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Association of Exposures to Seated Postures With Immediate Increases in Back Pain: A Systematic Review of Studies With Objectively Measured Sitting Time

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Abstract

Objective: The purpose of this study was to conduct a systematic review of studies to determine whether sitting time measured objectively (by laboratory controlled time trial, direct observation, or wearable sensor) is associated with the immediate increase in low back pain (LBP) (determined by pain scale rating) in people >18 years of age.

Methods: Four databases (PubMed, EMBASE, SPORTDiscus, and Cumulative Index to Nursing and Allied Health Literature) were searched from inception to September 1, 2018. Randomized controlled trials and cohort and cross-sectional studies, where objectively measured sitting time was temporally matched with a measure of LBP in adults, were included. Studies without a control session conducted on a separate day were excluded. Screening, full-text review, data extraction, and risk of bias assessment (Quality In Prognosis Studies) of included papers were performed independently by 2 reviewers, with a third available to resolve disagreements.

Results: In total, 609 articles were identified, 361 titles/abstracts were screened,75 full-text articles were assessed for eligibility, and 10 met the inclusion criteria. All but 1 reported sitting time to be associated with an immediate increase in LBP. Six of these reported clinically relevant pain levels (n = 330). Half of the included studies were rated as having a low risk of bias and the remaining were rated as having a moderate risk of bias.

Conclusion: Prolonged sitting increases immediate reporting of LBP in adults; however, no conclusion between sitting and clinical episodes of LBP can be made. Based upon these findings, we recommend that future prospective studies should match objectively measured sitting with temporally related pain measurements to determine whether prolonged sitting can trigger a clinical episode of LBP. (J Manipulative Physiol Ther 2020;xx:1-12)

Key Indexing Terms: *Low Back Pain; Sitting Position; Sedentary Behavior; Time Factors; Occupational Diseases; Accelerometry; Actigraphy; Pain Measurement; Risk Factors*

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Introduction

Low back pain (LBP) is the leading cause of disability globally, and years lived with disability caused by LBP has increased by more than 50% between 1990 and 2015.[1] For many years, sitting for prolonged periods of time has been reported to be associated with LBP regardless of whether or not an individual is currently experiencing LBP.[2,3] We hypothesize this association may be due to a number of theoretical pathways whereby nociception could be initiated within spine tissues when seated postures are adopted. Sitting involves flexed spine postures between 50% and 97% of end range of motion.[4-12] When joints move away from neutral and toward end ranges, the tissues surrounding the joints are subject to increasing levels of stress and strain. The involved mechanical forces (tension, compression, shear) applied to the spine, once surpassing thresholds, can trigger nociceptive signals via mechanical nociceptors embedded in these tissues. Since many spinal structures (eg, joint capsule, the peripheral third of intervertebral discs, tendons, muscles, and ligaments[13-15]) have these nociceptors, there are mechanical scenarios that could theoretically provoke a pain experience in sitting. Studies have confirmed the biological plausibility of these pathways to pain: that stretching of the posterior passive tissues of the spine (ligaments, tendons, and joint capsules) instigates inflammatory and cytokine responses,[15] that pain is perceived at lower thresholds when inflammation is present,[16] that spine flexion results in stress at the peripheral third of the intervertebral disc (secondary to the posterior migration of the nucleus[17]), and that sustained low-level activation of the erector spinae muscles, as occurs in seated postures, results in capillary compression and reduced oxygenation.[18] Further, a pain response is also evident in experimental studies, where increased reports of perceived pain have been observed in young, healthy populations in response to sitting durations greater than 1 hour.[5,6,19-21] Although there is recent evidence suggesting that sitting durations longer than 5 hours is predictive of a reoccurrence of LBP,[22] currently, it remains unknown whether or not seated postures cause clinical episodes of LBP.

Occupational sitting has been suggested as a risk factor for LBP; however, the data supporting this are unclear.[23,24] One reason for the difficulty in determining the association through epidemiological studies may be the high prevalence of both LBP and sitting in the general population,[25-27] in addition to the multifactorial nature of LBP itself.[1] Further, systematic reviews to date that explore the relation between sitting time and LBP development have included studies that characterized exposure through self-reported sitting time or assumed sitting time based on occupation for the exposure, both of which are known to underestimate actual durations and may bias the results.[23,24,28-30] The more specifically exposure is documented, the better the ability to observe an association with risk.[31,32] Thus, objective measure of sitting time, by direct observation, timed laboratory trial, or wearable sensors, should provide a more valid and reliable exposure measurement that can be related to back symptoms. Therefore, the purpose of this systematic review was to summarize the evidence regarding the association between objectively measured sitting time and immediate increase in perceived LBP.

