Association between objectively measured physical behaviour and neck- and/or low back pain: A systematic review

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Abstract

**Background and objective:** Clinical guidelines recommend physical activity to manage neck pain (NP) and low back pain (LBP). However, studies used to support these guidelines are based on self-reports of physical behaviour, which are prone to bias and misclassification. This systematic review aimed to investigate associations between objectively measured physical behaviour and the risk or prognosis of NP and/or LBP.

**Databases and data treatment:** Literature searches were performed in MEDLINE, Embase and Scopus from their inception until 18 January 2019. We considered prospective cohort studies for eligibility. Article selection, data extraction and critical appraisal were carried out by independent reviewers. Results were stratified on activity/sedentariness.

**Results:** Ten articles out of 897 unique records identified met the inclusion criteria, of which eight studied working populations with mainly blue-collar workers. The overall results indicate that increased sitting time at work reduces the risk of NP and LBP while increased physical activity during work and/or leisure increases the risk of these conditions among blue-collar workers; however, associations were weak. Physical activity was not associated with prognosis of LBP (no studies investigated prognosis of NP). Most of the included articles have methodological shortcomings.

**Conclusions:** This review indicates that, among blue-collar workers, increased sitting at work may protect against NP and LBP while increased physical activity during work and/or leisure may increase this risk. There was no evidence supporting physical activity as a prognostic factor for LBP. Findings should be interpreted with caution due to the weak associations and few available studies with methodological shortcomings.

**Significance:** Based on prospective cohort studies with objectively measured physical behaviour, this review questions the common notion that increased physical activity is associated with reduced risk or better prognosis of NP and/or LBP. We found that, among blue-collar workers, increased sitting time at work reduces the risk of NP and LBP, whereas physical activity somewhat increases the risk. Despite methodological shortcomings, there was consistency in the direction of the results, although high-quality articles reported the weakest associations.

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INTRODUCTION

Neck pain (NP) and low back pain (LBP) are leading causes of disability and their burden is expected to increase due to the ageing population (James et al., 2018). Both NP and LBP have high direct and indirect social and economic costs (Herman, Broten, Lavelle, Sorbero, & Coulter, 2019; Vlaeyen et al., 2018) and are common causes of work absence, reduced work productivity and early disability pension (Hartvigsen et al., 2018; Hoy et al., 2014). The severe negative consequences, both for the society and affected individuals, underscore the importance of identifying modifiable factors that can be targeted to reduce the risk and improve prognosis of NP and LBP.

Maintaining a physically active lifestyle is recommended in clinical guidelines to manage NP (Cote et al., 2016; Kjaer et al., 2017) and LBP (National Guideline Centre, 2016; Stochkendahl et al., 2018). However, the effect of physical activity and/or sedentariness on the risk and prognosis remains elusive (Cheung, Kajaks, & Macdermid, 2013; Pinto et al., 2014), and systematic reviews over the last decade have reported conflicting results. Some reviews have found that moderate or high leisure-time physical activity is associated with reduced risk of NP or LBP (Alzahrani, Mackey, Stamatakis, Zadro, & Shirley, 2019; Kim, Wiest, Clark, Cook, & Horn, 2018; Shiri & Falah-Hassani, 2017), while others have found no association (Bakker, Verhagen, Trijffel, Lucas, & Koes, 2009; Jun, Zoe, Johnston, & O’Leary, 2017; Øiestad et al., 2020; Paksaichol, Janwantanakul, Purepong, Pensri, & Beek, 2012; Sitthipornvorakul, Janwantanakul, Purepong, Pensri, & Beek, 2011). Furthermore, the risk of LBP was not associated with standing or walking at work (Rofey, Wai, Bishop, Kwon, & Dagenais, 2010b), sitting at work (Rofey, Wai, Bishop, Kwon, & Dagenais, 2010a) or a sedentary lifestyle (Chen, Liu, Cook, Bass, & Lo, 2009). Systematic reviews on prognosis have found that physical activity may have a positive effect on chronic LBP (Gordon & Bloxham, 2016) or concluded that there is limited evidence supporting physical activity as a prognostic factor for LBP (Hendrick et al., 2011; Oliveira et al., 2019).

A possible explanation for these inconsistent findings is the reliance on mainly self-reported measures of physical behaviour (i.e. sedentariness and physical activity). Self-reported physical behaviour is prone to bias and misclassification (Gupta et al., 2017; Lagersted-Olsen et al., 2014; Pedersen, Kitic, Bird, Mainsbridge, & Cooley, 2016), and it is strongly advocated that objective measurements (e.g. accelerometry) should be implemented in cohort studies when possible to obtain more valid estimates of physical behaviour in relation to health outcomes (Brug et al., 2017; Perruchoud et al., 2014). The number of studies with long-term objective measurements of physical behaviour has increased substantially during recent years (Silfve et al., 2018). It is, therefore, timely to perform a systematic review to provide an overview of the evidence on the association between objectively measured physical behaviour and the risk or prognosis of NP and LBP. The research questions for this review were as follows: (a) Is physical behaviour in pain-free individuals associated with the risk of NP and/or LBP? (b) Is physical behaviour in pain-afflicted individuals associated with the risk of new episodes with NP and/or LBP or persistence of NP and/or LBP?

