Is Objectively Measured Sitting Time Associated with Low Back Pain? A Cross-Sectional Investigation in the NOMAD study

Nidhi Gupta1*, Caroline Stordal Christiansen1, David M. Hallman2, Mette Korshøj1, Isabella Gomes Carneiro1, Andreas Holtermann1

1 Department of Musculoskeletal Disorders, National Research Centre for the Working Environment, Copenhagen, Denmark, 2 Department of Occupational and Public Health Sciences, Centre for Musculoskeletal Research, University of Gävle, Gävle, Sweden

* ngu@nrcwe.dk

Abstract

Background

Studies on the association between sitting time and low back pain (LBP) have found contrasting results. This may be due to the lack of objectively measured sitting time or because socioeconomic confounders were not considered in the analysis.

Objectives

To investigate the association between objectively measured sitting time (daily total, and occupational and leisure-time periods) and LBP among blue-collar workers.

Methods

Two-hundred-and-one blue-collar workers wore two accelerometers (GT3X+ Actigraph) for up to four consecutive working days to obtain objective measures of sitting time, estimated via Acti4 software. Workers reported their LBP intensity the past month on a scale from 0 (no pain) to 9 (worst imaginable pain) and were categorized into either low (≤5) or high (>5) LBP intensity groups. In the multivariate-adjusted binary logistic regression analysis, total sitting time, and occupational and leisure-time sitting were both modeled as continuous (hours/day) and categorical variables (i.e. low, moderate and high sitting time).

Results

The multivariate logistic regression analysis showed a significant positive association between total sitting time (per hour) and high LBP intensity (odds ratio; OR=1.43, 95% CI=1.15-1.77, P=0.01). Similar results were obtained for leisure-time sitting (OR=1.45, 95% CI=1.10-1.91, P=0.01), and a similar but non-significant trend was obtained for occupational sitting time (OR=1.34, 95% CI 0.99-1.82, P=0.06). In the analysis on categorized sitting time, high sitting time was positively associated with high LBP for total (OR=3.31, 95%
Conclusion
Sitting time is positively associated with LBP intensity among blue-collar workers. Future studies using a prospective design with objective measures of sitting time are recommended.

Introduction
Low back pain (LBP) is a major global health problem with annual prevalence rates ranging between 22 to 65% [1]. An increasing trend of LBP from 22% in 1987 to 30% in 2005 has been observed in the general working population in Denmark [2], which is consistent with other countries [3, 4]. The direct and indirect costs of LBP are enormous due to excessive use of health services, absence from work, and lost productivity [5–8].

Adults generally spend as much as 6–8 hours per day or more than 45–50% of their waking hours in a sitting position [9–13]. Previous research has indicated that prolonged sitting may be a risk factor for developing LBP [14, 15]. Possible mechanisms mentioned for a causal relationship between prolonged sitting and LBP are increased intra-discal pressure [16], stiffness of the lumbar spine [17], reduced strength of the lower back muscles [17, 18] and/or decreased metabolic exchange leading to excessive body weight [19]. In a cross-sectional study, Omokhodion and Sanya [20] observed a significant association between self-reported occupational sitting time (i.e. for more than 3 hours) and increased severity of LBP. This finding between sitting time and LBP is in line with some cross-sectional [20–27] and prospective studies [28], while being in contrast with other studies [29–32].

One reason for these contrasting results may be that most studies have utilized self-reported measurements of sitting time [24, 33]. Self-reported measures of sedentary behavior may be biased and provide less reliable and valid estimates than objective measures [34–37]. It was, therefore, suggested that objective measures of sedentary behavior should be preferred in investigations on its association with health outcomes [38]. Another reason for the contrasting results may be that several studies [39, 40] on the association between sitting time and LBP have been conducted on heterogeneous populations with respect to socioeconomic status [29, 31, 32], which may increase the risk for socioeconomic residual confounding [41]. Also, many studies investigating the association of sitting time with LBP have been performed on study populations with a relatively low variability of sitting time, such as office workers [42]. Therefore, literature may particularly benefit from studies among groups of workers homogenous according to their socioeconomic status and with higher between-subject variability of sedentary behavior.

Moreover, only few studies have measured both occupational and leisure-time sitting to investigate their possible independent or combined association with LBP [43]. Because occupational and leisure-time sitting may be correlated [44], it is important to either perform a combined analysis of occupational and leisure-time sitting, or to mutually adjust for these variables when investigating their independent association with LBP. Another reason for separating work and leisure periods is that they might differ with respect to the temporal variation in sitting periods, which could be important to both metabolic [45] and musculoskeletal symptoms [46].
Therefore, the aim of this study was to investigate the association between objectively measured sitting time (daily total, and during occupational and leisure periods) and LBP among blue-collar workers.

Material and Methods

Study Population and Design

This study is a part of a cross-sectional ‘New method for Objective Measurements of physical Activity in Daily living (NOMAD)’ study in Denmark. Blue-collar workers were recruited from seven workplaces (i.e., construction workers, cleaners, garbage collectors, manufacturing workers, assembly workers, mobile plant operators and workers in the health service sector). These workplaces were selected with the purpose to investigate a large dispersion in sitting time while being relatively homogeneous with respect to socioeconomic status. The workplaces were recruited primarily through contact with trade unions or safety representatives at the individual workplaces. The inclusion criterion at workplace level was the possibility for the workers to participate in the study activities during paid working hours. Inclusion criteria for individuals to participate in the study were primary work of at least 20 hours per week, being between 18 and 65 years of age, and giving a signed informed consent. Exclusion criteria were being a white-collar worker, pregnant, having fever, and reporting skin allergy to adhesive tape used for mounting objective measurement devices.

The study was approved by the Ethics Committee for the Capital Region of Denmark (journal number H-2–2011–047) and conducted in accordance with the Helsinki declaration [47].

The reporting of the study follows the recommendations of “Strengthening the Reporting of Observational Studies in Epidemiology” statement [48].

Procedure

All workers were invited to information meetings where the aim, contents, requirements and activities of the study were explained. All invited workers in the information meetings completed a screening questionnaire containing general information about demographic variables. Interested workers voluntarily provided their written informed consent to participate in the study. Data collection was conducted over four days with research staff visiting the workers at the workplace on days one and four. On the first day, workers interested in participating in the study (a) underwent anthropometric measurements, (b) were equipped with accelerometers for objective measures of sitting time, and (c) completed a short questionnaire containing a single item regarding LBP intensity. On day four, the workers returned the objective measurement devices.

Low back pain intensity. Self-reported information about LBP intensity was obtained using a modified version of the Standardized Nordic questionnaire for the analysis of musculoskeletal symptoms [49]. Workers were asked to rate their worst intensity of pain in the lower back during the past month on a response scale from 0–9, where 0 equaled ‘no pain’ and 9 equaled ‘worst imaginable pain’ [50]. The scale is horizontally oriented to resemble the visual analogue scale [51]. The workers were categorized into a ‘low’ (≤5), and ‘high’ (>5) pain group for the statistical analyses. These cut points were chosen based on a previous prospective cohort study on musculoskeletal risk factors for sickness absence among healthcare workers [50].

Objective measures of sitting time. Sitting time was estimated using two accelerometers (Actigraph GT3X+, Actigraph LLC, Florida, USA) for approximately four continuous days (4 x 24 hours)—a period generally covering at least two full working days including both occupational and leisure periods. Actigraph is a compact water resistant device (19x34x45mm, weight
19g) which measures tri-axial acceleration with a frequency of 30 Hz, a dynamic range of ±6G (1G = 9.81 m/s²) and precision of 12 bit.