Research Question

To determine whether sitting time measured objectively (by laboratory controlled time trial, direct observation, or wearable sensor) is associated with the immediate increase in LBP (determined by pain scale rating) in people >18 years of age.

Methods

The review protocol was registered with the International Prospective Register of Systematic Reviews on October 19, 2017 (CRD42017079738). The methodology and reporting format of this review followed the recommendations and guidelines of the Preferred Reporting Items of Systematic Reviews and Meta-analyses.[33]

Literature Search

Eligible articles were systematically identified through the following electronic databases: PubMed, EMBASE, SPORTDiscus, and Cumulative Index to Nursing and Allied Health Literature. The original search was performed on October 20, 2017, and updated on September 1, 2018, to include articles through August 31, 2018. All articles from the inception of each database up to the date of the search were included. The search strategy was developed by a health services librarian (M.S.), using keywords and subject headings that included back pain, discomfort, upper back, lower back, objective measure, sensor, laboratory, sitting, motion analysis, and video in either the title or abstract. The specific search strategies are included in the Appendix (available online). The reference lists of relevant articles were also screened to locate additional articles. The Preferred Reporting Items of Systematic Reviews and Meta-analyses flow diagram outlining the results of the search strategy are shown in Figure 1.

Eligibility Criteria

No language restrictions were used, and all articles that met the inclusion criteria for study design and population, exposure, and LBP were included for analysis.

Study Design and Population. Eligible study design included observational studies (laboratory controlled, cross sectional, cohort, and case control). Randomized controlled studies were included when the control and intervention

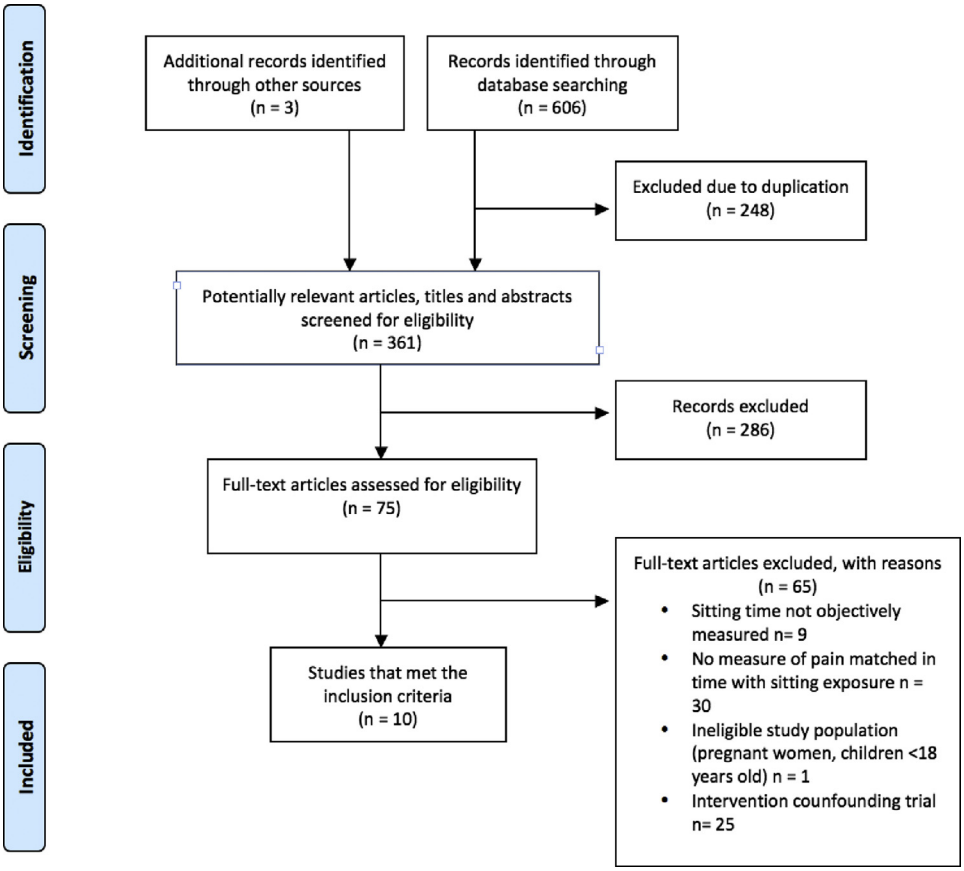

Fig 1. *PRISMA flow diagram outlining the results of our search strategy, screening, and selection of studies. PRISMA, Preferred Reporting Items of Systematic Reviews and Meta-analyses.*

sessions occurred on separate days (within-subject control) to ensure an adequate wash-out period or, alternatively, separate populations were randomized into the study arms. Data from control sessions only were considered for this review; comparisons to interventions were not considered. Studies that investigated self-ambulatory adults older than 18 years were included.