METHODS

The protocol for this systematic review was created a priori and registered in the international prospective register of systematic reviews (PROSPERO, reg. no. CRD42018100765). The development of the protocol and the reporting of results follow the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA-P; Moher et al., 2015).

2.1 Eligibility criteria

This systematic review was limited to prospective cohort studies of general-, working- or patient populations involving adults 18 years or older. Articles with other study designs (e.g. cross-sectional, case-control) were excluded due to the limited possibility to draw conclusions about causation. Eligible articles had to include objective measurements of habitual physical behaviour during free-living conditions at the workplace and/or during leisure-time in individuals with or without NP and/or LBP. Physical behaviour has been introduced as an umbrella term that encompass both sedentary behaviour and physical activity, including patterns of these behaviours (Bussmann & van den Berg-Emons, 2013). In this context, objective measurements of physical behaviour refer to methods that do not rely on information provided by the participant. Typically, such information is collected with wearable monitors (e.g. accelerometers, pedometers, inclinometers) or direct observation (e.g. video recordings). Thus, objective measurements are not subject to the reporting bias or recall problems associated with self-reports. Experimental pain studies and studies assessing exposure to ergonomic risk factors at the workplace, such as time with forward trunk flexion, arms overhead and repeated or heavy lifting, were excluded. We included studies assessing NP and/or LBP with or without radiation to the arms or legs, defined according to anatomical location, severity, duration of symptoms and/or consequences. Studies including individuals with NP and/or LBP of specific pathological origin (e.g. fractures, spinal cord injuries, tumours, inflammatory diseases, systemic diseases, infections, structural deformities) were excluded, as were studies of athletes or pregnant women, animal studies and secondary analyses of randomized controlled trials. Peer-reviewed articles published in the English, Dutch, Danish, German, Norwegian, Portuguese, Spanish or Swedish languages, understood by the authors of this paper, would be screened for eligibility.
2.2 | Search strategy

We performed a literature search with no limit on publication type or language in the following bibliographic databases: MEDLINE, Embase (via Ovid) and Scopus from their inception until 18 January 2019. Searches within grey literature were not included. Search terms covered the following domains: NP and/or LBP and different terminologies for objective measurements and physical behaviour. Pilot searches were done on the search terminology to ensure a comprehensive coverage of the literature. The design and execution of the searches were supervised by a trained research librarian (see Appendix S1 for the full search strategy). The reference lists of included articles and their forward citation tracking, previous systematic reviews on the topic and PROSPERO were inspected to identify additional articles. Identified articles were retrieved and managed in EndNote X8 (Bramer, Milic, & Mast, 2017).

2.3 | Selection of articles

Articles were selected through a two-stage screening process by two reviewer pairs (CKØ + IA and MV + PJM), who divided the retrieved articles between them. In the first stage, titles and abstracts were screened for eligibility with the reviewers blinded to each other's selections. Articles with uncertain eligibility were included in the second stage. Full-text of potentially eligible articles that met the inclusion criteria was obtained. In the second stage, the reviewers were still blinded to each other's decisions and made their final selection based on reading the full-text articles and checking the content against the eligibility criteria. The selection was thereafter discussed within each reviewer pair, and across review pairs in cases of uncertainty or disagreement, for final consensus about the eligibility of articles. At this second stage, reasons for excluding articles were recorded.

2.4 | Data extraction

Data from the included articles were extracted from pretested forms by the independent reviewer pairs (CKØ + IA and MV + PJM). Disagreements were discussed and when necessary, a fifth reviewer (JH) was consulted to arbitrate the decision. Data extraction included: study characteristics of the included articles, information on how physical behaviour was assessed (i.e. the exposure measurement), definition of NP and/or LBP, secondary outcomes and possible interactions if reported, and other information for assessment of methodological quality and risk of bias. Estimates of effect size, that is, odds ratio (OR), risk ratio (RR) and β coefficients were extracted from each included article. The precision of the estimated effect sizes was assessed by 95% confidence intervals (CI).

2.5 | Assessment of methodological quality and risk of bias

Critical appraisal of methodological quality and risk of bias was conducted using a modified version of the Quality in Prognosis Studies tool (QUIPS tool) developed by Hayden and colleagues (Hayden, Windt, Cartwright, Cote, & Bombardier, 2013). The QUIPS tool was modified to fit our purpose, for example, adjusting wording such as replacing 'prognostic factor' with 'measurement of physical behaviour'. For prognostic studies, we assessed the phase of investigation according to the framework for prognostic model research, described by Steyerberg et al. (2013), that is, the three main phases constitute model development (including internal validation), external validation and investigations of impact in clinical practice. We further assessed the reporting of the objective measurements of physical behaviour, as recommended by Montoye, Moore, Bowles, Korycinski, and Pfeiffer (2016). We assessed the reliability but not the validity of the assessment of NP and LBP. To evaluate if the effect of the exposure was distorted by another factor related to the exposure and outcome, we assessed whether the studies controlled for both potential confounders and modifiers (and not only 'study confounding' as in the original QUIPS tool). We refrained from evaluating the adequateness of the statistical analysis but assessed whether the strategy for model development was sufficiently described. Finally, to enhance transparency, we defined the requirements for rating an item as low risk of bias/good quality (green), moderate risk of bias/moderate quality (yellow) or high risk of bias/poor quality (red). As suggested in the original QUIPS tool, we made an overall rating of risk of bias and methodological quality for the six main items of the tool. The overall risk of bias/quality was appraised as: high risk of bias/poor quality (≥2 red + ≥2 yellow); moderate risk of bias/moderate quality (2 red or 1 red + ≥1 yellow); and low risk of bias/good quality (maximum 1 red). The modified QUIPS tool used in the current review was piloted to ensure consistency between reviewers. The reviewers were initially blinded to each other's critical appraisal and final consensus was thereafter reached through discussion between all authors.

