



OPEN ACCESS

ORIGINAL ARTICLE

The CONSTANCES job exposure matrix based on self-reported exposure to physical risk factors: development and evaluation

Bradley A Evanoff,¹ Marcus Yung,¹ Skye Buckner-Petty,¹ Johan Hviid Andersen,² Yves Roquelaure,³ Alexis Descatha,^{3,4,5} Ann Marie Dale¹

► Additional material is published online only. To view please visit the journal online (<http://dx.doi.org/10.1136/oemed-2018-105287>).

¹Division of General Medical Sciences, Washington University School of Medicine in St. Louis, St. Louis, Missouri, USA

²Department of Occupational Medicine, Danish Ramazzini Centre, Regional Hospital West Jutland, University Research Clinic, Herning, Denmark

³INSERM, U1085, IRSET (Institute de recherche en santé, environnement et travail), ESTER Team, University of Angers, Angers, France

⁴AP-HP, EMS (Samu92), Occupational Health Unit, Raymond Poincaré University Hospital, Garches, France

⁵INSERM, UMR 1168 UMS011, University of Versailles Saint-Quentin-en-Yvelines, Villejuif, France

Correspondence to

Dr Bradley A Evanoff, Division of General Medical Sciences, Washington University School of Medicine in St Louis, St Louis, MO 63110, USA; bevanoff@dom.wustl.edu

AD and AMD contributed equally.

Received 11 June 2018

Revised 28 November 2018

Accepted 16 December 2018

Published Online First

31 January 2019



© Author(s) (or their employer(s)) 2019. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

To cite: Evanoff BA, Yung M, Buckner-Petty S, et al. *Occup Environ Med* 2019;**76**:398–406.

ABSTRACT

Objectives Job exposure matrices (JEMs) can be constructed from expert-rated assessments, direct measurement and self-reports. This paper describes the construction of a general population JEM based on self-reported physical exposures, its ability to create homogeneous exposure groups (HEG) and the use of different exposure metrics to express job-level estimates.

Methods The JEM was constructed from physical exposure data obtained from the Cohorte des consultants des Centres d'examen de santé (CONSTANCES). Using data from 35 526 eligible participants, the JEM consisted of 27 physical risk factors from 407 job codes. We determined whether the JEM created HEG by performing non-parametric multivariate analysis of variance (NPMANOVA). We compared three exposure metrics (mean, bias-corrected mean, median) by calculating within-job and between-job variances, and by residual plots between each metric and individual reported exposure.

Results NPMANOVA showed significantly higher between-job than within-job variance among the 27 risk factors ($F(253, 21964)=61.33$, $p<0.0001$, $r^2=41.1\%$). The bias-corrected mean produced more favourable HEG as we observed higher between-job variance and more explained variance than either means or medians. When compared with individual reported exposures, the bias-corrected mean led to near-zero mean differences and lower variance than other exposure metrics.

Conclusions CONSTANCES JEM using self-reported data yielded HEGs, and can thus classify individual participants based on job title. The bias-corrected mean metric may better reflect the shape of the underlying exposure distribution. This JEM opens new possibilities for using unbiased exposure estimates to study the effects of workplace physical exposures on a variety of health conditions within a large general population study.

INTRODUCTION

A job exposure matrix (JEM) is a common method used in occupational epidemiology research to estimate workers' exposures to chemical or physical risk factors based on job titles, industry information and population exposure data. There is a surge in JEMs to estimate physical exposures such as posture, repetition and force in the study of work-related musculoskeletal disorders (MSD).^{1–9} JEMs can be constructed from four sources of data,

Key messages

What is already known about this subject?

- A job exposure matrix (JEM) is a cost-effective method to assess workplace physical risk factors (eg, repetitive motion, force exertion, posture).
- JEMs can be built from expert-rated assessments, direct measurement, self-reports or a hybrid of these methods.

What are the new findings?

- We constructed a general population JEM from self-reported physical exposures, which make use of workers' knowledge of their usual job exposures. JEM classified individuals into homogeneous exposure groups based on job title.
- By using bias-corrected mean exposures, which allow the job-level estimates to take into account the shape of the underlying exposure distribution, we found a greater between-job variance in exposures when compared with the use of mean or median exposures.

How might this impact on policy or clinical practice in the foreseeable future?

- A JEM is a low cost tool that can be useful for estimating current and past job-level exposures at the population level while minimising information bias.
- This new JEM constructed from self-reported exposures contributes to the growing literature on JEMs for physical risk factors, and will be used in future studies relating multiple health outcomes to workplace exposures within a large prospective cohort study (Cohorte des consultants des Centres d'examen de santé, CONSTANCES).
- JEMs may also be useful for clinical or compensation assessments among individuals when more detailed exposure data are not available.

or their combination: direct exposure measurements in a subset of the population,¹⁰ direct observations of workers,¹⁰ expert ratings of exposure¹ and self-reported exposures from individual workers in different jobs.¹¹

Table 1 Comparison between exposure estimates for symptomatic (pain >6) and asymptomatic (asymp) individuals

| Exposure variable | Description | N (asyp) | N (full) | Within-job variance (asyp) | Within-job variance (full) | β estimate | P value |
|-------------------------|---|----------|----------|----------------------------|----------------------------|------------------|---------|
| Physical intensity | <i>How would you describe the intensity of the physical efforts of your work during a typical day?</i> | 26821 | 34788 | 6.13 | 6.65 | 0.85 | 0.00 |
| Stand | <i>During a typical day of work: are you standing?</i> | 29597 | 35017 | 0.55 | 0.56 | 0.09 | 0.00 |
| Repetition | <i>On a typical day of work: do you repeat the same actions more than two times to four times per minute?</i> | 26424 | 34297 | 0.97 | 1.05 | 0.27 | 0.00 |
| Change tasks | <i>On a typical day of work: can you interrupt your work or change tasks or activities for 10 min or more each hour?</i> | 26581 | 34520 | 1.11 | 1.13 | -0.11 | 0.00 |
| Rest eyes | <i>During a typical day of work: can you rest your eyes for a few seconds outside of work breaks?</i> | 31848 | 34510 | 1.00 | 1.01 | -0.18 | 0.00 |
| Kneel or squat | <i>During a typical day of work: do you kneel or squat?</i> | 29574 | 34963 | 0.51 | 0.55 | 0.18 | 0.00 |
| Bend trunk | <i>During a typical day of work: do you lean forward or sideways regularly or for prolonged periods?</i> | 30853 | 34920 | 0.62 | 0.66 | 0.27 | 0.00 |
| Drive machinery | <i>On a typical day of work: do you drive construction machinery, a tractor, a self-propelled fork-lift or other mobile machinery at your workplace (except car or truck)?</i> | 29385 | 34984 | 0.15 | 0.16 | 0.01 | 0.09 |
| Drive car or truck | <i>On a typical day of work: do you drive a vehicle (automobile, truck, bus, ambulance, motorcycle, etc) on public roads, excluding commuting?</i> | 29357 | 34951 | 0.49 | 0.50 | 0.04 | 0.00 |
| Handle objects 1–4 kg | <i>How much time do you spend doing the following tasks or activities: handling or regularly moving a load, a part, an object weighing between 1 kg and 4 kg?</i> | 31116 | 34644 | 1.34 | 1.38 | 0.25 | 0.00 |
| Handle objects >4 kg | <i>How much time do you spend doing the following tasks or activities: handling or regularly moving a load, a part, an object weighing more than 4 kg?</i> | 28306 | 34555 | 0.91 | 0.98 | 0.21 | 0.00 |
| Carry loads <10 kg | <i>How much time do you spend doing the following tasks or activities: carry a load that weighs less than 10 kg?</i> | 28240 | 34475 | 0.83 | 0.89 | 0.19 | 0.00 |
| Carry loads 10–25 kg | <i>How much time do you spend doing the following tasks or activities: carry a load that weighs 10 kg to 25 kg?</i> | 28297 | 34568 | 0.54 | 0.60 | 0.17 | 0.00 |
| Carry loads >25 kg | <i>How much time do you spend doing the following tasks or activities: carry a load that weighs more than 25 kg?</i> | 28271 | 34533 | 0.41 | 0.45 | 0.14 | 0.00 |
| Use vibrating tools | <i>On a typical day of work, do you use: vibrating tools or place your hand(s) on vibrating machines?</i> | 28437 | 34747 | 0.16 | 0.19 | 0.06 | 0.00 |
| Use computer screen | <i>During a typical day of work, do you use: a computer screen or control panel?</i> | 31017 | 34792 | 0.55 | 0.56 | 0.01 | 0.19 |
| Use keyboard or scanner | <i>During a typical day of work, do you use: a keyboard, a mouse, or similar device (optical pen, scanner) to enter data?</i> | 28437 | 34735 | 0.61 | 0.63 | -0.01 | 0.98 |
| Bend neck | <i>How long do you spend in the following posture during a typical day of work: bending your head forward regularly or for a prolonged period?</i> | 32048 | 34732 | 1.14 | 1.14 | 0.36 | 0.00 |
| Arms above shoulder | <i>How long do you spend in the following posture during a typical day of work: work with one or two arms in the air (above the shoulders) regularly or for a prolonged period?</i> | 32712 | 34834 | 0.41 | 0.43 | 0.23 | 0.00 |
| Reach behind | <i>How long do you spend in the following posture during a typical day of work: reaching regularly for items behind your back?</i> | 29482 | 34839 | 0.30 | 0.34 | 0.15 | 0.00 |
| Arms abducted | <i>How long do you spend in the following posture during a typical day of work: working with one or two arms separated from the body regularly or for a prolonged period?</i> | 32634 | 34758 | 0.49 | 0.52 | 0.24 | 0.00 |
| Bend elbow | <i>How long do you spend in the following posture during a typical day of work: flex the elbow repeatedly or keep the elbow flexed against resistance?</i> | 33722 | 34703 | 0.55 | 0.57 | 0.45 | 0.00 |
| Rotate forearm | <i>How long do you spend in the following posture during a typical day of work: twist your forearm as if you are using a screwdriver?</i> | 32647 | 34786 | 0.26 | 0.28 | 0.15 | 0.00 |

continued

Table 1 continued

| Exposure variable | Description | N (asyp) | N (full) | Within-job variance (asyp) | Within-job variance (full) | β estimate | P value |
|--------------------|--|----------|----------|----------------------------|----------------------------|------------------|---------|
| Bend wrist | <i>How long do you spend in the following posture during a typical day of work: bending the wrist?</i> | 32 599 | 34 721 | 0.50 | 0.53 | 0.30 | 0.00 |
| Press base of hand | <i>How long do you spend in the following posture during a typical day of work: press/tap with the base of the hand on a surface or on a tool?</i> | 33 127 | 34 736 | 0.19 | 0.20 | 0.11 | 0.00 |
| