lumbar spine position when lifting in those who went on to develop new onset significant LBP (0 of 8 comparisons).
O'Sullivan 2006	n = 45 LBP n = 24 Control n = 21 LBP: Mean age 38.79 (9.24) BMI 26.43 (2.86) 100% Male Control: Mean age 38.24 (9.33) Mean BMI 25.05 (3.32) 100% Male	1200 Industrial workers were contacted via email and invited to volunteer for the study if they fitted into the inclusion criteria for either the control or LBP group. Volunteers were screened for exclusion criteria, and then allocated to the appropriate group. All subjects were manual workers, engaged in similar work activities at the time of testing. LBP: Reported a flexion injury to the lumbar spine, with ongoing pain over the preceding 18 months related to flexion activities and/or postures related to their work. All LBP subjects were performing their pre-injury duties for at least 3 months prior to testing to ensure physical work conditioning matched with the control group. Control The control subjects were male with a minimum of 2 years continuous employment in an industrial workplace. They had no history of significant LBP requiring medical intervention or time off work, and no history of low back ache in the preceding 3 months. Subjects in the control group were matched to the LBP subjects on the basis that they engaged in the same kind of work activity.	Subjects with pain > 3/10 on VAS during testing were excluded. No other pain data provided.	Digital photographs were taken with a Canon Digital 0IUS V camera (2.1 mega pixels). Photo-reflective balls were taped to the bony land- marks of each subject's left anterior superior iliac spine (ASIS), greater trochanter midpoint, lateral femoral condyle, lateral malleolus, and the spinous processes of T10, L2, L4 and S2. The posture photos were imported into Scion Image (Scion Corporation, Fredrick, USA), an image-processing programme that measures angles between manually marked positions on a digital image.	Lumbar spine	Mean peak lumbar flexion angle. The lumbar angle was measured as the angle between the intersection of the tangents drawn through the T10/L2 markers and the L4/S2 markers.	The lifting task involved a 12 kg box with handles being lifted 5 cm off the floor.	No difference was observed between the two groups. **LBP 188.86 (12.29) Controls 192.17 (13.93) P = .56** **This data was utilised for Meta-Analysis.** Independent t tests.	Measurement device accuracy is questionable. Reliability data is available but unknown validity.	No difference in mean peak lumbar Flexion (0 of 1 comparisons) between groups.
Sanchez-Zuriaga 2011	n = 56 LBP n = 39 Control n = 16 Gender not known. LBP: Mean age 45 (11) Mean BMI 24.9 (3.0) Control: Mean age 39 (11) Mean BMI 25.0 (4.0)	Recruitment method not known. LBP: Primary LBP, without sciatica and neurologic deficits, with repeated episodes of pain on the lumbar region during the last month. Time off work due to LBP in the last 6 months. Control: No history of LBP. 0 disability on ODI.	Pain information not known. LBP group disability score 33.7 (13.2) on ODI. Control group disability 0 on ODI	Kinematic analysis was performed by 3D video photogrammetric system which includes four cameras Pulnix TM-6740CL with a resolution of 1024 × 768 pixels and a frequency of 50 Hz. Lumbar motion: angle formed by the intersection of the line between T12 and L3 markers and the line between L5 and sacrum.	Lumbar spine	Mean lumbar flexion range of motion during the lifting task. Unknown if from standing or flexion past the vertical?	Lifted three different weights (an empty box and the same box with 5 and 10 kg loads) from a standing position. The box to be lifted was placed on the floor just in front of them and delivered to a table to the participants right. Lifting tasks were divided in flexion and extension phases.	Mean Lumbar flexion ROM during lifting **5kg box - LBP 28.0 ± 8.2 Controls 38.1 ± 10.7 P = <.01** **5kg box - LBP 26.9 ± 8.3 Controls 41.1 ± 8.6 P = <.01** **10kg Box - LBP 27.0 ± 9.2 Controls 38.9 ± 10.7 P = <.01** **This data were pooled for Meta-Analysis.** MANOVA and Linear regression.	Risk of bias seems higher in this study pain levels, gender and recruitment unknown.	Controls utilised greater range of lumbar movement when lifting (flexed more).
Shojaei 2017	n = 38 LBP n = 19 Control n = 19 100% female LBP: Mean age 58 (9) Mean BMI 27.5 (4.6) Control: Mean age 56 (9) Mean BMI 25.7 (4.1)	Controls were recruited via advertisement not known where LBP group recruited from. LBP: Health-care provider diagnosed non- specific LBP. Excluded if their LBP had lasted more than 3 months Control: No history of LBP during the past year or musculoskeletal disorders.	LBP group 3.84 (2.09) for level of pain and is based on the pain intensity construct of Wisconsin Brief Pain Inventory. Uncertain if they had pain at the time of testing.	Straps were used to attach wireless Inertial Measurement Units (IMUs; Xsens Technologies, Enschede, Netherlands) superficial to the T10 vertebral process, sacrum (S1), right thigh (superior to lateral femoral epicondyle), and right shank (superior to lateral malleolus). IMUs placed at the T10 and the S1 levels were assumed to measure rotations of the thorax and pelvis as rigid bodies, while the difference between these rotations was considered to represent lumbar flexion/extension.	Lumbar spine	Mean Peak Lumbar spine flexion and Lumbar spine flexion at peak moment component.	Participants were asked to lower a 4.5 kg load from an upright posture to their knee height, pause for 5 s at this flexed posture, and then extend back to the initial upright standing posture.	**Mean peak lumbar flexion** **LBP group 32.6 (11) vs Control 51.4 (13.4) F=18.06 P < .001** **This data was utilised for Meta-Analysis.** Mean lumbar flexion at peak moment component LBP 30.0 (9.8) vs Control 42.9 (13.7) F = 9.45 and P = 0.005 Univariate ANOVA tests.	Patients with non-chronic LBP vs. controls adopt distinct trunk kinematics involving less lumbar flexion to perform lifting and lowering task.	Pain group less peak lumbar flexion and less flexed at peak moment.