Exposure. Objectively measured sitting time as determined by wearable sensors (accelerometers or inclinometers) or laboratory-controlled trial time were included. No restrictions were placed on the length of exposure used in the studies. Sitting in any context (eg, occupational space, laboratory, leisure time, etc.) and in any country was included so long as the exposure was objectively measured.

Low Back Pain. Nonspecific LBP was defined as pain or discomfort between the lower margin of the 12th rib and the gluteal folds, with or without leg pain, where pain is not attributed to a specific physical cause or pathology.[1] Perceived back pain, measured by a self-reported scale (eg, visual analog scale, numerical rating scale), immediately or shortly after the exposure was included in this review.

Selection of Studies

Study selection was divided into 2 stages (Fig 1). Duplicate citations were removed by the health sciences librarian (M.S.) at the time of the search. In the first stage, 2 authors (D.D.C. and K.D. independently screened the titles and abstracts with the reasons for exclusion compared between the 2 reviewers. In the second stage, the full-text articles of potentially eligible studies were retrieved with each reviewer independently using standardized screening forms to identify relevant studies. The rationale for inclusion and exclusion were discussed and clarified, with discrepancies resolved through consultation with a third reviewer if necessary (J.H.).

Data Extraction

For each included article, 2 reviewers (D.D.C. and K.D.) independently extracted the following information: study setting, population demographics and baseline characteristics, details of control conditions, methodology, recruitment rates and study dropout numbers, and outcome

measures (including units and variance). Corresponding authors of included articles were contacted directly in an attempt to acquire missing data where required. To ensure accuracy of data extraction, regular meetings were held between the reviewers to discuss cases.

Quality of Reporting and Risk of Bias Assessment of Selected Studies

After data extraction for each paper, 2 independent assessors (M.F. and A.B.) completed an assessment of reporting quality and the risk of bias of the included articles using the Quality In Prognosis Studies tool.[34] This tool assesses 6 domains of potential biases: (1) study participation, (2) study attrition, (3) prognostic factor measurement, (4) outcome measurement, (5) study confounding, and (6) statistical analysis and reporting. For the purposes of this study, "prognostic factor measurement" was considered to be the sitting time. Risk of bias in each domain was evaluated as low, moderate, or high risk using the criteria described by Hayden et al (2013).[34] To best summarize our findings, we decided to assess overall risk of bias for each study using the following scheme: low risk of bias (6 low, no high risk on any section), moderate risk of bias (<6 low, 1 high), and high risk of bias (2 or more high ratings in any of the 6 domains). The 2 assessors independently completed the quality assessment for each included study. The assessors subsequently met via video conference to discuss and reach a consensus. If no consensus could be reached, a third assessor (J.H.) was available as a tie-breaker.

Results

Literature Search and Study Selection

Six hundred six articles were identified through the database searches, and 3 articles were identified through review of the reference lists of relevant papers and a hand search. Of these articles, we removed 248 duplicates. The titles and abstracts of the 361 remaining articles were screened, and of these, 75 full papers were accessed for further review of eligibility. Sixty-five articles were excluded and the remaining 10 articles,[21,35-43] including data for 330 participants, were included in this study (Fig 1).

Characteristics of Included Studies

Extracted data from the 10 included articles are found in Table 1. All but 2 (nonrandomized crossover, randomized crossover) identified articles were cross-sectional in design, and most were completed in North America with additional representation from Asia (Thailand, Japan, China) and Australia. Two studies were conducted in the field,[39,41] and the rest were conducted in a laboratory-controlled setting. Three studies[21,38,39] examined sitting in automobile seats, whereas the rest of the studies used office-type chairs. Of the 7 studies that examined an office-type chair, 1 study used a chair with the backrest removed.[43]

All studies included time-controlled trials of sitting. Durations of sitting ranged from 1 hour to an average of 6.96 h/d (including breaks) for 5 days with the sitting duration in most studies (8 of 10) being between 1 and 3 hours. In all studies, ratings of perceived LBP or discomfort were made with a C10 Borg Scale,[43] a visual analog scale (10 cm[21,36,40] or 100 mm[38,39,42]), the Nordic Musculoskeletal Questionnaire,[37,41] or the 5-point numerical rating scale.[35] Attempts were made to contact authors directly where pain rating data were presented with no reference to baseline measures. The summary measures are presented as either the average relative changes from baseline or odds ratio (OR) in the final column of Table 1.