Using Fixomull (Fixomull BSN medical GmbH, Hamburg, Germany), a double side tape (3 M, Hair-Set, St. Paul, Minnesota, USA) and a waterproof film (OpSite flexifix, Smith & Nephew, London, England), two accelerometers were placed at the recommended and standardized position on the thigh and trunk [52, 53]. One accelerometer was placed at the medial front of the right thigh, midway between the hip and knee joints [52]. The other accelerometer was placed at processus spinosus at the level of T1–T2 [53, 54]. The workers were instructed (a) to take off the accelerometers if they caused itching or any kind of discomfort such as disturbed sleep, (b) to perform a reference measurement in a standing upright position for 15 sec every day, and (c) to fill in a short diary everyday concerning their working hours, leisure time, sleep, non-wear time, and time of reference measurement.

Initialization of the Actigraph for recording and downloading of data was done using the manufacturer’s program (Actilife Software version 5.5, ActiGraph LLC, Pensacola, FL, USA).

The accelerometer data were further analyzed using a specially developed MATLAB based program, Acti4 (The National Research Centre for the Working Environment, Copenhagen, Denmark and Federal Institute for Occupational Safety and Health, Berlin, Germany) estimating the type, duration and variation of physical activities and body postures with high sensitivity and specificity [52]. In short, accelerometer data are first low-pass filtered with a 5 Hz 4th order Butterworth filter and then split-up into 2 sec intervals with 50% overlap. Afterwards, the individual’s reference measurement (i.e. standing in an upright position for 15 sec on every measured day) values of the thigh and trunk accelerometer were utilized to obtain the coordinate transformation between the axis of the accelerometers and the orientation of the thigh and trunk. The occurrence of sitting postures were identified according to a slightly revised procedure from Skotte, Korshoj [52] study, mainly due to the need to differentiate lying from sitting posture. In our study, sitting posture was defined as the posture in which the inclination of the thigh accelerometer is above 45° and the trunk accelerometer is below 45° [52]. In lying posture, the inclination of the thigh accelerometer is below 45° and the trunk accelerometer is above 45°.

All non-working days, sleep or bedtime periods, and non-wear periods were excluded from the analysis. The non-wear periods were identified based on the following criteria: (a) the software detected a period longer than 60 minutes showing zero counts per minute, (b) the worker reported non-wear periods, and (c) artefacts or missing data were detected by visual inspection.

Subsequently, sitting time on working days was categorized into the following settings; (a) total sitting time (i.e. total measured sitting hours divided by the number of days), (b) occupational sitting (i.e. total measured sitting hours during working periods divided by the number of days) and (c) leisure-time sitting (i.e. total measured sitting hours during leisure periods divided by the number of days). A day consisted of 24 hours starting from midnight to midnight. Work was defined as the self-reported hours spent at the primary occupation and leisure time as the remaining waking hours on a working day.

As this study was intended to address working days only, we included days comprising objective measurements of at least 4 hours of work per day. Further, only workers with at least one valid day comprising at least 10 hours of wear time were included for the analysis on total sitting time. For the specific analyses on occupational and leisure-time sitting, we included workers with at least one valid day of measurement. A valid day was based on the following criteria: (a) valid work: at least 4 hours of work time and 75% of the individual’s average reported working time, and (b) valid leisure time: at least 4 hours of leisure time and 75% of the individual’s average reported leisure time. The reason for choosing these criteria was to prevent bias.
due to inclusion of extreme unrepresentative data in the analysis and to reflect optimal daily wear time for valid measurements of sitting time. At least one valid day of measurement for estimating physical activities has been used as supported by previous studies [11, 55–57].

All sitting time variables were first treated as continuous variables. Later, to inspect for the possible non-linear relationship between sitting and LBP, the sitting time was also categorized into tertiles, termed as low, moderate and high sitting time.

**Covariates.** Gender was determined using a question “are you male or female?” The age of the workers was determined from the workers’ Danish unique civil registration number (CPR number). Smoking behavior was determined from the question: “Do you smoke?” with 4 response categories summarized into two groups; yes (yes daily; yes sometimes) and no (used to smoke, not anymore; and I have never smoked). Seniority in the job (total months) was determined with the question: “For how long have you had the kind of occupation that you have now?” The influence at work (decision authority/latitude) of the workers was determined by the 4-item scale from the Copenhagen Psychosocial Questionnaire [58] with Cronbach’s Alpha of 0.77. A sample item is “Do you have a large degree of influence concerning your work?”. The responses were scored on a Likert scale with response categories ranging from 0 (never) to 5 (always). A composite scale measuring influence at work was constructed by calculating the mean rating of all four items. For the analysis, this scale was recoded to 0–100 scale, whereby a larger score represented a higher degree of influence at work. The body mass index (BMI, kg/m²) was calculated using objectively measured height (m) and body weight (kg). The self-reported information on total time spent on occupational carrying and lifting was collected using a question: How much of your working time do you spend carrying or lifting things? with six response categories summarized into three groups; high lifting/carrying time (almost all the time, approximately ¾ of the time, and ½ of the time), moderate lifting/carrying time (¼ of the time) and low lifting/carrying time (rarely/very little and never). Age, job seniority, BMI, and influence at work were treated as continuous variables, while time spent carrying/lifting at work, gender, and smoking were entered as categorical variables in the statistical analyses.

**Statistical Analyses**

The association between total sitting time and LBP intensity was determined using binary logistic regression. In the primary model, dichotomized LBP [categorized into low (≤5) and high LBP (>5)] was entered as a dependent variable and continuous measures of total sitting time (in hours) as an independent variable. The model was further step-wise adjusted with the following covariates; step 1) age, gender, BMI, and smoking, step 2) step 1 + job seniority, influence at work, and occupational lifting/carrying time at work. Similar analyses were also performed by regressing the high and moderate sitting time categories against high LBP, referencing the low sitting time category.

Moreover, similar logistic regression analyses were performed on continuous (in hours) and categorical measures of occupational and leisure-time sitting (i.e. low, moderate and high), while adjusting for the above-mentioned covariates. Additionally, in the final step, the model was further adjusted for occupational or leisure-time sitting depending on the modelled variable (Step 3).

To test the consistency of the results, four different sensitivity analyses were performed. First, a similar logistic model (as explained above) was performed using a lower and higher cut point of high LBP intensity (i.e. ≥4 on the 0–9 scale and i.e. ≥6 on the 0–9 scale) than the cut point used in the primary analysis (i.e. >5 on the 0–9 scale). Second, further logistic regression analyses were performed modeling the normalized sitting time based on average measured hours per day (i.e. percent total sitting) instead of using absolute time of sitting as in the
primary analysis. Third, similar analyses were performed using log binomial regressions to calculate the relative risk (RR) instead of OR calculated via the logistic regression. Fourth, to investigate a potential bias due to wear time on the association between sitting time and LBP, we performed similar logistic regression analyses as in the primary analysis with further adjustment for number of valid days measured or average measured time per day.

Multi-collinearity diagnostic indicated no multi-collinearity issues (condition indices <30 and VIF values <10) between the chosen independent variables in this study. The covariates were selected \textit{a priori} based on previous studies on risk factors of LBP [59–69]. Specifically age, gender, BMI, and smoking were identified as potential individual risk factors while occupational lifting/carrying time, influence at work, and job seniority as occupational risk factors.

In all models, the OR/RR with 95% confidence intervals (CI) was estimated indicating the probability of reporting high LBP. Statistical Package for the Social Sciences (SPSS, IBM, version 21.0) was utilized to perform all statistical operations. The level of significance was set at $P<0.05$.