Appendix 4: Example of the pooled mean and pooled standard deviation calculations used in the forest plot

Data from Sanchez-Zuriaga et al 2011

Object lifted	Comparison	LBP (n = 39)	(SD)	Control (n = 16)	(SD)
Empty box	Lumbar flexion during lifting (Degrees)	28.0	8.2	38.1	10.7
5kg Box	Lumbar flexion during lifting (Degrees)	26.9	8.3	41.1	8.6
10kg box	Lumbar flexion during lifting (Degrees)	27.0	9.2	38.9	10.7
	Mean	**27.3**	**8.5**	**39.3**	**10.0**

The pooled means and pooled standard deviations were used within the forest plot.

(1) Formula used for the pooled mean:
$[(mean_1 \times n_1) + (mean_2 \times n_2) + (mean_3 \times n_3) + \ldots.] / n_1 + n_2 + n_3 \ldots$
Where n = the sample size.
In this case where the n was the same across the pooled samples, this formula could be simplified to:
$[mean_1 + mean_2 + mean_3 + \ldots. + mean_k]$ / the number of means (lift types) that were pooled.

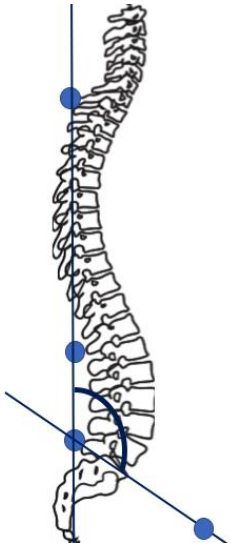
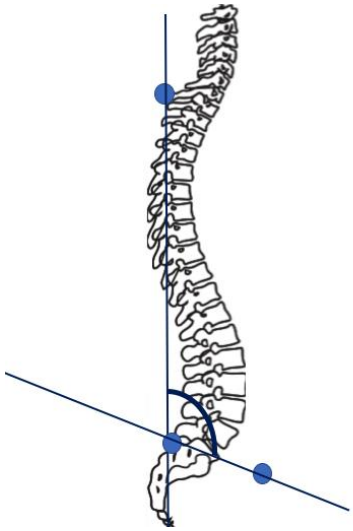
So, in this example: pooled mean = (28.0 + 26.9 + 27.0)/3 = 81.9/3 = 27.3

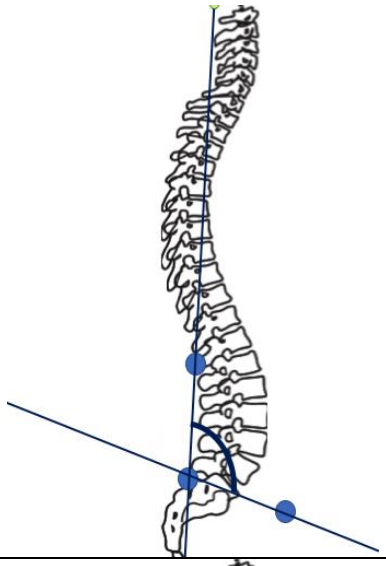
(2) Formula used for the pooled standard deviations (where the pooled samples had the same sample sizes):
Square root $[(sd_1^2 + sd_2^2 + sd_3^2 = \ldots + sd_k^2)$ / the number of sd (lift types) that were pooled]

So, in this example: pooled standard deviation = Square root [(10.7x10.7 + 8.6x8.6 + 10.7x10.7)/3] = Square root of 101.0 = 10.0

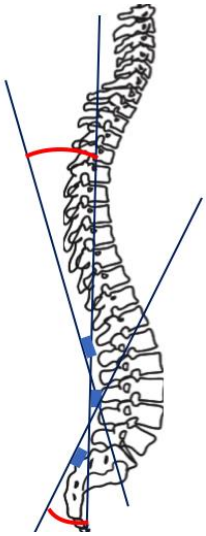
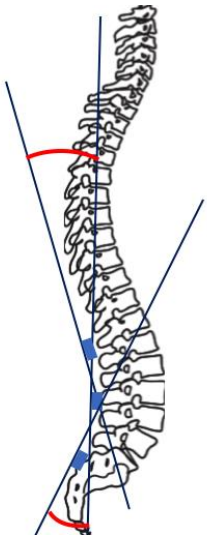
Reference;
Cohen, J. (1988), Statistical Power Analysis for the Behavioral Sciences, 2nd Edition. Hillsdale: Lawrence Erlbaum.

Appendix 5 – Lumbar flexion data capture representations

Study	Representative image of data capture in studies that measured <u>Thoraco-pelvic angles</u>
Commissaris et al 2002	Peak angle at box lift off LBP – 81.0 (7.7) Control – 78.3 (11.3) 
Lariviere et al 2002	Change in angle from upright standing to box lift off LBP - 41.5 (7.2) Control – 43.7 (7) 

Marich et al 2018	Change in angle from start of trunk flexion to end of trunk flexion LBP – 18.5 (5.8) Control – 18.6 (7.7)	
Marras et al 2001	Sagittal trunk position (Unknown if peak or change in angle) LBP – 22.5 (17.8) Control – 27.31 (20.84)	
O'Sullivan et al 2006	Peak angle at box lift off LBP – 189.8 (12.2) Control – 192.1 (13.9)	

Sanchez-Zuriaga et al 2011	Change in angle from start of trunk flexion to box lift off LBP – 27.3 (8.5) Control – 39.3 (10.0) 
Shojaei et al 2017	Difference between peak thoracic and peak sacral sensor = peak lumbar angle LBP - 32.6 (11) Control – 51.4 (13.4) 
Study	**Representative image of data capture in studies that measured <u>Intra-lumbar angles</u>**
Gombatto et al 2017	Difference between maximal and minimal angle was calculated for each lumbar region during lifting <u>Lower Lumbar region</u> LBP – 32.4 (11) Control – 39 (11.5) <u>Upper Lumbar region</u> LBP – 29.2 (8.5) Control – 25.4 (11.1) 

Hemming et al 2017	Difference between maximal and minimal angle was calculated for each lumbar region relative to the adjacent region during lifting <u>Lower Lumbar region</u> LBP – 0.3 (16) Control – 3 (12.5) <u>Upper Lumbar region</u> LBP – 4.9 (8.1) Control – 4.6 (7.1)	
Mitchell et al 2008/09	Lower lumbar peak flexion angle derived by inclination of L3 sensor relative to S2 sensor during lifting <u>Lower lumbar region</u> LBP - 0 (8.1) Control – 1.6 (8.7) Upper lumbar peak flexion angle derived by inclination of T12 sensor relative to L3 sensor during lifting <u>Upper lumbar region</u> LBP - 5.8 (8.1) Control – 6.6 (6.7)	
Mitchell et al 2010	Lower lumbar peak flexion angle derived by inclination of L3 sensor relative to S2 sensor during lifting <u>Lower lumbar region</u> LBP – 2.3 (7.2) Control – 0.9 (8.1) Upper lumbar peak flexion angle derived by inclination of T12 sensor relative to L3 sensor during lifting <u>Upper lumbar region</u> LBP – 7.1 (7.5) Control – 5.5 (7.7)	

*All data are mean (SD) for each group in degrees.
** Data metric in Dideriksen et al is dissimilar to these studies and therefore has not been represented.

Appendix 6 – Detailed synthesis of study findings

Study findings – Longitudinal study

Peak lumbar spine flexion during lifting at baseline was not a predictor of the incidence of disabling LBP at 12 months follow up (n = 107).[32] In this study, female nurses without disabling LBP at baseline performed symmetrical lifts of a pen and a 5kg box from the floor, and asymmetrical lifts of a pillow and a 5kg box from mid-thigh height. There were no differences in peak lumbar spine flexion with any lift type, at either the upper or lower lumbar spine between nurses who subsequently developed disabling LBP and those that did not. This longitudinal study, and the cross-sectional study also by Mitchell et al,[33,34] were of higher quality as compared to other studies in this review (Appendix 7).