2.6 | Data synthesis and analysis

The results from the literature search, critical appraisal and data extraction are presented in tables and figures. There are no significant deviations from the PROSPERO registered protocol in this review. However, due to the heterogeneous nature of the included articles in terms of the measurements of exposures and outcomes, it was not possible to perform a statistical meta-analysis. We therefore performed a narrative
data synthesis. Moreover, few articles included stratified analyses and we could not assess whether the association between physical behaviour and the risk or prognosis of NP and LBP was modified by other factors (e.g. age, sex, body mass index, physical work demands, socioeconomic status or sleep). Neither was it possible to investigate secondary outcomes (like disability, quality of life, sick leave, workability and drug use) as intended due to limited reporting. In our conclusions, we emphasized the evidence from high-quality articles.

3 | RESULTS

3.1 | Search results and selection of articles

A PRISMA flowchart of the article selection process is shown in Figure 1 (see Appendix S2 for list of full-text articles excluded from the review). We identified 1,248 records from the database searches and two additional articles after the screening of reference lists and citation tracking. After duplicate removal, 897 papers were screened at title/abstract level and 49 full-text articles were assessed for eligibility. In total, 10 articles were included, of which eight investigated the prospective association between physical behaviour and the risk of NP and/or LBP (Ariens et al., 2001; Ariens, Bongers, Hoogendoorn, Wal, & Mechelen, 2002; Hallman, Birk Jorgensen, & Holtermann, 2017; Hallman et al., 2016; Korshøj et al., 2018; Lunde, Koch, Knardahl, & Veiersted, 2017; Sitthipornvorakul, Janwantanakul, & Lohsoonthorn, 2015; Thiese, Hegmann, Garg, Poruczniak, & Behrens, 2011), and two articles investigated the effect of physical behaviour on prognosis of LBP (Bousema, Verbunt, Seelen, Vlaeyen, & Knottnerus, 2007; Hendrick et al., 2013).

3.2 | Characteristics of the included articles

Table 1 provides the main characteristics of the included articles. Eight articles were based on data from working populations and two from clinical/mixed populations. The articles were published between 2001 and 2017 and data had been collected between 1994 and 2013 (not reported in three articles). All the included articles were published in English, originating from studies in Europe (n = 7), United States (n = 1), New Zealand (n = 1) and Thailand (n = 1). The duration of data collection (when described) ranged from 4 weeks to 1 year while the number of follow-ups ranged from one to 14. Sample sizes included in the fully adjusted analyses ranged from 68 to 977 participants. Mean age of the participants ranged from 34.9 to 48.9 years while the percentage of females varied from 2% to 78%. Six of the
| 1st Author (year) | Country | Study population | Study design (cohort name) | Year of study - baseline (yr) - (no. follow-ups; time between) | Sample size - no. invited - (no. at baseline)* - [no. analysed]b | Age (yrs) and sex - mean (SD) - ♀ no. (%) | Assessment of physical behaviour - method/brand/software - (sensor placement) - [intended measurement time] | Outcome |
|-------------------|---------|------------------|---------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|--------|
| Hallman et al. (2016) | Denmark | Blue-collar workers | Prospective cohort (DPhacto) | - 2012 to 2013 - (14; 4 weeks) | - 2,107 - (662) - [595] | - 44.8 (9.8) - 280 (45) | - Accelerometry/Actigraph GT3X+/Acti4 - (thigh, upper arm, hip and trunk) - [24 hr/day, 4–5 days including 2 workdays] | Neck-shoulder pain |
| Hallman et al. (2017) | Denmark | Blue-collar workers | Prospective cohort (DPhacto) | - 2012 to 2013 - (14; 4 weeks) | - 2,107 - (662) - [595] | - 44.8 (9.8) - 280 (45) | - Accelerometry/Actigraph GT3X+/Acti4 - (thigh, upper arm, hip and trunk) - [24 hr/day, 4–5 days including 2 workdays] | Neck-shoulder pain |
| Korshøj et al. (2018) | Denmark | Blue-collar workers | Prospective cohort (DPhacto) | - 2012 to 2013 - (14; 4 weeks) | - 2,107 - (665) - [657] | - 45.0 (10.0) - 294 (44) | - Accelerometry/Actigraph GT3X+/Acti4 - (thigh and back) - [24 hr/day, 4–6 days] | Low back pain |
| Lunde et al. (2017) | Norway | Construction and healthcare workers | Prospective cohort (NR) | - NR - (1; 6 months) | - 1165 - (125) - [124] | - 39.9 (13.6) - 1 (2) | - Accelerometry/Actigraph GT3X+/Acti4 - (thigh and hip) - [3–4 consecutive days, work and leisure] | Low back pain |
| Thiese et al. (2011) | USA | Vocationally active adults | Prospective cohort (NR) | - 2006 to 2007 - (NR; 1 month) | - 119 - (68) - [68] | - 38.2 (11.3) - 18 (27) | - Accelerometry/Actigraph GT1M/ NR - (hip) - [7 consecutive days, waking hrs] | Low back pain |
| Sitthipornvorakul et al. (2015) | Thailand | White-collar workers | Prospective cohort (NR) | - NR - (4; 3 months) | - 4,000 - (387) - [362, neck pain; 366, low back pain] | - 34.9 (6.2) - 295 (76) | - Pedometer/CW700s/NR - (thigh) - [7 consecutive days, waking hrs] | Neck pain Low back pain |
| Ariens et al. (2001) | The Netherlands | Industrial and service workers | Prospective cohort (SMASH) | - 1994 - (3; 1 year) | - 2064 - (1,334) - [977] | - 35.7 (8.5) - 240 (26) | - Video recording/NR/NR - (NA) - [4 x 10 min or 14 min recordings, during a workday] | Neck pain |
eight articles on working populations included blue-collar workers. Three of these articles were from the DPhacto cohort study (Denmark) and two from the SMART cohort study (The Netherlands).

For the objective measurements of physical behaviour, two articles used video recordings, one used pedometer and the remaining six articles used accelerometry. Among the articles on working populations, three articles reported outcome on NP or neck-shoulder pain, one reported on sick leave due to NP, one article reported on both NP and LBP and three articles reported on LBP alone. The two articles from clinical/mixed populations investigated prognosis of acute and chronic LBP.

3.3 Critical appraisal

Table 2 shows the risk of bias and methodological quality of the included articles, the rightmost column showing the overall rating. Two articles from the DPhacto cohort were judged to have low risk of bias/good quality. Five articles were judged to have moderate risk of bias/moderate quality, while three articles (two from the SMASH cohort) were judged to have high risk of bias/low quality. Notably, all studies used a convenience sample and only the three articles from the DPhacto cohort included a non-responder analysis. Three articles did not report response rates at follow-ups. The overall quality of the exposure measurement was good, except in the two SMASH cohort articles where the description was insufficient to allow reproduction of the data collection and exposure measurement. In addition, these two articles did not report the reliability or reproducibility of the outcome measurement. Six of the 10 articles failed to describe the rationale for the choice of potential confounders and/or modifiers. The two articles on prognosis focused on model development (i.e. phase 1 studies). All articles but one (Bousema et al., 2007) had an acceptable description of the statistical analyses and reported adjusted estimates with 95% CIs.

3.4 Results of individual articles

Table 3 provides a detailed summary of the results of the included articles. All eight articles on working populations investigated risk of NP and/or LBP, while the two articles on clinical/mixed populations investigated prognosis of LBP. When the results of the individual articles on working populations were scrutinized, the following was noted for the two articles with low risk of bias/high quality: Hallman et al. (2016) found that increased sitting time at work was associated with a decline in neck-shoulder pain intensity during a
TABLE 2  Critical appraisal (modified version of the Quality in Prognosis Studies [QUIPS] tool). Quality/risk of bias on each item is indicated by colour (green = low risk of bias/good quality; yellow = moderate risk of bias/moderate quality; red = high risk of bias/poor quality). Overall quality/risk of bias (last column) is indicated by the same colours and appraised as: ≥2 red items + ≥2 yellow items = red; 2 red items or 1 red item + ≥1 yellow item = yellow; 1 red item = green

| 1st Author (year) | Study participation | Study attrition | Measurement of physical behaviour | Outcome measurement | Adjustment(s) for other variables | Statistical analysis and reporting | Overall quality and risk of bias |
|-------------------|---------------------|----------------|----------------------------------|---------------------|---------------------------------|----------------------------------|---------------------------------|
| Working population |                     |                |                                  |                     |                                 |                                  |                                 |
| Hallman et al. (2016) | Convenience sample |                |                                  |                     |                                 |                                  | No rationale for the choice of potential confounders and/or modifiers |
| Hallman et al. (2017) | Convenience sample |                |                                  |                     |                                 |                                  | No rationale for the choice of potential confounders and/or modifiers |
| Korshøj et al. (2018) | Convenience sample |                |                                  |                     |                                 |                                  |                                |
| Lunde et al. (2017) | Convenience sample; no non-responder analysis |                |                                  |                     |                                 |                                  | No rationale for the choice of potential confounders and/or modifiers |
| Thiese et al. (2011) |                     | Response rate at each follow-up not reported |                                  |                     |                                 |                                  | No rationale for the choice of potential confounders and/or modifiers |
| Sithipomvorakul et al. (2015) | Convenience sample; no non-responder analysis |                |                                  |                     |                                 |                                  | No rationale for the choice of potential confounders and/or modifiers |
| Ariens et al. (2001) | Convenience sample; no non-responder analysis |                | Not possible to reproduce data collection; measurement of physical behaviour not reported. | Reliability or reproducibility not reported. | No rationale for the choice of potential confounders and/or modifiers |
| Ariens et al. (2002) | Convenience sample; no non-responder analysis |                | Not possible to reproduce data collection; measurement of physical behaviour not validated. | Reliability or reproducibility not reported. | No rationale for the choice of potential confounders and/or modifiers |

(Continues)
In a second article based on data from the same cohort, Hallman et al. (2017) found that high leisure-time physical activity was associated with a slower decrease in neck-shoulder pain among women and men during a 12-month follow-up period, while high occupational physical activity was associated with slower decrease in neck-shoulder pain among men only. The reported associations were weak in both articles.

Among the four articles on working populations with moderate risk of bias/moderate quality the following was noted: Korshøj et al. (2018) found that increased sitting time at work among blue-collar workers was associated with a favourable course of LBP during a 12-month follow-up period. Likewise, Lunde et al. (2017) found that increased sitting time at work among healthcare workers was associated with reduced LBP intensity at 6-months follow-up. In the same article, increased time spent standing at work was associated with increased LBP intensity at 6-months follow-up. Thiese et al. (2011) investigated vocationally active adults and found that the tertile with the highest level of physical activity (work and leisure pooled) had higher risk of LBP compared to the middle tertile. In a study of white-collar workers, Sithipornvorakul et al. (2015) found that increased number of steps (work and leisure pooled) was associated with reduced risk of NP at 12-months follow-up.

The two articles from the SMART cohort were considered high risk of bias/low quality. In the first article, industrial and service workers who were sitting more than 95% of their work time had an increased risk of NP during a 3-year follow-up period compared to workers who were sitting <1% of the work time (Ariens et al., 2001). In the second article, workers who were sitting 1%–50% of the work time had reduced risk of sick leave due to NP compared to workers who were sitting <1% of the work time (Ariens et al., 2002).

Two articles with moderate to high risk of bias/moderate to poor quality investigated prognosis and found no association between baseline physical behaviour and LBP-related disability at 3-months follow-up (Hendrick et al., 2013) or recovery from LBP at 1-year follow-up (Bousema et al., 2007). These two studies included a combination of care-seekers and respondents to newspaper advertisements.

Table 4 provides a summary of the fully adjusted results according to exposures and outcomes. Three of four articles with low to moderate risk of bias and moderate to good quality indicate that increased sitting at work is associated with reduced risk of NP or LBP. Among the four articles investigating the effect of physical behaviour at work and/or during leisure, the three articles on blue-collar workers indicate that increased physical activity at work and/or during leisure increases the risk of NP and LBP. The one article on white-collar workers found that increased walking (work/leisure pooled) was associated with reduced risk of NP.
| 1st Author (year) | Exposure | Main outcome variables | Variables in fully adjusted models | Results (fully adjusted significant results with estimates in bold [crude estimates]) | Summary of findings<sup>a</sup> |
|-------------------|----------|------------------------|-----------------------------------|--------------------------------------------------------------------------------|-------------------------------|
| **Working population** | | | | | |
| Hallman et al. (2016)<sup>b</sup> | % time sitting at work past month reported via SMSs every fourth week over 1 year (14 in total). | Peak neck-shoulder pain | Age; sex; BMI; seniority; occupational sector; lifting/carrying time at work; sitting time at leisure; PA at work and leisure; working with dominant arm elevated >60°. | **Blue-collar workers (cleaning, transport, manufacturing):** More sitting time at work associated with a faster decline in neck-shoulder pain over 12 months (β −0.00, 95% CI −0.00 to 0.00 [β −0.00, 95% CI −0.001 to 0.00]). | Sitting at work associated with reduced risk of neck-shoulder pain over 12 months. Association is very weak. |
| Hallman (2017)<sup>b</sup> | % time PA at work and during leisure | Peak neck-shoulder pain past month reported via SMSs every fourth week over 1 year (14 in total). | Age; sex; BMI; occupational sector; lifting and carrying at work; time with upper arm elevated >60° at work and leisure; baseline pain intensity of neck-shoulder pain. | **Blue-collar workers (cleaning, transport, manufacturing):** LTPA associated with slower decrease in neck-shoulder pain over 12 months (β 0.00, 95% CI 0.00 to 0.10 [β 0.03, 95% CI 0.00 to 0.05]). LTPA associated with slower decrease in neck-shoulder pain over 12 months in women (β 0.05, 95% CI 0.00 to 0.09 [β 0.06, 95% CI 0.02 to 0.10]). OPA associated with slower decrease in neck-shoulder pain over 12 months in men (β 0.03, 95% CI 0.01 to 0.05 [β 0.04, 95% CI 0.01 to 0.06]). | LTPA associated with increased risk of neck-shoulder pain over 12 months among women and men. OPA associated with increased risk of neck-shoulder pain over 12 months in men. Associations are very weak. |
| Korshøj et al. (2018)<sup>b</sup> | Total time/ pattern of sitting at work | Peak LBP past month reported via SMSs every fourth week over 1 year (14 in total). | Diagnosis with herniated disc; LBP past 3 months prior to baseline; occupational lifting and carrying; sitting time during leisure. | **Blue-collar workers (cleaning, transport, manufacturing):** Longer duration of total and temporal sitting periods at work associated with favourable time course of LBP over 12 months (total sitting time, β −0.05, 95% CI −0.07 to −0.04 [β −0.05, 95% CI −0.07 to 0.04]; brief bursts ≤5 min, β −0.12, 95% CI −0.15 to −0.08 [β −0.12, 95% CI −0.16 to −0.09]; moderate periods 5–20 min, β −0.12, 95% CI −0.15 to −0.08 [β −0.12, 95% CI −0.16 to −0.09]); prolonged periods >20 min, β −0.12, 95% CI −0.16 to −0.09[β −0.12, 95% CI −0.16 to −0.09]). | Longer duration of total and temporal sitting at work associated with decreased risk of LBP over 12 months. Associations are very weak. |