\section*{Results}

\subsection*{Characteristics of the Study Population}

Out of 391 workers who were invited to the information meeting, 358 (92\%) workers were engaged in blue-collar occupations and being eligible for the study. Out of them, 259 (66\%) volunteered to participate in our study and 218 of them (56\%) answered to the single item of LBP (pain intensity) and participated in the objective measurements. Nine workers were excluded due to unavailability of at least one valid work day measurement. Eight out of 209 from the analysis on total sitting time and twenty-two out of 209 workers from the specific analyses on occupational and leisure-time sitting were excluded due to unavailability of at least one day with valid objective measurement periods. Finally, 201 (51\%) and 187 (48\%) workers were included in the main analyses on total, occupational and leisure-time sitting, respectively (Fig. 1).

In the analysis on total sitting time, a total of 8,223 valid waking hours were included with 500 valid days and a mean (SD) of 16.6 (1.6) waking hours per day. On average, workers were measured for 2.5 (SD 1.1) days, and 80\% of the workers wore accelerometers for \( \geq 2 \) valid measured days. In the occupational and leisure-time specific analyses, a total of valid 3,212 occupational and 3,151 leisure hours over 368 days, with 8.9 (SD 2.6) leisure, and 8.4 (SD 2.4) occupational hours per day were included.

On average, the participating blue-collar workers sat for 7.3 (SD 2.1) hours of total time, 3.0 (SD 1.4) hours of work time and 4.8 (SD 1.8) hours of leisure time each day. Total, occupational and leisure-time sitting ranged between 2.5–13.5, 0.3–6.6, and 0.7–10.3 hours, respectively.

A significant amount of workers (28\%) were manufacturing workers, followed by assemblers (16\%), cleaners (15\%) and construction workers (18\%), while the remaining workers were garbage collectors (9\%), personal care workers (7\%) and drivers (5\%). Sixteen percent of the workers reported high LBP (>5). The participating workers were predominantly males (58.2\%), non-smokers (56.8\%), had low influence at work (mean 43.7, SD 23.3) and reported moderate to high occupational lifting and carrying time (66.5\%) (Table 1).

Table 1 shows the characteristics of the included workers categorized into low and high intensity of LBP. There were no marked differences between groups with high and low LBP intensity in terms of age, BMI, job seniority, influence at work, distribution of gender, and number of valid measured days. However, workers with high LBP, compared to those with low LBP, were measured for slightly longer time and were exposed to longer total sitting time. A substantial proportion (58\%) of workers with high LBP were exposed to high total sitting time (i.e. >8 hours per day). There was no marked difference between the blue-collar occupations with respect to LBP intensity ($F = 1.48, P = 0.17$).
Approximately similar distributions of characteristics between low and high LBP intensity groups were observed among the 187 workers included in the occupational and leisure-time specific analyses (data not shown).

Table 2 shows the characteristics of the 201 workers stratified into low (≤6.4 h), moderate (6.5–8.3 h) and high (>8.3 h) total sitting time. The workers in the high sitting category were predominantly construction workers (28%) and assemblers (25%) while workers in the low sitting category were mostly manufacturing workers (61%). In the moderate sitting category, most workers were cleaners (21%), construction workers (19%), and manufacturing workers (18%).

The workers with high total sitting time were similar to the workers with low sitting time in most characteristics except that they were measured for slightly longer time, had slightly higher influence at work and more reported high LBP. The workers with moderate and low sitting time were approximately similar in terms of their overall descriptive characteristics.

When categorized based on occupational sitting time, the workers with high (>3.7h) and moderate sitting time (2.1–3.7h) were not significantly different from those with low sitting time (≤2.0h) for most descriptive characteristics, except for LBP intensity.
When categorized based on leisure-time sitting, the workers with high sitting time (>5.4h) were similar to those with low sitting time (0–3.9h), except that workers with high sitting time had higher job seniority, BMI, influence at work and LBP. However, no pronounced differences were observed between workers with low and moderate sitting time (4.0–5.4h).

**Association between the continuous measures of sitting time and LBP intensity**

Table 3 presents the results of the association between hours of sitting and high LBP intensity. There was a significant positive association between total sitting time and high LBP intensity (OR = 1.43). Adjustment for various confounders such as individual factors (age, gender, BMI, and smoking) and occupational factors (seniority, influence at work, and occupational lifting/carrying time) did not markedly influence the estimates or level of significance. We observed similar results for leisure-time sitting and high LBP intensity (OR = 1.38), which remained consistent after additional adjustment for occupational sitting time. We also found positive associations between occupational sitting time and high LBP intensity (OR = 1.36), but although the estimates remained similar, they became marginally insignificant (P = 0.06) with further adjustment for individual and occupational factors.
Table 2. Demographic characteristics of the blue-collar workers stratified on their objectively measured total sitting time.

| Variables                        | Low      | Moderate | High     |
|----------------------------------|----------|----------|----------|
|                                  | n (67)   | n (67)   | n (67)   |
| Gender                           |          |          |          |
| Male, n (%)                      | 36 (53.7)| 40 (59.7)| 41 (61.2)|
| Female, n (%)                    | 31 (46.3)| 27 (40.3)| 26 (38.9)|
| Age in years, M (SD)             | 43.7 (9.6)| 45.4 (10.7)| 45.0 (8.9)|
| Seniority in months, M (SD)      | 145.4 (137.9)| 164.3 (126.4)| 171.1 (142.8)|
| BMI in kg/m², M (SD)             | 25.7 (4.2)| 26.0 (4.8)| 27.4 (5.9)|
| Influence at work in 0–100%, M (SD)| 38.8 (22.5)| 42.9 (21.7)| 49.3 (24.7)|
| Mean hours measured per day, M (SD)| 16.0 (1.5)| 16.6 (1.3)| 17.1 (1.7)|
| Smokers (%)                      | 26 (40.6)| 27 (42.9)| 29 (46.0)|
| Occupational lifting/carrying time, n (%) |          |          |          |
| Low                              | 23 (34.3)| 23 (34.8)| 21 (31.3)|
| Moderate                         | 16 (23.9)| 15 (22.7)| 19 (28.4)|
| High                             | 28 (41.8)| 28 (42.4)| 27 (40.3)|
| LBP pain, M (SD)                 | 2.7 (2.4)| 2.4 (2.5)| 3.6 (2.7)|
| Low, n (%)                       | 60 (89.6)| 60 (89.6)| 48 (71.6)|
| High, n (%)                      | 7 (10.4)| 7 (10.4)| 19 (28.4)|
| Valid days of measurements, M (SD)| 2.7 (1.1)| 2.4 (1.0)| 2.4 (1.1)|
| Valid 1-day measurement, n (%)   | 67 (100)| 67 (100)| 67 (100)|
| Valid 2-day measurement, n (%)   | 57 (85.1)| 53 (79.2)| 50 (74.7)|
| Valid 3-day measurement, n (%)   | 37 (55.3)| 28 (41.8)| 31 (46.3)|
| Valid 4- day measurement, n (%)  | 18 (26.9)| 10 (15) | 12 (18) |
| Valid 5- day measurement, n (%)  | 2 (3.0)| 1 (1.5)| 0 (0.0) |

Table footnotes:
Low sitting = ≤6.4h, moderate sitting = 6.5–8.3h and high sitting >8.3h, BMI = body mass index, LBP = low back pain, M = mean, n = number of workers, SD = standard deviation.

doi:10.1371/journal.pone.0121159.t002

Table 3. Binary logistic regression analyses of the association between objectively measured sitting (hours/day) and high LBP intensity (>5 on scale 0–9) among blue-collar workers.

| Total sitting time | Occupational sitting time | Leisure-time sitting |
|--------------------|---------------------------|----------------------|
| Model              | n OR P 95%CI              | n OR P 95%CI         | n OR P 95%CI       |
| Crude a            | 201 1.43 0.01 (1.17–1.73) | 187 1.36 0.03 (1.03–1.80) | 187 1.38 0.01 (1.10–1.71) |
| Step 1 b           | 190 1.41 0.01 (1.15–1.73) | 176 1.31 0.07 (0.98–1.75) | 176 1.41 0.01 (1.10–1.82) |
| Step 2 c           | 185 1.43 0.01 (1.15–1.77) | 172 1.30 0.08 (0.97–1.75) | 172 1.41 0.01 (1.09–1.84) |
| Step 3 d           | - - - -                   | 172 1.34 0.06 (0.99–1.82) | 172 1.45 0.01 (1.10–1.91) |

Table footnotes:

n = number of workers, OR = odds ratio, 95%CI = 95% confidence interval,
a Crude model,
b Adjusted for age, gender, smoking and BMI (Individual factors, Step 1),
c Step 1+seniority, influence at work, and occupational lifting/carrying time (occupational factors, step 2),
d Step 2+sitting time in the opposite domain (Step 3).

doi:10.1371/journal.pone.0121159.t003
Associations between categories of total, occupational, and leisure-time sitting with LBP intensity

Table 4 shows the results of the binary logistic regression analyses on the association between categories of sitting time and high LBP intensity, with low sitting time as reference. The workers with high sitting time had a significantly higher probability of reporting high LBP intensity, both for total and leisure-time sitting. Adjustment for various confounders imposed no marked effect on these estimates or levels of significance. Reduced and non-significant positive associations were observed for moderate sitting for total (OR = 1.13) and leisure (OR = 1.39) time and high LBP. For the analysis based on categories of occupational sitting, we obtained positive and significant results in the crude model for moderate (OR = 4.53) and high (OR = 3.48) sitting time and high LBP. These estimates were not reduced with further adjustment for potential individual and occupational confounders, although the estimates for high sitting became marginally non-significant (P = 0.08) (Table 4).

Sensitivity analyses

To test the robustness of the results from the primary analyses, four additional sensitivity analyses were performed;

Table 4. Results of binary logistic regression models estimating the association between categories of sitting time and high intensity of low back pain (>5 on a scale 0–9) among blue-collar workers.

| Model | Total sitting time | Occupational sitting time | Leisure-time sitting |
|-------|--------------------|---------------------------|----------------------|
|       | n     | OR     | P  | 95%CI   | n     | OR     | P  | 95%CI   | n     | OR     | P  | 95%CI   |
| Crude |        |        |    |         |        |        |    |         |        |        |    |         |
| Low   | 1     | 1a     | 1a |         | 1     | 1a     | 1a |         | 1     | 1a     | 1a |         |
| Moderate | 201   | 1.00   | 1.00 | (0.33–3.03) | 187   | 4.53   | 0.01 | (1.41–14.56) | 187   | 1.66   | 0.40 | (0.51–5.38) |
| High  | 3.39   | 0.02   | (1.32–8.74) | 3.48   | 0.04   | (1.06–11.47) | 4.67   | 0.01   | (1.61–13.54) |
| Step 1 |        |        |    |         |        |        |    |         |        |        |    |         |
| Low   | 1     | 1a     | 1a |         | 1     | 1a     | 1a |         | 1     | 1a     | 1a |         |
| Moderate | 190   | 1.08   | 0.90 | (0.35–3.30) | 176   | 4.82   | 0.01 | (1.46–15.96) | 176   | 1.47   | 0.54 | (0.43–5.03) |
| High  | 3.21   | 0.02   | (1.20–8.60) | 2.86   | 0.10   | (0.83–9.83) | 5.34   | 0.01   | (1.71–16.66) |
| Step 2 |        |        |    |         |        |        |    |         |        |        |    |         |
| Low   | 1     | 1a     | 1a |         | 1     | 1a     | 1a |         | 1     | 1a     | 1a |         |
| Moderate | 185   | 1.13   | 0.84 | (0.36–3.52) | 172   | 4.49   | 0.01 | (1.34–15.06) | 172   | 1.50   | 0.52 | (0.43–5.20) |
| High  | 3.31   | 0.03   | (1.18–9.28) | 2.88   | 0.10   | (0.83–10.05) | 5.06   | 0.01   | (1.57–16.34) |
| Step 3 |        |        |    |         |        |        |    |         |        |        |    |         |
| Low   | -     | -      | -   |         | -     | -      | -   |         | -     | -      | -   |         |
| Moderate | -     | -      | -   |         | -     | -      | -   |         | -     | -      | -   |         |
| High  | -     | -      | -   |         | -     | -      | -   |         | -     | -      | -   |         |

Table footnotes:
Total sitting time: low <6.4h, moderate = 6.5–8.3h and high >8.3h; Occupational sitting: low <2.0h, moderate = 2.1–3.7h and high >3.7h; leisure-time sitting: low<3.9h, moderate = 4.0–5.4h and high>5.4h, n = number of workers, OR = odds ratio, 95%CI = 95% confidence interval,

a Reference
b Crude analysis,
c Adjusted for age, gender, smoking and BMI (individual factors, step 1).
d Step 1 + seniority, influence at work and occupational lifting/carrying time (occupational factors, step 2).
e Step 2 + sitting time during opposite domain depending on the modelled variable (step 3).
a) Logistic regression models on the association between hours of sitting and LBP were performed using lower (>4 on the 0–9 scale) or higher (>6 on the 0–9 scale) cut-points of high LBP intensity than the cut point used in the primary analysis (>5 on the 0–9 scale). In the analysis using a lower cut-point of high LBP, we obtained slightly reduced but significant positive associations for total sitting time (OR = 1.20, 95%CI = 1.01–1.42) and reduced, non-significant tendencies for a positive association for leisure-time sitting (OR = 1.17, 95%CI = 0.93–1.47) and occupational sitting (OR = 1.30, 95%CI = 0.99–1.68) compared to the primary analyses. When using a higher cut-point of LBP, positive tendencies were found, but the ORs were reduced and did not remain significant (total sitting time, OR = 1.21, 95%CI = 0.95–1.53; occupational sitting, OR = 1.24, 95%CI = 0.87–1.75; and leisure-time sitting, OR = 1.17, 95% CI = 0.85–1.61). For categorized sitting time, changing the cut-point of high LBP resulted in reduced non-significant positive associations between sitting time and LBP, both for total and occupational sitting, while remaining significant for leisure-time sitting when using the lower cut-point of LBP (data not shown).

b) Similar analyses were performed using normalized sitting time based on mean measured hours per day (i.e., percent sitting) instead of using absolute sitting time as in the primary analysis. Results showed reduced positive associations compared to the primary analysis [total sitting, OR = 1.05 (95%CI = 1.01–1.09), occupational sitting, OR = 1.04 (95%CI = 0.99–1.09) and leisure-time sitting, OR = 1.06 (95%CI = 1.01–1.12)]. Similar results to the primary analysis were observed when we modelled the moderate and high categories of percent sitting time against high LBP, referencing low sitting time for total and occupational sitting periods, although the positive association was reduced and non-significant for leisure-time sitting (data not shown).

c) We performed a third sensitivity analysis to investigate if calculation of relative risks (RR) will provide similar results compared to OR used in the primary analysis. The results remained largely unchanged compared to the primary analysis. In the analysis modelling the hours of sitting against high LBP, the RR were 1.35 (95%CI = 1.15–1.58) for total sitting time, 1.35 (95% CI = 1.10–166) for leisure-time sitting and 1.26 (95%CI = 1.00–1.57) for occupational sitting. Using the categories of sitting, the RR for high and moderate sitting time were 2.72 (95% CI = 1.17–6.32) and 1.08 (95%CI = 0.40–2.91) for total sitting time, 3.96 (95%CI = 1.50–10.46) and 1.41 (95%CI = 0.47–4.19) for leisure-time sitting and 2.80 (95%CI = 0.93–8.45) and 4.31 (95%CI = 1.43–13.00) for occupational sitting.

d) As the wear time varied between workers, we performed a fourth sensitivity analysis to investigate if estimates of the association between sitting time and LBP change with further adjustment for wear time (i.e. number of valid measured days or average measured time per day). These adjustments did not materially change the estimates, compared to the primary analysis. In the analysis with adjustment for number of valid measured days, the OR was 1.42 (95% CI = 1.14–1.76) for total sitting time, 1.35 (1.00–1.83) for occupational sitting and 1.43 (1.01–1.88) for leisure-time sitting. Similarly, with adjustment for average measured time per day, the OR was 1.35 (1.08–1.69) for total sitting time, 1.37 (1.01–1.85) for occupational sitting time, and 1.33 (0.98–1.81) for leisure-time sitting. Similar positive trends as in the primary analyses were observed when modelling categories of sitting time (low, moderate and high) against LBP (data not shown).

Discussion

This study aimed at investigating the association between sitting time, measured objectively using diurnal accelerometry, and LBP intensity among blue-collar workers. We observed a positive association between hours of total, occupational, and leisure-time sitting and LBP.
intensity. The estimates remained largely unchanged after adjustment for various individual and work-related factors. These positive associations between sitting time and LBP were also confirmed in the analyses based on categories of sitting time.

Most previous studies [40, 70, 71] have only focused on investigating the association between occupational sitting time and LBP, while very few studies [72, 73] have been conducted on total sitting time. We observed a clear positive association between total sitting time and LBP intensity, even after adjusting for potential individual and work-related confounders. These results were also confirmed in the analysis using categories of sitting time. In contrast to the results of our study, a previous case-control study [73] did not observe a clear positive association between total sitting time and LBP. Levangie [73] observed that clinical outpatients reporting sitting for 4–6 hours or for more than 9 hours per day tended to report high LBP (4–6 hours: OR = 1.54, 95%CI = 0.81–2.91; >9 hours: OR. 1.42, 95%CI = 0.73–2.78), compared to those sitting for less than 4 hours per day. However, none of these results were statistically significant. Also, patients sitting for 6–8 hours per day reported lower intensity of LBP compared to those sitting less than 4 hours a day, indicating an inverse relationship between sitting and LBP. The reasons behind the inconsistent findings in previous studies could be that they utilized self-reports of sitting time that may be imprecise [35, 74, 75], and potentially biased by factors like musculoskeletal complaints [76]. This methodological aspect of previous studies may have diluted the true association between sitting and LBP in these studies. Another reason could be that previous studies did not control for various individual and work-related factors, which may have confounded the results. To our knowledge, our study is the first of its kind in using objective measures of sitting time. We found a clear positive association between total sitting time and LBP intensity, which is in contrast to some previous studies using self-reported sitting time. Thus, further studies using objective measures of sitting time are needed before a conclusion about the association between sitting and LBP intensity can be drawn.

**Association between occupational and leisure-time sitting and LBP intensity**

We found a significant positive association between leisure-time sitting and LBP, even after adjusting for various potential individual and work-related confounders. A similar clear association was observed when we analyzed the association between categories (low, moderate, high) of leisure-time sitting and LBP. These results are consistent with some previous studies finding a significant positive association between sedentary time during leisure and LBP [77, 78]. However, most previous studies did not find significant or clear associations [28, 79–81]. In some studies, researchers even found tendencies for a protective effect for time spent watching TV or playing computer games on LBP [28]. Thus, future studies are needed to confirm our findings using objective measures of sitting time during leisure.

In the crude model, we observed a significant positive association between occupational sitting time and LBP. With further adjustment for different confounders, the OR did not decrease, but the association became marginally insignificant (P = 0.06). Similar findings were found for categories of occupational sitting time and LBP. Correspondingly, Lis, Black [40] in a meta-analysis summarized the OR for the association between occupational sitting and LBP from previous studies to be 1.99. However, half of the studies included in this meta-analysis were not significant. Although some previous studies also have found a positive association between occupational sitting time and LBP [21, 28, 82, 83], others have not [29, 30, 84].

There can be a number of reasons behind these contrasting findings of previous studies investigating the association of occupational and leisure-time sitting with LBP. First, most studies did not adjust for several potential confounders as well as for sitting time in the remaining time...
of the day. Second, most previous studies have relied on self-reports of sitting time, that may be inaccurate and biased [35, 76] and consequently this may have diluted a true association between sitting time and LBP. Thus, future studies using objective measures of sitting while adjusting for important confounders are needed to further confirm the findings of the present study.

Methodological considerations, strengths and weaknesses

We hypothesized sitting to be associated with LBP. However, since the etiology of LBP is multifactorial, it was important to adjust for potential confounders in the association between sitting time and LBP. When we adjusted for a number of potential individual confounders, the results remained stable from the crude model. Additionally, the results remained consistent even after adjusting for job specific characteristics such as "influence at work" and "occupational lifting/carrying time".

The OR tends to overestimate the magnitude of relative risk (RR) if the prevalence of the outcome is high [85]. In this study, the prevalence of the outcome 'high LBP' was relatively high (16%). Therefore, we also performed a sensitivity analysis using the RR instead of OR as an estimate of the association between sitting and LBP. As expected, we obtained similar trends using RR compared with the OR. These results indicate the robustness of the primary results of this study.

It has been argued that transforming continuous data into categories ought to be avoided as it results in a loss of information and reduces the precision of the individual exposure estimates [86]. On the other hand, categorizing exposure into simple categories provide useful and easily interpretable information. Thus, we performed analyses based on both continuous and categorical measures of sitting time. Both analyses generally produced similar results in their association with high LBP, which further supports the robustness of the present findings. However, using continuous percent sitting time (percentage of average measured time per day), instead of absolute sitting time as applied in the primary analyses, reduced the ORs for all analyses, although the ORs remained significant for total and leisure-time sitting. Using categories based on percent sitting time, the ORs were similar to the primary analysis besides for leisure-time sitting which was reduced and non-significant. Generally, the results of these sensitivity analyses for occupational sitting remained positive but reduced and non-significant. The reduced and non-significant results may be explained by the wide range of time spent in different periods, i.e., workers being classified in different sitting categories or different extremes of the range of sitting time when using absolute values and percentages of sitting time. However, adjustment for average measured time per day in the analysis did only marginally change the estimates of the association between sitting and LBP for all domains, compared to the primary analysis.

We used a cut point of > 5 for high LBP on a scale of 0–9 which was based on a previous prospective study on the association between LBP and sickness absence [50]. However, some previous studies have used different cut-points of high LBP [87]. Thus, we tested the association between sitting time and LBP using both lower and higher cut-points of high LBP than in the primary analyses. Although, the direction of the association did not change, we obtained lower estimates for the association between total, occupational and leisure-time sitting and LBP both when applying lower and higher cut-points for LBP compared to primary analysis. We do not know the reasons for the reduced estimates and level of significance when applying lower and high cut-points for high LBP. However, it highlights the need for replicating the analyses of this study in other and larger datasets.

The main strength of this study was the use of objective measures of sitting time to determine the association of sitting time with LBP. The Actigraph accelerometers used in this study
are water resistant and easy to wear during long-term measurements. This measurement device has been utilised previously on workers with physically demanding jobs [88]. Another strength of the study is the use of a validated software, Acti4, to determine the accurate sitting time. Acti4 has previously determined sitting postures during free living conditions with a high sensitivity and specificity of 98% and 93%, respectively. Additionally, we recruited a study population with a wide range of occupational and leisure-time sitting, providing a necessary contrast in the sitting time exposure despite their homogenous socioeconomic status.