In all but 1 study, [42] pain ratings increased from baseline after the sitting exposure and, where presented, ORs of developing pain during the exposure were greater than 1. Kowalsky et al reported that discomfort ratings were significantly higher in the sitting condition; however, less than half of the participants reported pain after the exposure (45%, OR 0.32).

Quality of Reporting, Risk of Bias Assessment, and Synthesis of Evidence

Reporting in all included studies was appropriately done with some exceptions. Specifically, all included studies except 1[43] failed to justify their sample size. More complete details of the recruitment strategy, period, and locations could have been included by most of the studies, and the reporting of the statistical analysis was unclear in 1 study.[36] Consequently, 5 of the 10 included studies were rated as having an overall low risk of bias,[35,38,40,42,43] and 5 were rated as having a moderate risk of bias.[21,36,37,39,41] No study was rated as having an overall high risk of bias or as having a high risk of bias in any 1 domain. The author of 1 paper was reached to clarify a question of sample size during the risk of bias assessment. Consensus was attained by the 2 assessors for all included studies without the need to engage the third assessor. A summary of the risk of bias assessment is presented in Table 2. A sensitivity analysis was conducted including only the 5 studies that were rated as having an overall low risk of bias ($n = 121$).[35,38,40,42,43] Also among these studies, an increased pain rating from baseline after sitting exposure was also observed.

Discussion

Summary of Findings

We found that sitting for total durations ranging from 1 hour to 6.96 h/d for 5 days is associated with immediate increases in LBP in people with and without a clinical

Table 1. *Characteristics and Results for the Included Studies in Alphabetical Order*

Article	Design	Population	Exposure	Pain Measure	Main Result	Pain Increase (*Clinically Relevant)
Akkarakittichoke and Janwantanakul 2017 (Thailand)[43]	Cross-sectional (lab)	46 participants (23 LBP, average age 29.6 y ± 5.3; 23 control, average age 29.6 y ± 5.1), reporting sitting at least 4 h/workday with no current or past history of known spinal disorders, neurologic defect, osteoarthritis, rheumatoid arthritis, gout, kidney diseases, open wound or contusion at the buttocks or posterior thigh region, hemorrhoids, current pregnancy, and BMI < kg/m^2 or > 23 kg/m^2.	Participants were exposed to sitting at a computer workstation on a backless office chair while typing a standardized text passage for **1 h**.	C10 Borg scale taken at 10-min intervals throughout the sitting trial	Pain rating data estimated from graphs: healthy participants at 0 min = 0.9 and 60 min = 2.9 (+2); LBP participants at 0 min = 0.9 and 60 min = 5.5 (+4.6)	Yes* +2 healthy +4.6 LBP
Aota et al, 2007 (Japan)[36]	Cross-sectional (lab)	31 male participants (average age 21.2 y ± 0.6) Participants were free of back pain for a period of 6 mo before and at the time of the study.	Participants were exposed to a **2-h** exposure of constrained sitting in an experimental chair in 3 conditions (no lumbar support, with lumbar support, and with continuous passive motion lumbar support). Testing was completed on 3 consecutive days in a randomized presentation. For all sessions, participants were free to read books and no specific instruction was given regarding sitting posture.	10 cm VAS with anchors of 0 cm "least" and 10 cm "the most discomfort experienced" taken immediately after the 2-h sitting trial	Mean pain rating data from the "no lumbar support"/control trial = 8.1 cm ± 1.5 following exposure *Assume increase since participants were "free of back pain at the time of the study"	Yes* +8.1
Baker et al, 2018 (Australia)[37]	Cross-sectional (lab)	20 participants: 7 male (average age 32 SD 9.3 y, weight 49.6 SD 4.4 kg, and height 180.6 SD 6.2 cm) and 13 female (average age 36.2 SD 7.6 y, weight 64.2 SD 15.4 kg, and height 166.5 SD 7.3 cm) Inclusion criteria were ages between 18 and 65 y, English and computer literacy, and physical ability to sit for 2 h. Exclusion criteria were height and weight ranges that precluded proper setup of the workstation and individuals with pre-existing pain.	Participants were exposed to a **2-h** exposure of sitting in a standard office chair, with backrest, at a workstation that had been adjusted to their size. Participants were free to sit and move as normally as possible, including the ability to stand up if needed (only 1 person did this). The standardized computer task involved a series of cognitive function tests that required both mouse and keyboard input.	Modified version of the Nordic Musculoskeletal Questionnaire to rate intensity of MSK discomfort between anchors of 0 = "no discomfort" and 100 = "discomfort as bad as it can be." Data were collected at baseline and at 30-min intervals throughout the sitting trial.	Discomfort rates increased significantly over time for all body areas (low back at 0 min = 4.8 [±7.2] and at 120 min = 16.3 [±14.3]). Clinically meaningful discomfort increases from baseline apparent by 90 or 120 min were statistically significant for the low back (120 min IRR = 4.20, $P \leq .001$).	Yes* +11.5