(Continues)
| 1st Author (year) | Exposure | Main outcome variables | Variables in fully adjusted models | Results (fully adjusted significant results with estimates in bold [crude estimates]) | Summary of findingsa |
|------------------|----------|------------------------|-----------------------------------|----------------------------------------------------------------------------------|---------------------|
| Lunde et al. (2017) | Minutes sitting and standing at work and during leisure | LBP intensity past 4 weeks scored on a 4-point scale at 6-months follow-up. | Age; sex; BMI; smoking; heavy lifting at work; forward bending at work; social climate at work; decision control at work; fair leadership at work; empowering leadership at work; sitting time during leisure. | *Healthcare workers*: Duration of sitting at work negatively associated with LBP intensity ($\beta = -0.34$, 95% CI $-0.66$ to $-0.02$ [$\beta = -0.35$, 95% CI $-0.57$ to $-0.13$]). Duration of standing at work positively associated with LBP intensity ($\beta = 0.58$, 95% CI 0.04 to 1.11 [$\beta = 0.34$, 95% CI $-0.05$ to 0.72]). *Construction workers*: No significant associations between sitting and standing and LBP intensity (at work or full day). | Longer duration of sitting at work among healthcare workers associated with decreased risk of LBP intensity at 6-months follow-up. Standing at work among healthcare workers associated with increased risk of LBP intensity. |
| Thiese et al. (2011) | Time spent in light, moderate and vigorous PA quantified by counts/min | LBP intensity scored on a 10-point VAS at monthly follow-ups after a pain-free period of >90 days. | Age; sex; BMI; back compressive force; tobacco use; depression; seeing a health care provider for LBP; light PA and moderate/ vigorous PA (mutually adjusted). | *Vocationally active adults*: The highest tertile (314–650 counts/min) (RR 4.95, 95% CI 1.12 to 21.9 [RR 3.68, 95% CI 1.06 to 12.77]) associated with increased risk of LBP, referencing the middle tertile (232–314 counts/min). Minutes with moderate/vigorous activity (>760 counts/min) adjusted for light activity associated with risk of LBP in the lowest (36–92 min/d) (RR 13.0, 95% CI 1.79 to 94.6 [RR 14.60, 95% CI 1.20 to 17.62]) and highest (124–298 min/d) (RR 9.53, 95% CI 1.56 to 58.0 [RR 36.14, 95% CI 1.54 to 24.44]) tertile, referencing the middle tertile. No significant association between the lowest tertile of mean counts (100–232 counts/min) and risk of LBP. No significant association between light activity (251–760 counts/min) and risk of LBP. | Higher level of PA associated with increased risk of LBP (mean number of days during follow-up until onset of LBP or censure was 241.7, SD 109.4). |
| Sithipomvorakul et al. (2015) | Mean daily walking steps | NP and LBP lasting >24 hr past month and pain intensity >30 mm on a 100 mm VAS collected monthly over a 12-month period. | For NP: History of NP; chair adjustability; physical job demands. For LBP: History of LBP; standing >2 hr during work; psychological job demands. | *Sedentary workers*: Daily walking steps negatively associated with onset of NP (OR 0.86, 95% CI 0.74 to 1.00 [OR 0.88, 95% CI 0.76 to 1.02]). No significant association between daily walking steps and onset of LBP. | Increasing number of daily walking steps associated with reduced risk of NP during a 12-month follow-up period. |

(Continues)
| 1st Author (year) | Exposure                  | Main outcome variables                                                                 | Variables in fully adjusted models                                                                 | Results (fully adjusted significant results with estimates in bold [crude estimates])                                                                 | Summary of findings<sup>a</sup> |
|------------------|---------------------------|-----------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| Ariens et al. (2001)<sup>c</sup> | % time sitting at work | Occurrence of NP last 12 months scored on 4-point scale (seldom or never; sometimes; regular; prolonged) at three annual follow-ups. | Age; sex; driving a vehicle (work); frequent flexion or rotation of the upper part of the body (work); neck flexion (work); neck rotation (work); force exertion with hands or arms (leisure-time); driving a vehicle (leisure); quantitative job demands; decision latitude. | *Industrial and service workers:* Sitting more than 95% of the working time associated with increased risk of NP at annual follow-up, referencing workers sitting <1% of the working time (RR 2.34, 95% CI 1.05 to 5.21 [RR 2.01, 95% CI 1.04 to 3.88]). No significant associations between sitting at work 1%–95% and NP. | Sitting time at work >95% associated with increased risk of NP during a 3-year follow-up period. |
| Ariens et al. (2002)<sup>c</sup> | % time sitting at work | Sickness absence due to NP with a minimal duration of 3 days during 3-year follow-up. | Age; sex; neck flexion of >45°; neck rotation of >45°; decision authority; skill discretion; frequent flexion or rotation of the upper part of the body during leisure-time; driving a vehicle during leisure-time; sports participation; coping. | *Industrial and service workers:* Sitting 1%–50% of the working time associated with reduced risk of sickness absence due to NP, referencing workers sitting <1% of the working time (RR 0.32, 95% CI 0.13 to 0.76 [RR 0.38, 95% CI 0.17 to 0.87]). No significant associations between sitting >50% of the working time and risk of sickness absence due to NP. | Sitting time at work 1%–50% associated with reduced risk of sickness absence due to NP. Association is weak. |