Study findings – Cross-sectional studies

Only two of the 43 comparisons from all the included cross-sectional studies indicated that the LBP group displayed greater peak lumbar flexion when lifting (see Appendix 3). Seven of the 43 comparisons displayed less lumbar flexion in the LBP group during lifting. Most (34/43) of the findings indicated that there was no difference between how participants with and without LBP positioned their lumbar spine when lifting.

Cross-sectional studies – Intra-lumbar angles

Four studies[17,20,21,33,34] provided a more precise estimate of lumbar spine flexion and had lower risk of bias compared to the other cross-sectional studies.[15,27-29,39,42,43] There were differences across these studies in measurement device, mass of the object lifted (pen – 5kg box), marker set position and the requirements of the lifting task. Despite the diversity across studies, the findings were consistent. Only Gombatto et al[20] (2 of 18 comparisons across studies) found a significant difference between groups with and without LBP (more flexed

upper lumbar and less flexed lower lumbar in people with LBP). No other study found a significant difference where the LBP group displayed greater lumbar flexion during lifting.

Cross-sectional studies – Thoraco-pelvic angles

Between group comparisons of people with and without LBP in three (Marras et al,[29] Shojaei et al[43] and Sanchez et al[42]) of these six studies all showed (6 of 6 comparisons) a consistent difference where the LBP group demonstrated significantly *less* peak lumbar spine flexion when lifting than the group without LBP. The mass of the object lifted in these studies ranged between an empty box and a 11.4kg box. These studies were of lower quality as all three studies did not account for or identify confounders, inadequately described the methodology and there was questionable validity of the measurement tool used to infer lumbar spine flexion.

The studies by Lariviere et al[27] and O'Sullivan et al,[39] showed no differences in lumbar spine flexion between groups for any lifting comparison (0 of 9). These studies were also of lower quality due to limitations in the validity of the lumbar spine flexion measurement. For example, the study by O'Sullivan et al[39] used a 2D analysis of photographs of lumbar spine peak flexion, where anatomical markers were placed at T10, L2, L4 and S2. Lumbar flexion was calculated by the intersection of the tangents drawn through the T10/L2 markers and the L4/S2 markers (see Appendix 4). In Lariviere et al,[27] the anatomical marker set was placed at C7, L5 and the iliac crest. Therefore, the estimates of peak lumbar flexion are less valid in these studies, as the marker sets do not accurately capture lumbar spine movement.

Commissaris et al[15] was the only other study to demonstrate significantly greater lumbar spine flexion between groups with and without LBP during lifting (126.3 degrees (SD16.8)

LBP vs 109.0 degrees (SD12.3) no LBP, p=.031) but only in 1 of 5 comparisons. However, this outlier finding was only produced when the researchers altered the relative pelvis segment to include a greater trochanter marker, which confounds the measurement of lumbar spine flexion by introducing hip movement into the measurement (anatomical marker set at C7, T12, L5 and the greater trochanter).

					Critical Appraisal Criteria										
	1	2	3	4	5	6	7	8	9	10	11	12	Study level quality score	Rationale for overall classification of each study	
Author															
Commissaris et al 2002	x	x	x	x	x	x	x				x		Low	Extra weighting was placed on item 8 (has the measurement tool which was used for assessing lumbar kinematics been validated?) and item 9 (were lumbar kinematics measured in a way that is equivalent to a known 'gold standard' for motion analysis?) of the critical appraisal assessment. The reason was that, in the context of this systematic review, those items carry particular risk to the internal validity of the study because they are central to the measurement of the 'exposure' (lumbar spine kinematics).	
Dideriksen et al 2014	x	x	x	x	x	x	x	x		x	x	x	Moderate		
Gombatto et al 2017	x		x	x	x	x	x	x	x	x	x	x	High		
Hemming et al 2017		x		x	x	x		x	x	x	x	x	High		
Lariviere et al 2002	x		x	x	x	x	x	x			x	x	Low		
Marich et al 2018	x		x	x	x	x	x	x		x	x	x	Moderate		
Marras et al 2001						x		x		x	x	x	Low		
Mitchell et al 2008/09 (cross-sectional)	x	x	x	x	x	x	x	x	x	x	x	x	High		
Mitchell et al 2010 (longitudinal)	x	x	x	x	x	x	x	x	x	x	x	x	High		
O'Sullivan et al 2006	x	x	x			x	x	x		x	x	x	Low		
Sanchez-Zuriaga et al 2011	x									x	x	x	Low		
Shojaei et al 2017	x	x		x	x	x	x	x		x	x	x	Low		
Totals by question	**83%**	**58%**	**67%**	**75%**	**75%**	**92%**	**75%**	**83%**	**33%**	**83%**	**100%**	**92%**	**Low**		