(continued on next page)

Table 1. (*continued*)

Article	Design	Population	Exposure	Pain Measure	Main Result	Pain Increase (*Clinically Relevant)
Cardoso et al, 2018 (Canada)[39]	Cross-sectional (field)	40 participants (20 male, 20 female; average age 50.4 y ± 13.4) with a valid class 1, 2, or 3 driver's license and experience driving a standard transmission	Participants were recruited to drive a long-haul truck (without a trailer) for a **90-min** round trip along a portion of the Trans Canada Highway on 2 separate days in a random presentation. Prior to each driving session, the participants were fitted to each truck seat according to best ergonomic practices and preferred configuration.	100-mm VAS with anchors of 0 mm "no discomfort" and 100 mm "worst discomfort imaginable" taken at baseline and after 45 and 90 min of driving	Mean pain rating data averaged between left and right sides = increase of 9.65% over the exposure	Yes Increase of 9.65%
Cardoso et al, 2018 (Canada)[38]	Cross-sectional (lab)	20 participants (10 male average age 22.3 y ± 2.16, 10 female average age 22.1 y ± 0.8) with no history of back injury or pain within the previous month	Participants completed 2 **2-h** laboratory sessions, on separate days in a random order where they completed a simulated driving trial in a control and test truck seat.	100-mm VAS with anchors of 0 mm "no discomfort" and 100 mm "worst discomfort imaginable" taken at 15-min intervals throughout the sitting trial	Mean pain rating data averaged between left and right sides = increase of 6% of over the exposure	Yes Increase of 6%
De Carvalho and Callaghan, 2011 (Canada)[21]	Cross-sectional (lab)	20 participants (10 male average age 26.4 y ± 3.5 and 10 female average age 25.2 ± 3.2) free of LBP	Participants were exposed to **2 h** of simulated driving in an automobile seat.	10-cm VAS for head/neck, shoulders, upper and low back pain at baseline, after 1 hour, and after 2 hours. Anchors of 0 = "no discomfort at all" and 10 = "worst discomfort imaginable" taken at baseline and after the first and second hour of sitting.	Perceived pain ratings for men: baseline = 0 cm, 2 h = 18 cm (+18) and women: baseline = 0 cm, 2 h = 20 cm (+20)	Yes* +18 men +20 women
Dunk and Callaghan, 2010 (Canada)[40]	Cross-sectional (lab)	32 participants (16 with sitting aggravated LBP were age- and sex-matched to 16 asymptomatic controls) Exclusion criteria included a previous diagnosis of a neurologic deficit and/or lower-extremity impairment, stenosis, spondylolisthesis, recent fracture, severe structural deformity, or previous surgical intervention.	Participants were exposed to **90 min** of sitting while completing simulated office tasks in 15-min intervals: (1) mouse task, (2) typing task, (3) combination mouse and typing task. The 3 tasks were presented in a random order and then repeated in the same order.	10-cm VAS at baseline and 15-min intervals throughout the sitting trial for 3 regions of the low back: central and right and left sides. Anchors of 0 = "no discomfort" to 10 = "worst discomfort imaginable"	Perceived back pain ratings were presented as differences from baseline and were approximated from graphs: asymptomatic participants 0 min = 0 cm, 90 = 2 cm (+2 cm), and clinical participants 0 cm, 90 min = 20 cm (+20 cm).	Yes* +2 cm asymptomatic +20 clinical