**Clinical/mixed population**

| Hendrick et al. (2013) | Activity counts during free living converted to kcals/minute | RMDQ at 3 months. | Age; sex; BMI; occupation; PA at baseline; PA change to follow-up; PA prior to the onset of LBP; fear avoidance; anxiety and depression; emotional distress; baseline RMDQ; baseline LBP. | *People with LBP:* No association between PA and RMDQ (β 0.00, 95% CI 0.00 to 0.00). | PA not associated with prognosis of LBP at 3-months follow-up. |
| Bousema et al. (2007) | Activity counts/day during free living | Recovered from LBP, i.e., pain-free for at least 3 weeks at 1-year follow-up. | None | *People with LBP:* No association between PA and recovery from LBP (no estimate reported). | PA not associated with prognosis of LBP at 1-year follow-up. |

**Abbreviations:** LBP, low back pain; LTPA, leisure-time physical activity; NP, neck pain; OPA, occupational physical activity; OR, odds ratio; PA, physical activity; RMDQ, Roland Morris Disability Questionnaire; RR, relative risk; SD, standard deviation; VAS, visual analogue scale; β, beta coefficients.

<sup>a</sup>Overall quality/risk of bias indicated by colour (green = low risk of bias/good quality; yellow = moderate risk of bias/moderate quality; red = high risk of bias/poor quality).

<sup>b</sup>DPhacto cohort.

<sup>c</sup>SMASH cohort.

<sup>d</sup>Inconsistent reporting in text and table, estimates from table used here.
This systematic review provides an overview of the association between objectively measured physical behaviour (i.e. sedentariness and activity) and risk or prognosis of NP and LBP. Ten articles from seven studies met the inclusion criteria, of which seven articles were considered to have low/moderate risk of bias and moderate/good quality. Eight articles investigated risk or change of NP or LBP and two articles investigated prognosis of LBP, whereas none of the included articles investigated prognosis of NP. The main findings were that (a) increased sitting time at work among blue-collar workers reduces the risk of NP and LBP, (b) increased physical activity during work and/or leisure among blue-collar workers increases risk of NP and LBP and (c) there is no evidence supporting the notion that physical behaviour influences the prognosis of LBP. The articles on risk or change of NP or LBP with low risk of bias/good quality reported weak associations and small effect sizes. Noteworthy, the results from the articles with moderate risk of bias/moderate quality mainly go in the same direction as the high-quality articles, despite being heterogeneous in terms of outcome, measurement of physical behaviour, duration of follow-up and statistical methods. Regarding prognosis, the two included articles had moderate and high risk of bias and moderate and low quality, respectively. Neither of these articles indicated that physical behaviour influences the prognosis of LBP in any direction.

In contrast to previous reviews (Alzahrani et al., 2019; Bakker et al., 2009; Chen et al., 2009; Jun et al., 2017; Kim et al., 2018; Paksaichol et al., 2012; Roffey et al., 2010a,b; Shiri & Falah-Hassani, 2017; Sitthipornvorakul et al., 2011), we found that increased physical activity increases the risk of NP and LBP while increased sitting time at work reduces this risk. Possible explanations for the discrepancy in findings between our review and previous reviews are the focus on different domains of physical behaviour (work vs. leisure) and our restriction to prospective studies with objective measurements of physical behaviour. Recent reviews have been restricted to leisure-time physical activity (Alzahrani et al., 2019; Shiri & Falah-Hassani, 2017), while five of the eight articles in the current review included measurements of physical behaviour during working hours only. Furthermore, six of the eight articles on working populations included blue-collar workers who typically have high levels of physical activity at work. Thus, the reduced risk associated with increased sitting at work and the increased risk with increased physical activity should be interpreted in view of the study populations under investigation.

From studies on cardiovascular health, it appears that leisure-time physical activity mainly has health-enhancing effects while occupational physical activity may have negative effects on cardiovascular health (Holtermann, Krause, Beek, & Straker, 2018). The underlying mechanism for this so-called
‘physical activity paradox’ is unclear but it is conceivable that the different patterns of physical behaviour between work and leisure (e.g. intensity, duration, time for restitution etc.) elicit distinct biomechanical loadings and physiological responses which over time have differential impact on various health outcomes, including musculoskeletal health. Only one article in the current review reported on the independent effects of work and leisure-time physical activity within the same study sample and found that increased physical activity in both domains was associated with slower decline in NP among blue-collar workers over a 12-month follow-up period (Hallman et al., 2017). Notably, the one article on white-collar workers found that increased total physical activity (work and leisure combined) was associated with reduced risk of NP during a 12-month follow-up period (Sitthipornvorakul et al., 2015). It is likely that the greater part of physical activity among these white-collar workers occurred during leisure-time, indicating a possible beneficial effect of leisure-time physical activity on risk of NP. Nevertheless, further longitudinal studies with objective measurements are needed to clarify if physical behaviour during work and leisure have a contrasting effect on risk and prognosis of NP and LBP.