The main limitation of the study is the use of a cross-sectional study design from which an inference about a causal relationship cannot be made. Thus, prospective studies on the association between objectively measured sitting time and LBP are needed. Another limitation of the study is the relatively limited sample size, which may have reduced the generalizability of our findings. Thus, future studies investigating the association between sitting time and LBP are recommended to use larger and representative sample size.

Practical implications
The results of this study indicate a positive association between sitting time and LBP among blue-collar workers. Although, this relationship should be further investigated using a prospective design before recommendations can be made, the results of this study imply that future interventions may be needed for reducing sitting time even among blue-collar workers with high sitting exposure and LBP.

Conclusion
To our knowledge, this is the first study to investigate the association between sitting time, assessed objectively for several days, and LBP intensity. Our study indicates that sitting time is positively associated with LBP intensity among blue-collar workers. Future studies using prospective designs with larger sample sizes and objective measurements of sitting time are needed to confirm these findings.

Supporting Information
S1 Dataset. This dataset contains two data files, ‘total sit’ and ‘occupational and leisure sit’. The data file ‘total sit’ contains data for investigating the association between total sitting time (N = 201) and low back pain and the data file ‘occupational and leisure sit’ contains data for investigating the association between occupational and leisure-time sitting and low back pain (N = 187).

Acknowledgments
We would like to thank Jørgen Skotte from The National Research Centre for the Working Environment (NRCWE), Copenhagen, Denmark, for his technical assistance in this study.

Author Contributions
Conceived and designed the experiments: AH. Performed the experiments: CSC MK. Analyzed the data: NG AH IGC. Wrote the paper: NG AH DH MK CSC IGC.

References
1. Walker BF. The prevalence of low back pain: a systematic review of the literature from 1966 to 1998. J Spinal Disord. 2000; 13(3):205–17. PMID: 10872758
2. Ekholm O, Kjellner M, Davidsson M, Hesse U, Eriksen L, Christensen AI, et al. Sundhed og sygelighed i Danmark 2005 og udviklingen siden 1987. København: Statens Institut for Folkesundhed, 2006.

3. Freburger JK, Holmes GM, Agans RP, Jackman AM, Darter JD, Wallace AS, et al. The rising prevalence of chronic low back pain. Arch Intern Med. 2009; 169(3):251–8. doi: 10.1001/archinternmed.2008.543 PMID: 19204216

4. Meucci RD, Fassa AG, Paniz VM, Silva MC, Wegman DH. Increase of chronic low back pain prevalence in a medium-sized city of southern Brazil. BMC Musculoskelet Disord. 2013; 14:155. doi: 10.1186/1471-2474-14-155 PMID: 23634830

5. Hoogendoorn WE, Bongers PM, de Vet HC, Ariens GA, van Mechelen W, Bouter LM. High physical work load and low job satisfaction increase the risk of sickness absence due to low back pain: results of a prospective cohort study. Occup Environ Med. 2002; 59(5):323–8. PMID: 11983847

6. van Tulder MW, Koes BW, Bouter LM. A cost-of-illness study of back pain in The Netherlands. Pain. 1995; 62(2):233–40. PMID: 8545149

7. Dagenais S, Caro J, Haldeman S. A systematic review of low back pain cost of illness studies in the United States and internationally. Spine. 2008; 33(18):2215–22. doi: 10.1097/BRS.0b013e3181644449

8. Coste J, Delecouillerie G, Delara AC, Paolaggi JB. Clinical course and prognostic factors in acute low-back-pain—An inception cohort study in primary-care practice. Br Med J. 1994; 308 (6928):577–80. PMID: 8148683

9. Spittaels H, Van Cauwenbergh E, Verbestel V, De Meester F, Van Dyck D, Verloigne M, et al. Objectively measured sedentary time and physical activity time across the lifespan: a cross-sectional study in four age groups. Int J Behav Nutr Phys Act. 2012; 9:149. doi: 10.1186/1479-5868-9-149 PMID: 23249449

10. Vandelanotte C, Duncan MJ, Short C, Rockloff M, Ronan K, Happell B, et al. Associations between occupational indicators and total, work-based and leisure-time sitting: a cross-sectional study. BMC Public Health. 2013; 13:1110. doi: 10.1186/1471-2458-13-1110 PMID: 24289321

11. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Pate RR, et al. Amount of time spent in sedentary behaviors in the United States, 2003–2004. Am J Epidemiol. 2008; 167(7):875–81. doi: 10.1093/aje/kwm390 PMID: 18303006

12. Bjork Petersen C, Bauman A, Gronbaek M, Wulff Helge J, Thygesen LC, Tolstrup JS. Total sitting time and risk of myocardial infarction, coronary heart disease and all-cause mortality in a prospective cohort of Danish adults. Int J Behav Nutr Phys Act. 2014; 11:13. doi: 10.1186/1479-5868-11-13 PMID: 24498933

13. Bennie J, Chau J, van der Ploeg H, Stamatakis E, Do A, Bauman A. The prevalence and correlates of sitting in European adults—a comparison of 32 Eurobarometer-participating countries. Int J Behav Nutr Phys Act. 2013; 10(1):1–13. doi: 10.1186/1479-5868-10-1 PMID: 23281722

14. Pope MH, Goh KL, Magnusson ML. Spine ergonomics. Annu Rev Biomed Eng. 2002; 5:49–80. PMID: 12815127

15. Corlett EN. Background to sitting at work: research-based requirements for the design of work seats. Ergonomics. 2000; 43(4):486–93. PMID: 10801082

16. Nachemson AL. Disc pressure measurements. Spine (Phila Pa 1976). 1981; 6(1):93–7.

17. Beach TA, Parkinson RJ, Stothart JP, Callaghan JP. Effects of prolonged sitting on the passive flexion stiffness of the in vivo lumbar spine. Spine J. 2005; 5(2):145–54. PMID: 15749614

18. Kong PW. Changes in perceived comfort, strength and electromyographic response in lower back, hip and leg muscles during 8-hour prolonged sitting. In: Lim CT, Goh JCH, editors. 6th World Congress of Biomechanics (WCB 2010) August 1–6, 2010 Singapore. IFMBE Proceedings. 31: Springer Berlin Heidelberg; 2010. p. 75–8.

19. McGill SM, Hugson RL, Parks K. Lumbar erector spinae oxygenation during prolonged contractions: implications for prolonged work. Ergonomics. 2000; 43(4):486–93. PMID: 10801082

20. Omokhodion FO, Sanya AO. Risk factors for low back pain among office workers in Ibadan, Southwest Nigeria. Occup Med (Lond). 2003; 53(4):287–9. PMID: 12815127

21. Skov T, Borg V, Orhede E. Psychosocial and physical risk factors for musculoskeletal disorders of the neck, shoulders, and lower back in salespeople. Occup Environ Med. 1996; 53(5):351–6. PMID: 8673184

22. Spyropoulos P, Papathanasiou G, Georgoudis G, Chronopoulos E, Koutis H, Koumoutsou F. Prevalence of low back pain in greek public office workers. Pain Physician. 2007; 10(5):651–9. PMID: 17876361

