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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

OBJECTIVE: To evaluate whether lumbar spine flexion during lifting is a risk factor for low back pain (LBP) onset/persistence or a differentiator of people with and without LBP.

DESIGN: Etiology systematic review with meta-analysis.

LITERATURE SEARCH: Database search of ProQuest, CINAHL, MEDLINE, and Embase up to August 21, 2018.

STUDY SELECTION CRITERIA: We included peer-reviewed articles that investigated whether lumbar spine position during lifting was a risk factor for LBP onset or persistence or a differentiator of people with and without LBP.

DATA SYNTHESIS: Lifting-task comparison data were tabulated and summarized. The meta-analysis calculated an n-weighted pooled mean ± SD of the results in the LBP and no-LBP groups. If a study contained multiple comparisons (ie, different lifting tasks that used various weights or directions), then only 1 result from that study was included in the meta-analysis.

RESULTS: Four studies (1 longitudinal study and 3 cross-sectional studies across 5 articles) included in meta-analysis measured lumbar flexion with intralumbar angles and found no difference in peak lumbar spine flexion when lifting (1.5°; 95% confidence interval [CI]: −0.7°, 3.7°; P = .19 for the longitudinal study and −0.9°; 95% CI: −2.5°, 0.7°; P = .29 for the cross-sectional studies). Seven cross-sectional studies measured lumbar flexion with thoracopelvic angles and found that people with LBP lifted with 6.0° less lumbar flexion than people without LBP (95% CI: −11.2°, −0.9°; P = .02). Most (9/11) studies reported no significant between-group differences in lumbar flexion during lifting. The included studies were of low quality.

CONCLUSION: There was low-quality evidence that greater lumbar spine flexion during lifting was not a risk factor for LBP onset/persistence or a differentiator of people with and without LBP.
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KEY WORDS: *lift, manual handling, posture*

Back pain is the leading cause of disability globally, and work-related low back pain (LBP) accounts for an estimated annual loss of 818 000 disability-adjusted life-years.[5,6,20,41] Lifting is a common risk factor for the development and exacerbation of LBP.[12,14,45,46] It is believed that lifting with a flexed lumbar spine has a causative role in lifting-related LBP,[16,39] and that lifting-related LBP is due to the combined angular (kinematic) position and load (kinetic force) on the lumbar spine.[1]

Workplace health and safety personnel and health care practitioners commonly advise that increased flexion (kyphotic curvature) of the lumbar spine should be avoided when lifting, and that 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 worldwide.[24,32,45] Health care practitioners advocate the practice of keeping a straight back to reduce lumbar flexion when lifting.[39] Critically, implementing lifting advice in health care and the workplace has not been accompanied by reduced occupational LBP.[32] Such lifting advice was based on cadaveric studies that found the lumbar spine to be susceptible to failure when repeatedly flexed and weaker when flexion and compression are combined.[2,19,31,37] However, we do not fully understand how applicable the findings of these cadaveric studies are to real-life lifting situations.

Early in vivo work has demonstrated higher lumbar intradiscal pressure during

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forward bending of the trunk or when a load was lifted.[38,48] A limitation of the in vivo studies was that they did not consider lumbar spine curvature during lifting and were conducted without comparing groups with and without LBP. Spinal loads are similar when lifting with a flexed spine compared 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.[12,13,23]

Therefore, we aimed to evaluate (1) whether lumbar spine flexion during lifting was a risk factor for LBP onset and/or persistence and (2) whether lumbar spine flexion during lifting was different in people with and without LBP.

METHODS

The review protocol was prospectively registered in PROSPERO (CRD42017075661). A meta-analysis was added to the registered protocol when, after data extraction, the data were found to be suitable for meta-analysis.

Eligibility Criteria

Included studies (1) measured lumbar spine position with a marker set that identified 2 or more separate anatomic regional landmarks to allow calculation of lumbar spinal inclination relative to the vertical/horizontal, or lumbar spine angulation, or inclination relative to the pelvis; (2) measured lumbar spine position during natural/unconstrained lifting of an external load; (3) 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 (4) were published in the 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 August 21, 2018 (see search strategy in **APPENDIX A**, available at www.jospt.org). 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 2 authors independently (N.S. and L.N.), with assistance from a senior health faculty librarian. Any discrepancies were first discussed, and, if needed, any disagreement was resolved by a third reviewer (P.K.).

Quality Assessment

A modified critical appraisal checklist (**APPENDIX B**, available at www.jospt.org)[36] was used to assess and summarize quality at both individual study and domain levels. The basis for a study to be classified as low, moderate, or high quality depended on scores across the 12 domains. In this systematic review, we afforded more weight to domains 8 (Has the measurement tool used for assessing lumbar kinematics been validated?) and 9 (Were lumbar kinematics measured in a way that is equivalent to a known gold standard for motion analysis?) than to the other 10 domains, which focused on assessing risks to internal validity (ie, bias), as they measured aspects of exposure (lumbar spine kinematics). The assessment of study quality was performed by 2 authors (N.S. and L.N.), using a third author (P.K.) to resolve disagreements.

We used the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach[4] to assess the quality and summarize overall certainty of the body of evidence included in our systematic review. The included studies were cross-sectional and nonrandomized longitudinal studies, study designs that are considered to provide "low-quality" evidence, according to the GRADE guidelines. The other criteria set by the GRADE were then used to upgrade or downgrade certainty.

TABLE 1 Inclusion and Exclusion Criteria for the Screening Process

Inclusion Criteria	Exclusion Criteria
1. Measured the lumbar spine using any type of marker set that identified 2 or more separate anatomic regional landmarks that allowed a. 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. Calculation of the lumbar spine relative to the pelvis (lumbar spine angulation or inclination, either 2 segments or more) So that the measurement of spine inclination was relative to the vertical/horizontal or the spine was flexed relative to the pelvis or hips	• Used 0 to 1 markers on the spine or self-reported measures of lumbar spine position
2. Had an LBP group or examined LBP in some way as a result of lifting	• Specific back pain, radiculopathy, nerve root irritation, spinal stenosis, rheumatologic/inflammatory (eg, rheumatoid arthritis) or neurological conditions (eg, multiple sclerosis)
3. Participants must have been lifting an external load during the measurement period. There were no upper or lower load limits on the weight of the external load participants lifted	• Functional tasks in any sport other than weightlifting
4. Must have been relevant to the question of whether the position of the lumbar spine during lifting was either a. A risk factor for pain onset or pain persistence (longitudinal studies), or b. A differentiator of people with and without LBP (cross-sectional)	• 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 • Participants were pregnant, had a lower-limb amputation, or had 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

Abbreviation: LBP, low back pain.

Data Extraction

The following data were extracted from each included study: (1) title, year, author, type of study; (2) type and duration of intervention, sample size, and participant characteristics (sex, age, course of LBP, pain intensity, previous episodes, recruitment period, selection criteria, context); (3) measures of lumbar kinematics, follow-up periods, and loss to follow-up; and (4) relevant results. Data extraction was conducted by 2 authors independently (N.S. and L.N.) and later checked for similarity.

Data Synthesis

One longitudinal study[33] combined data from people with no LBP-related and mild LBP-related disability, having found at baseline no differences in the movement characteristics of those without LBP and those with mild LBP. The combined group of those with no LBP and mild LBP was compared to a group with significantly disabling LBP, a contrast that we preserved in the analysis.

Two cross-sectional studies[34,35] reported a no-LBP group and 2 pain subgroups. For meta-analysis, we combined the results of the pain subgroups. In 2 studies,[34,35] different lifting comparisons were recorded using the same cohort and were therefore pooled. Where necessary, we contacted authors[17,21,22,31,34] to clarify data. Some authors[22,34] provided additional data for meta-analysis. We estimated upper and lower lumbar sagittal plane degrees of flexion from 1 study[21] by direct measurement of an enlarged version of the published graph of the results, using the Adobe Acrobat measurement tool (Adobe Inc, San Jose, CA).

Lifting-task comparisons were tabulated and summarized (**SUPPLEMENTAL DATA FILE**, available at www.jospt.org). For meta-analysis, we calculated an n-weighted pooled mean ± SD of the results for the LBP and no-LBP groups. When a study contained multiple comparisons, such as different lifting tasks that used various weights or directions,[28] the means and SDs of those tests were pooled to create a single result for each study to be included in the forest plot (see **APPENDIX C**, available at www.jospt.org, for an example).

The meta-analysis was performed in Review Manager 5.3 (The Nordic Cochrane Centre, Copenhagen, Denmark), using a random-effects model. We analyzed lumbar angles for the upper and lower spinal regions separately, as these regions may move differently.[34] When a study's reported data were not suitable for the meta-analysis and requests for necessary data from the authors were not answered, we excluded the study from meta-analysis.

There were 2 main methods of measuring "lumbar spine flexion" (see **APPENDIX D**, available at www.jospt.org). Method 1 involved applying markers or sensors on the skin overlying thoracic spine and pelvis landmarks (thoracopelvic angles; used in 7 studies).[15,27,29,31,40,42,43] Where authors included 2 or more different measures of lumbar spine position during lifting (eg, a thoracopelvic angle and a measure of trunk inclination relative to the vertical), we used the thoracopelvic angles for meta-analysis, as they more accurately reflect lumbar flexion.[15,27] Method 2 involved multiple markers or sensors placed on the skin overlying the lumbar spine region (intralumbar angles).[17,21,22,33-35]

For the meta-analysis, we subgrouped data based on quality of the measurement of lumbar spine flexion (intralumbar being of higher quality than thoracopelvic). Instead of weighting these studies in the meta-analysis, we presented them as separate subgroups. Heterogeneity was assessed using the I^2 statistic. We presented longitudinal and cross-sectional studies, being conceptually different, as separate subgroups.

RESULTS

The search yielded 2289 studies after duplicates were removed. We excluded 2255 studies based on title and abstract. Thirteen papers from 12 independent studies, with 697 total participants, met the inclusion criteria. Mitchell et al[34,35] reported results from the same cohort; therefore, the results were combined. One longitudinal and 11 cross-sectional studies (13 articles)

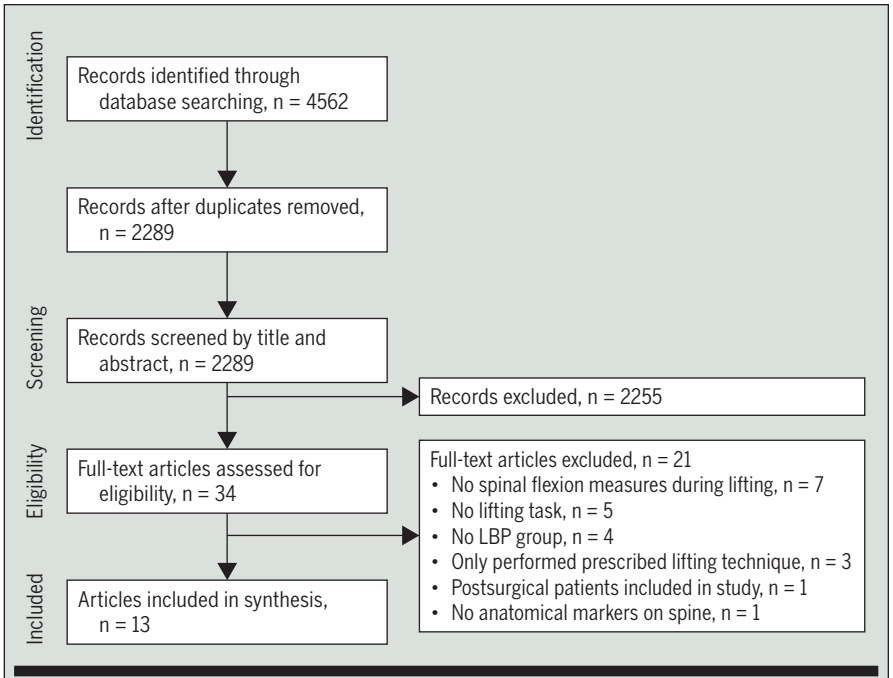


FIGURE 1. PRISMA flow diagram of the article-screening process up to August 21, 2018. Abbreviation: LBP, low back pain.

met the inclusion criteria (**FIGURE 1**). The characteristics of included studies are summarized in **TABLE 2** and detailed in the **SUPPLEMENTAL DATA FILE**, including the descriptions of study populations.

Meta-analysis

Four studies (1 longitudinal study[33] and 3 cross-sectional studies across 5 articles[17,21,22,34,35]) measured lumbar flexion with intralumbar angles. There were no differences in peak lumbar spine flexion when lifting (longitudinal study, 1.5°; 95% confidence interval [CI]: −0.7°, 3.7°; P = .19 and cross-sectional studies, −0.9°; 95% CI: −2.5°, 0.7°; P = .29) and no significant heterogeneity (I^2 = 0% and 3%, respectively) (**FIGURE 2**).

Seven cross-sectional studies measured lumbar flexion with thoracopelvic angles. People with LBP lifted with 6.0° less lumbar flexion than people without LBP (95% CI: −11.2°, −0.9°; P = .02). There was substantial heterogeneity (τ^2 = 34.4, P<.01, I^2 = 76%). We did not conduct sensitivity analyses because results across studies

TABLE 2 Characteristics of the Included Studies

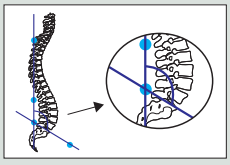
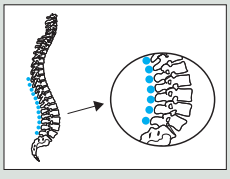
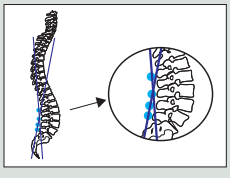
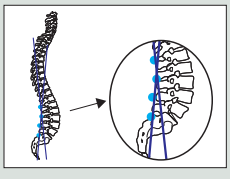
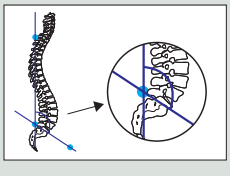
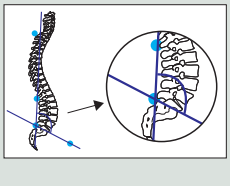
Study/Design	Sample Source	Sample Size, Sex, Age, BMI[a]	LBP at Time of Testing	Levels of Pain and Disability in LBP Group[a]	Measurement Device, Lumbar Spine Marker/Sensor Placement, Lifted Object	Schematic of Lumbar Spine Markers/Sensors
Commissaris et al[15] Cross-sectional	Postpregnancy exercise class	n = 16 (LBP, 7; control, 9); 100% female LBP: age, 33.4 ± 3.6 y; BMI, 22.3 ± 3.0 kg/m^2 Control: age, 34 ± 3.4 y; BMI, 22.9 ± 2.9 kg/m^2	Yes	Pain: median baseline VAS pain, 2.7 (0.2-9.8) Disability: median Disability Rating Index, 2.9 (1.0-6.9)	2-camera optoelectronic system C7, T12, L5, ASIS, and greater trochanter 8.3-kg box	
Dideriksen et al[17] Cross-sectional	Pain clinic, GPs, or advertising	n = 34 (LBP, 17; control, 17); 59% female (LBP) and 53% female (control) LBP: age, 32.5 ± 9.6 y; BMI, 23.6 kg/m^2 Control: age, 29.7 ± 7.3 y; BMI, 22.5 kg/m^2	Yes	Pain: baseline NRS, 1.8 ± 1.5 Disability: ODI, 14.2% ± 7.2%	Epionics SPINE 12 angle sensors (25 mm) along the spine, starting at the PSIS 5-kg box	
Gombatto et al[21] Cross-sectional	Orthopaedic clinic	n = 35 (LBP, 18; control, 17); 61% female (LBP) and 59% female (control) LBP: age, 28.1 ± 13.1 y; BMI, 24.4 ± 2.9 kg/m^2 Control: age, 25.6 ± 8.7 y; BMI, 25.2 ± 3.5 kg/m^2	Yes	Pain: baseline NRS, 2.1 ± 1.9 Disability: modified ODI, 18% ± 12.7%	9-camera 3-D Vicon[b] L1, L3, L4, and L5 Light digital metronome	
Hemming et al[22] Cross-sectional	University health boards	n = 78 (LBP, 50; control, 28); 50% female (LBP) and 52% female (control) LBP: age, 42.2 ± 10.5 y; BMI, 22.2 ± 4.2 kg/m^2 Control: age, 38.5 ± 11.2 y; BMI, 21.5 ± 4.1 kg/m^2	Yes	Pain: baseline VAS, 4.5 ± 1.4 Disability: ODI, 22% ± 11.28%	8-camera 3-D Vicon[b] T12, L2, L4, and PSIS Pen and 2.5-kg box	
Larivière et al[27] Cross-sectional	Unknown	n = 33 (LBP, 15; control, 18); 0% female LBP: age, 39 ± 3 y; BMI, 23.2 ± 2.3 kg/m^2 Control: age, 40 ± 4 y; BMI, 24.2 ± 2.6 kg/m^2	Yes	Pain: lifting VAS, 2.6 ± 2.7 Disability: unknown	5-camera 2-D motion capture C7, L5, and midpoint of the pelvic crest 12-kg box	
Marich et al[29] Cross-sectional	Advertisements	n = 42 (LBP, 26; control, 16); 58% female (LBP) and 63% female (control) LBP: age, 38.5 ± 12.3 y; BMI, 24.0 ± 2.6 kg/m^2 Control: age, 37.4 ± 11.0 y; BMI, 23.6 ± 2.4 kg/m^2	Yes	Pain: baseline NRS, 3.0 ± 1.0 Disability: modified ODI, 24.2% ± 12.8%	8-camera 3-D Vicon T12 and S1 Lightweight box	

Table continues on page 125.

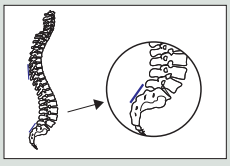
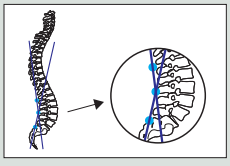
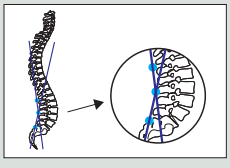
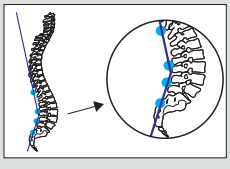
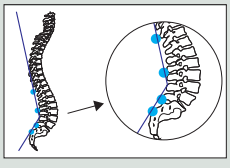
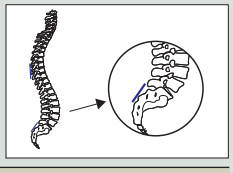
were consistent. For description of the individual study results, see **APPENDIX E** (available at www.jospt.org).

Quality Assessment

The quality assessment information at domain level is summarized in **TABLE 3**. The full detail is reported in **APPENDIX B** and **APPENDIX F** (available at www.jospt.org) and informed the GRADE quality assessment.

The methods of the 12 included studies were diverse, with disparate capture devices used to measure lumbar spine position during lifting tasks, each with different measurement system errors. Four studies measured lumbar spine flexion using a method that has been validated against a known gold standard for laboratory-based motion capture.[21,22,33-35] For this reason, the quality of evidence from these studies is higher than that from the other studies in this review. These 4 studies and the study by

TABLE 2 Characteristics of the Included Studies (continued)

Study/Design	Sample Source	Sample Size, Sex, Age, BMI[a]	LBP at Time of Testing	Levels of Pain and Disability in LBP Group[a]	Measurement Device, Lumbar Spine Marker/Sensor Placement, Lifted Object	Schematic of Lumbar Spine Markers/Sensors
Marras et al[31] Cross-sectional	Orthopaedic clinic	n = 44 (LBP, 22; control, 22); 45% female LBP: age, 39.0 ± 10.1 y; BMI, 31.3 kg/m^2 Control: age, 36.4 ± 11.1 y; BMI, 25.4 kg/m^2	Yes	Pain: baseline NRS, 4.8 Disability: unknown	Lumbar motion monitor (triaxial electrogoniometer) Thoracic spine and sacrum 4.5-, 6.8-, 9.1-, and 11.4-kg weights	
Mitchell et al[34,35] Cross-sectional	University nursing programs	n = 170 (LBP, 134; control, 36); 100% female LBP: age, 22.7 ± 4.5 y; BMI, 23.2 ± 3.9 kg/m^2 Control: age, 21.7 ± 3.5 y; BMI, 21.9 ± 2.8 kg/m^2	Unknown	Pain: VAS at pretesting, <3/10 Disability: ODI, 14.6% ± 7.7%	Polhemus 3SPACE and FASTRAK[b] T12, L3, and S2 Pen, pillow, and 5-kg box	
Mitchell et al[33] Longitudinal	University nursing programs	n = 107 (LBP, 31; control, 76); 100% female LBP: age, 21.7 ± 4.5 y Control: age, 21.7 ± 3.7 y	Unknown	Pain: unknown Disability: significant (definition in article)	Polhemus 3SPACE and FASTRAK[b] T12, L3, and S2 Pen, pillow, and 5-kg box	
O'Sullivan et al[40] Cross-sectional	Industrial workers	n = 45 (LBP, 24; control, 21); 0% female LBP: age, 38.7 ± 9.2 y; BMI, 26.4 ± 2.8 kg/m^2 Control: age, 38.2 ± 9.3 y; BMI, 25.0 ± 3.3 kg/m^2	Unknown	Pain: VAS at pretesting, <3/10 Disability: unknown	Canon Digital IXUS V camera T10, L2, L4, and S2 12-kg box	
Sánchez-Zuriaga et al[42] Cross-sectional	Unknown	n = 55 (LBP, 39; control, 16); sex unknown LBP: age, 45 ± 11 y; BMI, 24.9 ± 3.0 kg/m^2 Control: age, 39 ± 11 y; BMI, 25.0 ± 4.0 kg/m^2	Unknown	Pain: unknown Disability: ODI, 33.7% ± 13.2%	4-camera 3-D video (Pulnix TM-6740CL) T12, L3, L5, and sacrum Empty box, 5-kg box, and 10-kg box	
Shojaei et al[43] Cross-sectional	Unknown	n = 38 (LBP, 19; control, 19); 100% female LBP: age, 58 ± 9 y; BMI, 27.5 ± 4.6 kg/m^2 Control: age, 56 ± 9 y; BMI, 25.7 ± 4.1 kg/m^2	Unknown	Pain: WBPI pain intensity, 3.84 ± 2.0 Disability: RMDQ, 6.1 ± 4.5	2 Xsens Technologies IMUs T10 and S1 4.5-kg weight	

Abbreviations: ASIS, anterior superior iliac spine; BMI, body mass index; GP, general practitioner; IMU, inertial measurement unit; LBP, low back pain; NRS, numeric rating scale (0-10); ODI, Oswestry Disability Index (0%-100%); PSIS, posterior superior iliac spine; RMDQ, Roland-Morris Disability Questionnaire (0-24); VAS, visual analog scale (0-10); WBPI, Wisconsin Brief Pain Inventory (0-10).

[a]*Values are mean or mean ± SD unless the median (range) is stated.*

[b]*Gold standard measure for lumbar spine motion analysis.*

Dideriksen et al[17] measured intralumbar angles, but with varying motion-capture devices, lumbar marker positioning, and validity of lumbar spine flexion measurement.[17,21,22,33-35]

In 7 studies, it was not possible to accurately estimate lumbar spine flexion (ie, kyphosis between L1 and L5) because marker or sensor locations were more indicative of trunk flexion relative to the pelvis (thoracopelvic angles).[15,27,29,31,40,42,43] The study populations in these studies were also poorly described, including an absence of recruitment details,[27,29,42,43] ambiguous inclusion criteria of the LBP group,[15,31] and no disability measures for the LBP group.[15,27,31,40] Sample sizes of studies in this review were similar to many motion-analysis studies, but only 5 studies reported any type of power calculation.[21,22,29,34,35,40] The quality of the individual included studies ranged from low to high (**APPENDIX F**).

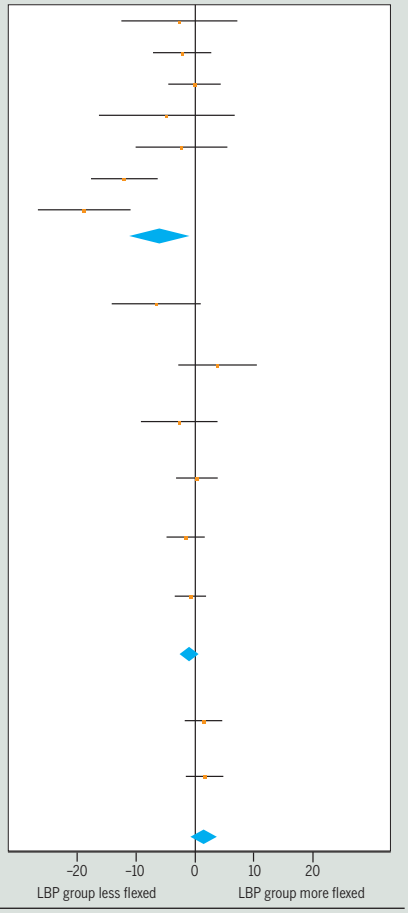
Certainty of Evidence: Summary of GRADE Results

We rated the overall quality of the body of evidence in the review as "low," which the GRADE approach defines as "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 cur-

Lumbar Flexion During Lifting

	LBP Group		Control Group			
Subgroup/Study	**Mean ± SD deg**	**Total, n**	**Mean ± SD deg**	**Total, n**	**Weight**	**MD IV, Random (95% Confidence Interval)**
Cross-sectional: thoracopelvic						
Commissaris et al[15]	78.3 ± 11.3	7	81 ± 7.7	9	3.6%	−2.70 (−12.47, 7.07)
Larivière et al[27]	41.5 ± 7.2	15	43.7 ± 7.0	18	7.3%	−2.20 (−7.07, 2.67)
Marich et al[29]	18.5 ± 5.8	26	18.6 ± 7.7	16	7.8%	−0.10 (−4.48, 4.28)
Marras et al[31]	22.5 ± 17.8	22	27.3 ± 20.8	22	2.9%	−4.80 (−16.24, 6.64)
O'Sullivan et al[40]	189.8 ± 12.2	24	192.1 ± 13.9	21	4.8%	−2.30 (−9.99, 5.39)
Sánchez-Zuriaga et al[42]	27.3 ± 8.5	39	39.3 ± 10.0	16	6.6%	−12.00 (−17.58, −6.42)
Shojaei et al[43]	32.6 ± 11.0	19	51.4 ± 13.4	19	4.8%	−18.80 (−26.60, −11.00)
Subtotal[a]		152		121	37.8%	−6.04 (−11.18, −0.89)
Cross-sectional: intralumbar						
Gombatto et al[21] (lower lumbar spine)	32.4 ± 11.0	18	39.0 ± 11.5	17	5.0%	−6.60 (−14.06, 0.86)
Gombatto et al[21] (upper lumbar spine)	29.2 ± 8.5	18	25.4 ± 11.1	17	5.7%	3.80 (−2.78, 10.38)
Hemming et al[22] (lower lumbar spine)	0.3 ± 16.0	50	3.0 ± 12.5	28	5.8%	−2.70 (−9.11, 3.71)
Hemming et al[22] (upper lumbar spine)	4.9 ± 8.1	50	4.6 ± 7.1	28	8.8%	0.30 (−3.16, 3.76)
Mitchell et al[34,35] (lower lumbar spine)	0.0 ± 8.1	134	1.6 ± 8.7	36	9.1%	−1.60 (−4.76, 1.56)
Mitchell et al[34,35] (upper lumbar spine)	5.8 ± 8.1	134	6.6 ± 6.7	36	9.7%	−0.80 (−3.38, 1.78)
Subtotal[b]		404		162	44.0%	−0.88 (−2.51, 0.74)
Longitudinal: intralumbar						
Mitchell et al[33] (lower lumbar spine)	2.3 ± 7.2	31	0.9 ± 8.1	76	9.1%	1.40 (−1.72, 4.52)
Mitchell et al[33] (upper lumbar spine)	7.1 ± 7.6	31	5.5 ± 7.7	76	9.1%	1.60 (−1.57, 4.77)
Subtotal[c]		62		152	18.2%	1.50 (−0.73, 3.72)



[a]*Heterogeneity: τ^2 = 34.38, χ^2 = 24.84, df = 6 (P<.001), I^2 = 76%. Test for overall effect: z = 2.30 (P = .02).*
[b]*Heterogeneity: τ^2 = 0.14, χ^2 = 5.16, df = 5 (P = .40), I^2 = 3%. Test for overall effect: z = 1.07 (P = .29).*
[c]*Heterogeneity: τ^2 = 0.00, χ^2 = 0.01, df = 1 (P = .93), I^2 = 0%. Test for overall effect: z = 1.32 (P = .19).*
Abbreviations: IV, inverse variance; LBP, low back pain; MD, mean difference.

FIGURE 2. Meta-analysis of studies comparing lumbar flexion during lifting in people with and without LBP. Negative values, reported in Mitchell et al[33-35] for greater lumbar flexion, have been reversed for uniformity in this forest plot.

vature (thoracopelvic angles), a measurement system that was not adequately validated, and the methodological quality of the included studies was usually low. We judged inconsistency to be low for the cross-sectional and longitudinal intralumbar results due to low statistical heterogeneity in the meta-analyses. Among the cross-sectional studies that reported thoracopelvic angles, there was significant statistical heterogeneity (I^2 = 76%, P<.001) in the meta-analysis, indicating inconsistency of the effect size. None of the included studies showed unequivocal evidence of an association between lifting with a more flexed lumbar position and LBP. There was little indirectness, beyond the previously mentioned use of thoracopelvic angles. For imprecision, we noted that 4 of 15 results from the meta-analysis favored greater flexion in the LBP group and had 95% CIs that substantially crossed zero, indicating considerable uncertainty in the estimate. Sample sizes were small in comparison to most trials of treatment effect, but small samples are common in biomechanical studies because repeated measures (repetitions) increase statistical power. We judged publication bias to be unlikely, having found no unequivocal evidence of an association between LBP and lumbar flexion during lifting.

DISCUSSION

There was low-quality evidence of no longitudinal relationship between greater lumbar spine flexion during lifting and LBP onset or persistence. There was low-quality evidence of no cross-sectional relationship between greater lumbar spine flexion during lifting and LBP. Only 2 of 43 comparisons reported greater lumbar flexion in people with LBP: one cross-sectional study that measured intralumbar angles found that in the LBP group, upper lumbar spine flexion was 4° greater but lower lumbar spine flexion was less[21]; another study[15] with a high risk of bias (a less accurate measure of lumbar spine flexion) found greater lumbar spine flexion in only 1 of 5 between-group comparisons.

There is no credible in vivo evidence to support the dogma[10,11,39] that lumbar spine flexion should be minimized when lifting to prevent LBP onset, persistence, or recurrence. More comparisons found that 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 loading of the lumbar spine may be a risk factor in both the onset and persistence of LBP,[12,47] 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 when lifting with a flexed spine versus a straight spine.[18,25,44] Previous studies do not support the current advice.[32,46] Therefore, the advice to minimize lumbar spine flexion during lifting to reduce the risk of LBP is difficult to justify.

Increased exposure to forward trunk inclination (bending) and lifting have separately been associated with LBP in other reviews.[12,23] Greater exposure to forward trunk inclination in the workplace, lifting frequencies of greater than 25 lifts per day, and regularly lifting over 25 kg were associated with increased risk of LBP. Importantly, no study in either of these reviews[12,23] measured lumbar position or trunk position during lifting. The studies in these reviews[12,23] used self-report questionnaires and video observation of unknown validity and reliability to analyze time spent in various degrees of trunk inclination (bending at work) or lifting exposures. 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 comprised 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 23 kg.[26] While

TABLE 3 Domain-Level Quality Score

Critical Appraisal Domain	Studies Scoring Yes, %
1. Were the people with LBP (or with persistent LBP) and those 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 versus no pain measured in a valid and reliable way?	75
5. Was pain versus 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 that 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

Abbreviation: LBP, low back pain.

all of these factors might have influenced the results of these studies, higher levels of pain, disability, and the weight lifted were not associated with more lumbar flexion in the included studies. Nonetheless, it is possible that in future studies of populations with higher levels of pain, LBP that is specific to lifting, and where there is a requirement to lift a greater weight, there may be differences between symptomatic and control groups.

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 to very low. We endeavored 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 was associated with a more flexed lumbar spine during lifting, it is unlikely that future research of similar quality would contradict our results. Because the results were so consistent, we believe that a GRADE score of "very low" quality of evidence, representing "very little confidence in the effect estimate," is not justified.

Among the cross-sectional studies that measured lumbar flexion with thoracopelvic angles, there was significant statistical heterogeneity. This is likely due to the clinical diversity (study populations) and methodological diversity (measurement approaches) across these studies. Such diversity is common in epidemiological (nonrandomized) studies. While we chose to retain the pooled estimate as a broad summary estimate, the point estimate for lumbar flexion from cross-sectional thoracopelvic angles should be interpreted with caution.

There is a lack of high-quality studies of people with and without LBP that have measured lumbar spine flexion during lifting using measures validated against a gold standard for motion analysis. Other variables that can be reported from measurement of lumbar kinematics during lifting, such as time spent in peak flexion, effect of fatigue on lumbar kinematics, and other aspects of movement variability, were not captured by this review or simply were not reported in studies of people with and without LBP. There is also a paucity of longitudinal studies. Therefore, future high-quality work in this area may be warranted to definitively establish whether lumbar kinematics during lifting is a factor of concern, especially as this topic is so controversial.

The sample sizes were generally small and usually without an adequate power analysis. Only 3 studies[21,29,34,35] reported the core components of a sample-size calculation: the size of the difference they were powering to detect, alpha level (*P* value), variance, and the confidence 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, 2 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 2 comparisons from all the included studies indicated that the LBP group displayed greater peak lumbar flexion when lifting. Although the thoracopelvic measures suggested that the LBP group used less lumbar flexion when lifting, we consider that measure of lumbar flexion to be less precise.

Clinical Implications

It is commonly believed that lifting with a flexed lumbar spine is a risk factor for LBP.[10,11,39] This has led to the current common advice by health professionals and the occupational health industry warning people about the risk of pain and injury to their back if they lift with a flexed back.[46] This advice is provided without in vivo kinematic evidence to support it. 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 increased risk of LBP is not justified.

Limitations

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

CONCLUSION

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 low back pain (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 1 longitudinal study included, and it only captured lifts of low load. No study evaluated lifts of over 12 kg.

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STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors made a substantial contribution to (1) the conception, design, or analysis and interpretation of the data, and (2) drafting the article or revising it critically for important intellectual content. All authors assume public responsibility for the work.

DATA SHARING: All data relevant to the study are included in the article or within the supplementary files.

PATIENT AND PUBLIC INVOLVEMENT: There was no patient or public involvement in this research.

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APPENDIX A

SEARCH STRATEGY

The search involved the use of both key word searching in the title and abstract fields as well as subject heading searching across the 4 concepts of the search strategy.

1. **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
2. **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"
3. **TASK** load* or mov* or lift* or carry or "manual handl*" or handl* or "functional tasks"
4. **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 4 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 Adult, Human, Peer reviewed/article, and English language.

APPENDIX B

ADAPTED CRITICAL APPRAISAL CHECKLIST[a]

Reviewer _____ Date_____

Author_____ Year_____ Record Number_____

	Yes	No	Unclear	Not Applicable
1. Were the people with LBP (or with persistent LBP) and those without LBP (or without persistent LBP) comparable in their current characteristics other than regarding their lumbar spine position? 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 versus 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 versus 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 that 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 information

Comments (including reason for exclusion)

_____

_____

[a]*Adapted with permission from the Joanna Briggs Institute.*[36]

Explanation of Critical Appraisal Checklist Items

How to cite the original critical appraisal tool: Critical appraisal checklist for case-control studies. *Joanna Briggs Institute Reviewer's 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 without LBP (or without persistent LBP) comparable other than regarding their lumbar spine position during lifting?

APPENDIX B

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 whether patients were included in the study based on a specified diagnosis or a 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 fulfill all the eligibility criteria defined for the cases, except for those relating to lumbar spine position during lifting.
4. Was pain versus no pain measured in a valid and reliable way?
   The study should clearly describe the method of measurement of LBP. A judgment 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 versus 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 when the estimated exposure effect is biased by the presence of some difference between the comparison and case groups (apart from the exposure of interest). Typical confounders include baseline characteristics, prognostic factors, or cointerventions. A confounder is a difference between the comparison and case groups that 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 utilized 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 of the 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 is equivalent to a known gold standard for motion analysis?
   Assessing validity requires that a gold standard be 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 (ie, functional magnetic resonance imaging or similar) or must have incorporated a 3-D capture of the position of the lumbar spine that measured 2 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 the repeatability of the measurements of interest. These usually include intraobserver reliability and interobserver 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 was 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.

Abbreviation: LBP, low back pain.

APPENDIX C

EXAMPLE OF THE POOLED MEAN AND SD CALCULATIONS USED IN THE FOREST PLOT

Lumbar Flexion During Lifting[a]

Object Lifted	LBP (n = 39)	Control (n = 16)
Empty box	28.0 ± 8.2	38.1 ± 10.7
5-kg box	26.9 ± 8.3	41.1 ± 8.6
10-kg box	27.0 ± 9.2	38.9 ± 10.7
Total[b]	27.3 ± 8.5	39.3 ± 10.0

Abbreviation: LBP, low back pain.
[a]*Values are mean ± SD degrees. Data from Sánchez-Zuriaga et al.*[42]
[b]*The pooled means and SDs were used within the forest plot (***FIGURE 2***).*

Formula used for the pooled mean[1]:

$$(1)\ [(\text{mean}_1 \times n_1) + (\text{mean}_2 \times n_2) + (\text{mean}_3 \times n_3)]/n_1 + n_2 + n_3 \ldots,$$

where n is 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$_3$ + ... + mean$_k$)/the number of means (lift types) that were pooled]. So, in this example (low back pain group), the pooled mean was (28.0 + 26.9 + 27.0)/3 = 81.9/3 = 27.3.

Formula used for the pooled SDs (where the pooled samples had the same sample sizes)[1]:

$$(2)\ \sqrt{\frac{SD_1^2 + SD_2^2 + SD_3^2 + \ldots + SD_k^2}{\text{number of pooled SDs (lift types)}}}$$

So, in this example (control group), the pooled SD is the square root of [(10.7 × 10.7) + (8.6 × 8.6) + (10.7 × 10.7)/3] = square root of 101.0 = 10.0.

Reference

1. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.

APPENDIX D

LUMBAR FLEXION DATA-CAPTURE REPRESENTATIONS[a]

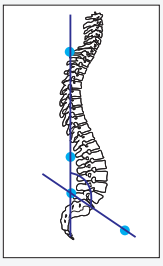
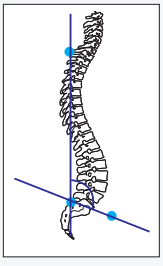
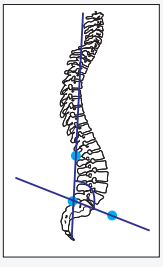
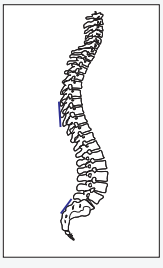
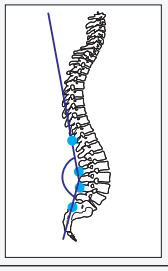
Subgroup/Study	Measurement	Representative Image
Thoracopelvic angles		
Commissaris et al[15]	Peak angle at box lift-off: LBP, 78.3° ± 11.3°; control, 81.0° ± 7.7°	
Larivière et al[27]	Change in angle from upright standing to box lift-off: LBP, 41.5° ± 7.2°; control, 43.7° ± 7.0°	
Marich et al[29]	Change 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[31]	Sagittal trunk position[b]: LBP, 22.5° ± 17.8°; control, 27.3° ± 20.8°	
O'Sullivan et al[40]	Peak angle at box lift-off: LBP, 189.8° ± 12.2°; control, 192.1° ± 13.9°	

Table continues on page B6.

APPENDIX D

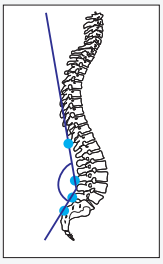
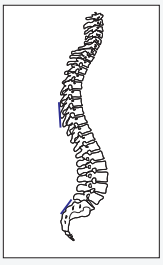
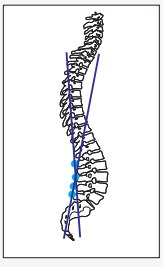
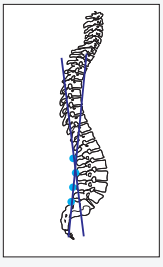
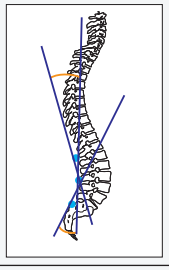
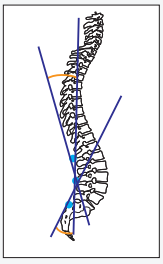
Subgroup/Study	Measurement	Representative Image
Sánchez-Zuriaga et al[42]	Change in angle from start of trunk flexion to box lift-off: LBP, 27.3° ± 8.5°; control, 39.3° ± 10.0°	
Shojaei et al[43]	Difference between peak thoracic and peak sacral sensor is the peak lumbar angle: LBP, 32.6° ± 11.0°; control, 51.4° ± 13.4°	
Intralumbar angles		
Gombatto et al[21]	Lower lumbar region[c]: LBP, 32.4° ± 11.0°; control, 39.0° ± 11.5° Upper lumbar region[c]: LBP, 29.2° ± 8.5°; control, 25.4° ± 11.1°	
Hemming et al[22]	Lower lumbar region[d]: LBP, 0.3° ± 16.0°; control, 3.0° ± 12.5° Upper lumbar region[d]: LBP, 4.9° ± 8.1°; control, 4.6° ± 7.1°	
Mitchell et al[34,35]	Lower lumbar region[e]: LBP, 0° ± 8.1°; control, 1.6° ± 8.7° Upper lumbar region[f]: LBP, 5.8° ± 8.1°; control, 6.6° ± 6.7°	

Table continues on page B7.

APPENDIX D

Subgroup/Study	Measurement	Representative Image
Mitchell et al[33]	Lower lumbar region[e]: LBP, 2.3° ± 7.2°; control, 0.9° ± 8.1° Upper lumbar region[f]: LBP, 7.1° ± 7.6°; control, 5.5° ± 7.7°	

Abbreviation: LBP, low back pain.
[a]*Values are mean ± SD. The data metric in Dideriksen et al[17] is dissimilar to these studies and therefore has not been represented.*
[b]*It is unknown whether the data represent peak angle or change in angle.*
[c]*The difference between maximal and minimal angles was calculated for each lumbar region during lifting.*
[d]*The difference between maximal and minimal angles was calculated for each lumbar region relative to the adjacent region during lifting.*
[e]*Peak flexion angle derived by inclination of the L3 sensor relative to the S2 sensor during lifting.*
[f]*Peak flexion angle derived by inclination of the T12 sensor relative to the L3 sensor during lifting.*

APPENDIX E

DETAILED SYNTHESIS OF STUDY FINDINGS

Longitudinal Study

Peak lumbar spine flexion during lifting at baseline was not a predictor of the incidence of disabling LBP at 12-month follow-up (n = 107).[33] In this study, female nurses without disabling LBP at baseline performed symmetrical lifts of a pen and a 5-kg box from the floor, and asymmetrical lifts of a pillow and a 5-kg 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 who did not. This longitudinal study and the cross-sectional study by Mitchell et al[34,35] were of higher quality compared to other studies in this review (**APPENDIX F**).

Cross-sectional Studies

Only 2 of the 43 comparisons from all included cross-sectional studies indicated that the LBP group displayed greater peak lumbar flexion when lifting (see **SUPPLEMENTAL DATA FILE**). 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.

Intralumbar Angles

Four studies[17,21,22,34,35] provided a more precise estimate of lumbar spine flexion and had lower risk of bias compared to the other cross-sectional studies.[15,27,29,31,40,42,43] There were differences across these studies in measurement device, mass of the object lifted (pen to 5-kg box), marker set position, and the requirements of the lifting task. Despite the diversity across studies, the findings were consistent. Only Gombatto et al[21] (2 of 18 comparisons across studies) found a significant difference between groups with and without LBP (more flexed upper lumbar spine and less flexed lower lumbar spine in people with LBP). No other study found a significant difference where the LBP group displayed greater lumbar flexion during lifting.

Thoracopelvic Angles

Between-group comparisons of people with and without LBP in 3 (Marras et al,[31] Shojaei et al,[4,3] and Sánchez-Zuriaga et al[42]) of these 7 studies all showed (6/6 comparisons) a consistent difference, whereby the LBP group demonstrated significantly less peak lumbar spine flexion when lifting than did the group without LBP. The mass of the object lifted in these studies ranged between an empty box and an 11.4-kg box. These 3 studies were of lower quality, as they did not account for or identify confounders, inadequately described the methodology, and had questionable validity of the measurement tool used to infer lumbar spine flexion.

The studies by Larivière et al[27] and O'Sullivan et al[40] showed no differences in lumbar spine flexion between groups for any lifting comparison (0/9). 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[40] used a 2-dimensional 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 D**). In Larivière 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.

The Commissaris et al[15] study was the only other study to demonstrate significantly greater lumbar spine flexion in the LBP group compared to the control group during lifting (LBP, 126.3° ± 16.8° versus no LBP, 109.0° ± 12.3°; $P = .031$), 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, the anterior superior iliac spine, and the greater trochanter).

Abbreviation: LBP, low back pain.

APPENDIX F

CRITICAL APPRAISAL[A]

	Item[b]												
Study	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total Score[c]**
Commissaris et al[15]	x	x	x	x	x	x	x				x		Low
Dideriksen et al[17]	x	x	x	x	x	x	x	x		x	x	x	Moderate
Gombatto et al[21]	x		x	x	x	x	x	x	x	x	x	x	High
Hemming et al[22]		x		x	x	x		x	x	x	x	x	High
Larivière et al[27]	x		x	x	x	x	x	x			x	x	Low
Marich et al[29]	x		x	x	x	x	x	x		x	x	x	Moderate
Marras et al[31]						x		x		x	x	x	Low
Mitchell et al[34,35]	x	x	x	x	x	x	x	x	x	x	x	x	High
Mitchell et al[33]	x	x	x	x	x	x	x	x	x	x	x	x	High
O'Sullivan et al[40]	x	x	x			x	x	x		x	x	x	Low
Sánchez-Zuriaga et al[42]	x									x	x	x	Low
Shojaei et al[43]	x	x		x	x	x	x	x		x	x	x	Low
Item totals	83%	58%	67%	75%	75%	92%	75%	83%	33%	83%	100%	92%	Low

[a]*Extra weighting was placed on item 8 (has the measurement tool that 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).*

[b]*See* **APPENDIX B** *for details of each item of the critical appraisal checklist.*

[c]*Study-level quality.*