Article	Design	Population	Exposure	Pain Measure	Main Result	Pain Increase (*Clinically Relevant)
Foley et al, 2016 (Australia)[41]	Nonrandomized cross-over (field)	78 adult participants (50 male and 38 female) ranging in age from 22 to 63 who had ongoing employment with the company and no planned upcoming leave and sufficient English language proficiency	Participants completed 3 phases: baseline (regular office, **5 d**), intervention (activity-based work, 4 wk), and then follow-up (regular office, 5 d). Measurements in each environment were collected over a 5-d period during work hours. Sitting exposure measured by accelerometer: (percentage of sedentary time) Baseline = 80.28%, intervention = 81.41%, and follow-up = 82.01%. Average h/wk = 43.39; therefore, these percentages approximately translate to an 8.678-h workday. Baseline = **6.96**, intervention = 7.06, and follow-up = 7.11 h of sitting per day.	MSK discomfort in the last 7 days was rated with the Nordic Musculoskeletal Discomfort Questionnaire) at baseline, after at least 2 wk of the 4-wk intervention, and 3 wk following the end of the intervention.	MSK discomfort results: Participants were twice as likely to report LBP at baseline compared with during the intervention (OR 1.98, 95% CI 1.06 to 3.67); lower odds of reporting pain were found comparing baseline with follow-up (OR 1.43, 95% CI 0.81-2.51) and intervention with follow-up (OR 0.72 95% CI 0.38-1.37).	Yes OR 1.98
Kowalsky et al, 2018 (US)[42]	Randomized cross-over (lab)	25 overweight participants (16 male and 9 female) with an average age of 42 y (SD 12) were recruited from the general population. Inclusion criteria required all participants to be inactive (<90 min of moderate to vigorous activity per week), not be taking any medications that could affect cardiometabolic responses, and spend at least 20 h/wk sitting at a desk. Exclusion criteria included a cardiovascular event in the past 6 mo; atrial fibrillation; being in a weight-loss program; being treated for heart disease, cancer, end-stage renal disease, or any other serious condition; smoking on most days of the week; being pregnant in the past 6 mo; breastfeeding in the past 3 mo; or not being able to stand.	Participants were randomized to a sit or sit/stand condition on 2 separate days at least 5 days, but not more than 14 days apart. The study schedule (including breakfast and lunch) were standardized (30% daily caloric need: 55% carbohydrate, 35% fat, and 10% protein) and they completed nonstandardized desk work for 2 3-h-and-40-min periods (morning and afternoon, total exposure time = **7.3 h**). To increase generalizability, participants were able to go to the washroom as needed and move as naturally as they could in each condition with the goal of remaining at the desk (sitting or standing).	Discomfort rated on a 100-point scale that ranged from no discomfort to extreme discomfort for 15 separate body regions was taken at baseline and then every 2 h during the trial.	Discomfort ratings were significantly higher in the sit condition compared to the sit/stand condition. Percentage of participants reporting discomfort following the sit trial: 45% (OR = 0.32) Increase in rating (log points) from 0.4 to 1.0	No OR 0.32
Li et al, 2017[35] (China)	Cross-sectional (lab)	18 healthy participants (12 male and 6 female) ranging in age from 18 to 39 y	Participants were seated for **3 h** in 3 different seat pitch (32 in, 30 in, and 28 in) conditions in a laboratory.	Discomfort (collected using a body map and 5-point numerical rating scale). Taken after 5 min of the sitting trial and then at 30-min intervals until the end of the trial.	Overall discomfort rating for the 28-in pitch (control) condition: 0 h = 1.02, 3.0 h = 3.31 (+2.29)	Yes* +2.29

BMI, body mass index; *IRR*, incidence rate ratio; *LBP*, low back pain; *MSK*, musculoskeletal; *SD*, standard deviation; *VAS*, Visual Analog Scale.

Table 2. *Results From the Assessment of Methodological Quality and Reporting of the Included Studies Using the QUIPS Tool*

Article	Study Population	Study Attrition	Prognostic Factor Measurement	Outcome Measure	Study Confounding	Statistical Analysis and Presentation	Overall Risk of Bias
Akkarakittichoke and Janwantanakul 2017[43]	Low risk	Low risk	Low risk	Low risk	Moderate risk	Low risk	Low risk
Aota et al, 2007[36]	Moderate Risk	Low risk	Low risk	Low risk	Low risk	Moderate risk	Moderate risk
Baker et al, 2018[37]	Moderate Risk	Low risk	Low risk	Low risk	Moderate risk	Low risk	Moderate risk
Cardoso et al, 2018[38]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Cardoso et al, 2018[39]	Moderate risk	Low risk	Low risk	Low risk	Moderate risk	Low risk	Moderate risk
De Carvalho and Callaghan, 2011[21]	Moderate risk	Low risk	Low risk	Low risk	Moderate risk	Low risk	Moderate risk
Dunk and Callaghan, 2010[40]	Moderate risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Foley et al, 2016[41]	Low risk	Moderate risk	Moderate risk	Low risk	Moderate risk	Low risk	Moderate risk
Kowalsky et al, 2018[42]	Low risk	Low risk	Low risk	Low risk	Low risk	Moderate risk	Low risk
Li et al, 2017[35]	Low risk	Low risk	Low risk	Low risk	Moderate risk	Low risk	Low risk

QIPS, Quality In Prognosis Studies.

history of LBP in both laboratory and field settings. Similar results were found when including only the studies with a low risk of bias.

Interpretation of Findings

The consistency of the above finding was high, with only the Kowalsky et al[42] study reporting an OR below 1. The study population included in Kowalsky et al[42] can be classified as obese, with an average body mass index of 31.9 ± 5.0 kg/m^2, thus setting it apart from the populations studied in the rest of the included studies.

Where studies involved both asymptomatic and symptomatic groups,[40,43] participants with a history of LBP reported higher levels of pain intensity than asymptomatic controls after an identical exposure to sitting in a laboratory setting.[40,43] However, the pain response, although lower, was evident in both people with LBP and people without LBP. Typically it is assumed that sitting aggravates existing cases of LBP,[44] but we found that sitting also provoked pain in individuals without a history of LBP. At this point it is not known whether transient pain experienced by individuals in response to sitting is clinically relevant, predictive of future significant LBP, or merely a nuisance. Future work is warranted in this area.

In 6 of the 10 studies, in both healthy and symptomatic participants, the increase in pain over the sitting exposure could be considered to surpass the threshold of minimal clinically important difference: having an increase of more than 2 points on a 10-point scale/20 mm on a 100-mm scale[45] (Table 1). This pain response is evident in both the laboratory and field settings. Laboratory studies provide extremely controlled environments, which means that they are often not generalizable to the real world. However, evidence of this pain response is apparent after 90 minutes of driving in the field ($n = 40$)[39] and across 5 working days in a real office setting ($n = 75$),[41] suggesting that this phenomenon is not restricted to the laboratory environment alone.

Comparison to Existing Literature

This systematic review of literature, having objective measures of sitting exposure, has found a positive relation between sitting and immediate increase in LBP. This result contradicts many studies that have not included an objective measure of exposure.[24,28-30] Publication bias is always a threat (ie, where only studies finding a significant increase in reported LBP are published), and one must consider that this is the reason for the lack of studies showing no increase in LBP. However, LBP was not the main outcome measure in most of the studies included in this review; therefore, the likelihood of this problem should be low.

The literature is replete with inconsistent reports regarding the association between sitting and LBP, with some studies showing a positive association,[23,46-48] particularly in those who drive,[49-57] whereas others do not.[24,28-30,58-61] The fact that both sitting and LBP are so

prevalent in society, paired with the complex multifactorial nature of LBP, likely contributes to the confusion. Further, the relationship may be different for subsets of the general population (eg, for individuals of different body mass, occupation, or clinical history). In addition, this work shows a number of methodological factors play a role. Specifically, many studies rely on self-reported sitting time. Several studies have demonstrated that self-reported sitting time has low[62-65] to moderate[66] validity, and a direct comparison of self-reported sitting time and objectively measured sitting time has shown that self-reports can underestimate total sitting time.[67] This is not to say that the subjective experience of individuals regarding exposure is not important in the overall understanding of this problem, only that an accurate quantification of exposure is necessary to determine whether a response (such as pain) is related to it. Either over-reporting or under-reporting the exposure would not be helpful for answering this question. Similarly, recall bias could be involved when a measure of LBP is not temporally related to the exposure (ie, taken during or immediately after). To address this, our review searched specifically for evidence regarding this relationship based on objective measurements of sitting exposure and included only those studies that reported ratings of pain immediately or shortly after the exposure. From our findings, it is apparent that, at least for short-term durations, sitting does result in immediate increases in LBP reporting. There are a number of ways a large-scale study could objectively measure sitting exposure over more realistic durations of time. With the rapid improvements in wearable sensor technology, accelerometer-based measures of activity can easily be incorporated to track postures and confirm sitting durations.[68] Other options may include video monitoring, seat- or desk-based sensors, or a combination of objective measures with self-report to increase accuracy. Regardless of how this is done, there is no doubt that improving estimates of exposure will vastly improve our ability to confidently determine the relationship between sitting and LBP.