23. Rotgoltz J, Derazne E, Froom P, Grushecky E, Ribak J. Prevalence of low back pain in employees of a pharmaceutical company. Isr J Med Sci. 1992; 28(8–9):615–8. PMID: 1337542
24. Walsh K, Varnes N, Osmond C, Styles R, Coggon D. Occupational causes of low-back pain. Scand J Work Environ Health. 1989; 15(1):54–9. PMID: 2522238
25. Lee Y-H, Chiou W-K. Risk factors for low back pain, and patient-handling capacity of nursing personnel. J Safety Res. 1994; 25(3):135–45.
26. Krapac L, Sakic D. Locomotor strain syndrome in users of video display terminals. Arh Hig Rada Toksi-kol. 1994; 45(4):341–7. PMID: 7654147
27. Yue P, Liu F, Li L. Neck/shoulder pain and low back pain among school teachers in China, prevalence and risk factors. BMC Public Health. 2012; 12(1):1–8.
28. Sjolie AN. Persistence and change in nonspecific low back pain among adolescents: a 3-year prospective study. Spine (Phila Pa 1976). 2004; 29(21):2452–7. PMID: 15507810
29. Xu Y, Bach E, Ohreda E. Work environment and low back pain: the influence of occupational activities. Occup Environ Med. 1997; 54(10):741–5. PMID: 9404522
30. Vingard E, Alfredsson L, Hagberg M, Kilbom A, Theorell T, Waldenstrom M, et al. To what extent do current and past physical and psychosocial occupational factors explain care-seeking for low back pain in a working population? Results from the Musculoskeletal Intervention Center-Norrtalje Study. Spine (Phila Pa 1976). 2000; 25(4):493–500.
31. Linton SJ. Risk factors for neck and back pain in a working population in Sweden. Work Stress. 1990; 4(1):41–9.
32. Macfarlane GJ, Thomas E, Papageorgiou AC, Croft PR, Jayson MI, Silman AJ. Employment and physical work activities as predictors of future low back pain. Spine (Phila Pa 1976). 1997; 22(10):1143–9. PMID: 9160474
33. Damkot DK, Pope MH, Lord J, Frymoyer JW. The relationship between work history, work environment and low-back pain in men. Spine. 1984; 9(4):395–9. PMID: 6236564
34. Clark B, Thorp A, Winkler E, Gardiner P, Healy G, Owen N, et al. Validity of self-report measures of workplace sitting time and breaks in sitting time. Med Sci Sports Exerc. 2011; 43(10):1907–12. doi: 10.1249/MSS.0b013e31821820a2 PMID: 21926535
35. Lagersted-Olsen J, Korshoj M, Skotte J, Carneiro IG, Sogaard K, Holtermann A. Comparison of objectively measured and self-reported time spent sitting. Int J Sports Med. 2013; 35(6):534–40. doi: 10.1055/s-0033-1358467 PMID: 24258469
36. Affuso O, Stevens J, Catellier D, McMurray RG, Ward DS, Lytle L, et al. Validity of self-reported leisure-time sedentary behavior in adolescents. J Negat Results Biomed. 2011; 10:2. doi:10.1186/1477-5751-10-2 PMID: 21314953
37. Kwak L, Proper KI, Hagströmer M, Sjöström M. The repeatability and validity of questionnaires assessing occupational physical activity—a systematic review. Scand J Work Environ Health. 2011; 37(1):6–29. PMID: 20802979
38. Healy GN, Owen N. Sedentary behaviour and biomarkers of cardiometabolic health risk in adolescents: an emerging scientific and public health issue. Rev Esp Cardiol. 2010; 63(3):261–4. PMID: 20196885
39. Chen SM, Liu MF, Cook J, Bass S, Lo SK. Sedentary lifestyle as a risk factor for low back pain: a systematic review. Int Arch Occup Environ Health. 2009; 82(7):797–806. doi:10.1007/s00420-009-0410-0 PMID: 19301029
40. Lis AM, Black KM, Korn H, Nordin M. Association between sitting and occupational LBP. Eur Spine J. 2007; 16(2):283–98. PMID: 16736200
41. Jorgensen MB, Nabe-Nielsen K, Clausen T, Holtermann A. Independent effect of physical workload and childhood socioeconomic status on low back pain among health care workers in Denmark. Spine (Phila Pa 1976). 2013; 38(6):E359–66. doi: 10.1097/BRS.0b013e31828435d4 PMID: 23492797
42. Juul-Kristensen B, Sogaard K, Stroyer J, Jensen C. Computer users’ risk factors for developing shoul-der, elbow and back symptoms. Scand J Work Environ Health. 2004; 30(5):390–8. PMID: 15529802
43. Nourbakhsh MR, Moussavi SJ, Salavati M. Effects of lifestyle and work-related physical activity on the degree of lumbar lordosis and chronic low back pain in a Middle East population. J Spinal Disord. 2001; 14(4):283–92. PMID: 11481549
44. Chau JY, van der Ploeg HP, Meron D, Chey T, Bauman AE. Cross-sectional associations between occupational and leisure-time sitting, physical activity and obesity in working adults. Prev Med. 2012; 54(3–4):195–200.
45. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ, et al. Breaks in sedentary time: Beneficial associations with metabolic risk. Diabetes Care. 2008; 31(4):661–6. doi: 10.2337/dc07-2046 PMID: 18252901
46. Mathiassen SE. Diversity and variation in biomechanical exposure: what is it, and why would we like to know? Appl Ergon. 2006; 37(4):419–27. PMID: 16764816
47. World Medical A. World medical association declaration of helsinki: Ethical principles for medical research involving human subjects. JAMA. 2013; 310(20):2191–4. doi: 10.1001/jama.2013.281053 PMID: 24141714
48. Vandenbroucke JP, von Elm E, Altman DG, Gotzsche PC, Mulrow CD, Pocock SJ, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. PLoS Med. 2007; 4(10):e297. PMID: 17941715
49. Kuorinka I, Jonsson B, Kilbom A. Standardized Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergonomics. 1987; 18:233–7. PMID: 15676628
50. Andersen LL, Clausen T, Mortensen OS, Burr H, Holtermann A. A prospective cohort study on musculoskeletal risk factors for long-term sickness absence among healthcare workers in eldercare. Int Arch Occup Environ Health. 2012; 85(6):615–22. doi: 10.1007/s00420-011-0709-5 PMID: 21986907
51. Pincus T, Santos R, Breen A, Burton AK, Underwood M. A review and proposal for a core set of factors for prospective cohorts in low back pain: a consensus statement. Arthritis Rheum. 2008; 59(1):14–24. doi: 10.1002/art.23251 PMID: 18163411
52. Skotte J, Korshoj M, Kristiansen J, Hanisch C, Holtermann A. Detection of physical activity types using triaxial accelerometers. J Phys Act Health. 2014; 11(1):76–84. doi: 10.1123/pah.2011-0347 PMID: 23249722
53. Korshoj M, Skotte JH, Christiansen CS, Mortensen P, Kristiansen J, Hanisch C, et al. Validity of the Acti4 software using ActiGraph GT3X+accelerometer for recording of arm and upper body inclination in simulated work tasks. Ergonomics. 2014; 57(2):247–53. doi: 10.1080/00140139.2013.869358 PMID: 24392673
54. Lunde LK, Koch M, Knardahl S, Waersted M, Mathiassen SE, Forsman M, et al. Musculoskeletal health and work ability in physically demanding occupations: study protocol for a prospective field study on construction and health care workers. BMC Public Health. 2014; 14(1):1075.
55. Tudor-Locke C, Johnson WD, Katzmarzyk PT. Accelerometer-determined steps per day in US adults. Med Sci Sports Exerc. 2009; 41(7):1384–91. doi: 10.1249/MSS.0b013e318199885c PMID: 19516163
56. Schuna JM Jr., Johnson WD, Tudor-Locke C. Adult self-reported and objectively monitored physical activity and sedentary behavior: NHANES 2005–2006. Int J Behav Nutr Phys Act. 2013; 10:126. doi: 10.1186/1479-5868-10-126 PMID: 24215625
57. Hesketh KR, McMinn AM, Ekelund U, Sharp SJ, Collings PJ, Harvey NC, et al. Objectively measured physical activity in four-year-old British children: a cross-sectional analysis of activity patterns segmented across the day. Int J Behav Nutr Phys Act. 2014; 11:1. doi: 10.1186/1479-5868-11-1 PMID: 25540041
58. Pejtersen JH, Kristensen TS, Borg V, Bjorner JB. The second version of the Copenhagen Psychosocial Questionnaire. Scand J Public Health. 2010; 38(3 Suppl):8–24.
59. Hamberg-van R, Ariens GAM, Blatter BM, van Mechelen W, Bongers PM. A systematic review of the relation between physical capacity and future low back and neck/shoulder pain. Pain. 2007; 130(1–2):93–107. PMID: 17521812
60. Hooftman WE, van Poppel MN, van der Beek AJ, Bongers PM, van Mechelen W. Gender differences in the relations between work-related physical and psychosocial risk factors and musculoskeletal complaints. Scand J Work Environ Health. 2004; 30(4):261–78. PMID: 15458009
61. Leboeuf-Yde C. Back pain—individual and genetic factors. J Electromyogr Kinesiol. 2004; 14(1):129–33. PMID: 14759758
62. Wai EK, Rodriguez S, Dagenais S, Hall H. Evidence-informed management of chronic low back pain with physical activity, smoking cessation, and weight loss. Spine J. 2008; 8(1):195–202. doi: 10.1016/j.spinee.2007.10.024 PMID: 18164467
63. Burdorf A, Sorock G. Positive and negative evidence of risk factors for back disorders. Scand J Work Environ Health. 1997; 23(4):243–56. PMID: 9328215
64. Riihimaki H. Low-back pain, its origin and risk indicators. Scand J Work Environ Health. 1991; 17(2):81–90. PMID: 1828614
65. Jansen JP, Morgenstern H, Burdorf A. Dose-response relations between occupational exposures to physical and psychosocial factors and the risk of low back pain. Occup Environ Med. 2004; 61(12):972–9. PMID: 15550602
66. Bjork-van Dijken C, Fjellman-Wiklund A, Hildingsson C. Low back pain, lifestyle factors and physical activity: a population based-study. J Rehabil Med. 2008; 40(10):864–9. doi: 10.2340/16501977-0273 PMID: 19242625
67. Eatough EM, Way JD, Chang CH. Understanding the link between psychosocial work stressors and work-related musculoskeletal complaints. Appl Ergonomics. 2012; 43(3):554–63. doi: 10.1016/j.apergo.2011.08.009 PMID: 21944295
68. Hartvigsen J, Lings S, Leboeuf-Yde C, Bakketeig L. Psychosocial factors at work in relation to low back pain and consequences of low back pain; a systematic, critical review of prospective cohort studies. Occup Environ Med. 2004; 61(1):e2. PMID: 14691283