Strengths of this systematic review include the comprehensive literature search in three electronic databases conducted by a trained research librarian, an investigator team with extensive experience in systematic reviews and knowledge about NP and LBP, the use of comprehensive checklists to assess risk of bias/methodological quality, blinding of reviewers during data extraction and the focus on prospective studies using objective measurements of physical behaviour. There are some important methodological limitations of the included articles that need to be considered when interpreting the findings in this review. In prospective cohort studies, one needs to consider the possibility of reverse causality bias (Gage, Munafo, & Davey Smith, 2016; e.g. instead of physical behaviour influencing the risk of NP and LBP it is the other way around). We noted that in most of the studies on risk or change, it was unclear whether people with ongoing NP or LBP were included at baseline, and only two articles adjusted for baseline pain intensity in their analysis (Hallman et al., 2017; Korshøj et al., 2018). While the results remained unchanged in the article by Korshøj et al. (2018), the increased risk of NP over a 12-month period with increased leisure-time physical activity disappeared in the article by Hallman et al. (2017) after adjusting for baseline pain. Thus, in most of the included articles, the presence of NP or LBP at baseline could have influenced the baseline physical behaviour and hence distorted the supposed causative association between the exposure and outcome. For example, if NP or LBP at baseline led to reduced rather than increased baseline physical activity (Lin et al., 2011; Zadro et al., 2017), this would likely lead to an underestimation of the risk-enhancing effect of increased physical activity on risk of NP and LBP. Likewise, if NP or LBP at baseline led to increased sitting time, this would likely underestimate the association between increased sitting time and reduced risk of NP and LBP. These putative underestimations rest on the assumptions that physical activity indeed increases the risk of NP and LBP, and conversely, that increased sitting time reduces this risk. Thus, provided that these assumptions are true, reducing the potential reversed causality bias (e.g. by excluding pain-afflicted individuals at baseline) would likely strengthen the association between increased physical activity among blue-collar workers and increased risk of NP and LBP, and strengthen the association between increased sitting time and reduced risk of NP and LBP.

Another potential limitation in this body of literature, pertinent to the compositional nature of physical behaviour data and the failure of the included articles to consider this in the analytic approach and interpretation of findings. Long-term objective measurements of physical behaviour constitute compositional data because the duration of various physical behaviours and sleep are inherently codependent, that is, increasing the duration of one behaviour will necessarily reduce the duration of at least one other behaviour because the total time is fixed (e.g. within a workday, full day [24 hr] etc.; Dumuid et al., 2019). Thus, whether a change in one type of behaviour is beneficial (or harmful) for NP and LBP depends on the compensatory shifts in other behaviours (Dumuid et al., 2018; Gupta et al., 2018). None of the articles in the current review considered the compositional nature of physical behaviour data in their analysis and further studies are therefore warranted to determine the possible domain-specific and causative effect of physical behaviour on risk of NP and LBP (Gupta et al., 2019). There is evidence that different compositions of physical behaviour may have distinct impacts on outcomes such as obesity, mortality, blood pressure and cardiometabolic biomarkers (Grig et al., 2018; Gupta et al., 2019). Importantly, an analytic approach based on the principles of compositional data analysis can provide information about the optimal balance between different physical behaviours to promote musculoskeletal health (Pedisic, 2014). However, whether a ‘physical behaviour balance model’ provides a useful framework for understanding risk and/or prognosis of NP and LBP cannot be deduced from the included papers in this current review. We therefore argue that future studies should include long-term objective measurements of physical behaviour and incorporate compositional data analysis. Importantly, sleep may have profound impact on risk and prognosis of NP and LBP (Mork et al., 2014; Uhlig, Sand, Nilsen, Mork, & Hagen, 2018) and should therefore be included in a compositional data analysis approach (Matricciani et al., 2018). Knowledge gained from such studies may provide input to future recommendations for an optimal time distribution between different physical behaviours and sleep to promote musculoskeletal health.
CONCLUSION

This systematic review indicates that, among blue-collar workers, increased sitting time at work may protect against NP and LBP while increased physical activity during work and/or leisure is not protective and may even slightly increase this risk. Associations were weak, especially in articles with low risk of bias/high quality. There was no evidence supporting physical activity as a prognostic factor for LBP. The current findings should be interpreted with caution due to few available studies, and the methodological shortcomings. Future prospective cohort studies should include long-term objective measurements of physical behaviour, incorporate a compositional data analysis approach and consider the possible domain-specific effects of physical behaviour on risk and prognosis of NP and LBP.

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CONFLICT OF INTEREST

None declared.

AUTHOR CONTRIBUTIONS

CKØ, MV, IA, MC and PIM were involved in the conception of this study, while CKØ, MV, IA, CLY, JH and PJM contributed to the study design. CKØ wrote the protocol published in PROSPERO with critical revisions from all authors. The design and execution of the searches were done by CKØ supervised by a trained research librarian. CKØ, MV, IA and PJM assessed studies for inclusion and did the data extraction with assistance from JH when necessary. All authors were involved in the critical appraisal supervised by CLY. Analysis and interpretation of data were done by all the authors. CKØ drafted the report with critical revision and contribution from all authors. All authors have given their approval prior to publication of the final version of this systematic review article.

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section.

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