Risk of Bias Assessments of the Included Studies (eg, Recruitment Method, the Inclusion of Representative Samples, Small Sample Size, Statistical Analysis)

Half of the included studies in this review were rated as having a low risk of bias and half were rated as having a moderate risk of bias. To be conservative, the overall risk of bias of the data included in this review could be considered to be low-moderate. Most studies provided partial or no information about the method used to identify the population of interest, recruitment period, and place of recruitment. Similarly, most studies did not provide details regarding potential confounding factors, such as the validity and reliability of the method used to measure confounders and appropriate accounting for confounding factors. A few studies failed to report the inclusion or exclusion criteria for participants or define LBP in the context of their studies. These details would be very straightforward to address and improve the quality of studies in the future, especially in laboratory-controlled cross-sectional designs.

Strengths and Limitations

A strength of this current review is that a comprehensive and systematic search strategy was used to identify potential articles related to the research question. In particular, we specifically searched for articles that involved sitting over sedentary behavior. This choice was made because sedentary behaviors, such as seated postures, also include lying down and reclining, which we consider different enough to warrant separate analysis. Second, there was no limitation of language or time, which would minimize the chance of missing potential articles to include. Third, the protocol from this review was registered before starting the project. With the exception of not being able to combine the data quantitatively in a meta-analysis owing to the heterogeneity of the included studies (seat types, populations, study designs, and study durations), there were no significant deviations from the planned protocol.

There are a few limitations of this review. First, although 1 field study did include exposures up to 6.96 h/d (including breaks) for 5 days, most studies (8 of 10) were conducted in laboratories with sitting duration ranging from 1 hour to 3 hours, often without control for postures and activities adopted by the participants before the data collection; therefore, these results may not be generalizable to longer durations of sitting. Second, most of the included studies used a cross-sectional design. Given the short follow-up duration, the dose-response relationship between sitting duration and LBP in the long term remains unclear. Third, the quality assessment tool used, Quality In Prognosis Studies, was designed to assess prognostic studies and not the cross-sectional studies that were included in this review. Because only the prognostic factor criterion was adapted to fit these studies, the use of the tool in this case should provide an accurate assessment of risk of bias. Further, we developed a scheme to provide an overall score, which also deviates from the recommendation of the tool's authors.[34] The issue with this could be that a high risk of bias in any 1 domain would invalidate an otherwise good study. In our situation, this limitation does not change the overall interpretation of our findings, and the method provided our reviewers with a straightforward and objective way to capture a summary risk of bias for each individual study. Finally, the sample sizes of the included studies were small, with each having less than 100 participants. As such,

large-scale field-based experiments with long-term follow-up that objectively monitor sitting exposure with temporally linked ratings of LBP are warranted to better understand the relationship between sitting time and clinical episodes of LBP.

Conclusion

Objective measures of sitting time are associated with immediate increased ratings of perceived LBP in adults with and without a recent history of LBP. It remains unknown whether this increase has clinical implications. No conclusion between sitting and clinically relevant episodes of LBP can be made. Based upon our findings, we recommend that future prospective studies should match objectively measured exposure with temporally related measures of pain to determine whether sitting time is a trigger of a clinical episode of LBP.

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Contributorship Information

Concept development (provided idea for the research): D.D.C., K.D., J.H.
Design (planned the methods to generate the results): D.D.C., K.D., J.H., M.S., M.F., A.B., A.W., M.S.J., G.K., J.A., M.F.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): D.D.C., K.D.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): D.D.C., K.D., M.S., M.F., A.B., A.W.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): D.D.C., K.D., M.S., M.F., A.B., A.W., M.S.J.
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Writing (responsible for writing a substantive part of the manuscript): D.D.C., K.D., M.S., M.F., A.B., A.W., M.S.J.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): D.D.C., K.D., M.S., M.F., A.B., A.W., M.S.J., G.K., J.H., J.A., M.F.

Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jmpt.2019.10.001.

Practical Applications

- Objectively measured sitting time in both people with and without low back pain (LBP), and in both field and laboratory environments, resulted in immediate increases in perceived LBP.
- Future studies should include objective measures of the sitting exposure together with temporally related clinical outcome measures to determine the relation to clinical episodes of LBP.

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