69. Linton SJ. Occupational psychological factors increase the risk for back pain: a systematic review. J Occup Rehabil. 2001; 11(1):53–66. PMID: 11706777

70. Roffey DM, Wai EK, Bishop P, Kwon BK, Dagenais S. Causal assessment of awkward occupational postures and low back pain: results of a systematic review. Spine J. 2010; 10(1):89–99. doi: 10.1016/j.spinee.2009.09.003 PMID: 19910263

71. Hartvigsen J, Leboeuf-Yde C, Lings S, Corder EH. Is sitting-while-at-work associated with low back pain? A systematic, critical literature review. Scand J Public Health. 2000; 28(3):230–9. PMID: 11045756

72. Magora A. Investigation of the relation between low back pain and occupation. VII. Neurologic and orthopedic condition. Scand J Rehabil Med. 1975; 7(4):146–51. PMID: 130674

73. Levangie PK. Association of low back pain with self-reported risk factors among patients seeking physical therapy services. Phys Ther. 1999; 79(8):757–66. PMID: 10440662

74. Celis-Morales CA, Perez-Bravo F, Ibanez L, Salas C, Bailey ME, Gill JM. Objective vs. self-reported physical activity and sedentary life: effects of measurement method on relationships with risk biomarkers. PLoS One. 2012; 7(5):e36345. doi: 10.1371/journal.pone.0036345 PMID: 22909532

75. Clemes SA, David BM, Zhao Y, Han X, Brown W. Validity of two self-report measures of sitting time. J Phys Act Health. 2012; 9(4):533–9. PMID: 21946087

76. Balogh I, Orbaek P, Ohlsson K, Nordander C, Unge J, Winkel J, et al. Self-assessed and directly measured occupational physical activities—influence of musculoskeletal complaints, age, and gender. Appl Ergon. 2004; 35(1):49–56. PMID: 14985140

77. Hildebrandt VH, Bongers PM, Dul J, van Dijk FJ, Kemper HC. The relationship between leisure time physical activities and musculoskeletal symptoms and disability in worker populations. Int Arch Occup Environ Health. 2000; 73(8):507–18. PMID: 11100945

78. Szpalski M, Gunzburg R, Balague F, Nordin M, Melot C. A 2-year prospective longitudinal study on low back pain in primary school children. Eur Spine J. 2002; 11(5):459–64. PMID: 12384754

79. Yip VY. New low back pain in nurses: work activities, work stress and sedentary lifestyle. J Adv Nurs. 2004; 46(4):430–40. PMID: 15117354

80. Croft PR, Papageorgiou AC, Thomas E, Macfarlane GJ, Silman AJ. Short-term physical risk factors for new episodes of low back pain. Prospective evidence from the South Manchester Back Pain Study. Spine (Phila Pa 1976). 1999; 24(15):1556–61. PMID: 10457575

81. Jones GT, Watson KD, Silman AJ, Symmons DPM, Macfarlane GJ. Predictors of Low Back Pain in British Schoolchildren: A Population-Based Prospective Cohort Study. Pediatrics. 2003; 111(4):822–8. PMID: 12671119

82. Masset D, Malchaire J. Low back pain. Epidemiologic aspects and work-related factors in the steel industry. Spine (Phila Pa 1976). 1994; 19(2):143–6.

83. Pietri F, Leclerc A, Boitel L, Chastang JC, Morcrette JF, Blondet M. Low-back pain in commercial travelers. Scand J Work Environ Health. 1999; 25(1):52–8. PMID: 1532455

84. Svensson HO, Andersson GB. The relationship of low-back pain, work history, work environment, and stress. A retrospective cross-sectional study of 38- to 64-year-old women. Spine (Phila Pa 1976). 1989; 14(5):517–22. PMID: 2524891

85. Merrill RM. Principles of epidemiology workbook: Exercises and activities. Jones & Bartlett Learning; 2011.

86. Royston P, Altman DG, Sauerbrei W. Dichotomizing continuous predictors in multiple regression: a bad idea. Stat Med. 2006; 25(1):127–41. PMID: 16217841

87. Ozguler A, Leclerc A, Landre M-F, Pietri-Taleb F, Niedhammer I. Individual and occupational determinants of low back pain according to various definitions of low back pain. J Epidemiol Community Health. 2000; 54(3):215–20. PMID: 10746116

88. Strijk JE, Proper KI, van der Beek AJ, van Mechelen W. A worksite vitality intervention to improve older workers’ lifestyle and vitality-related outcomes: results of a randomised controlled trial. J Epidemiol Community Health. 2012; 66(11):1071–8. doi: 10.1136/jech-2011-200626 PMID: 22268128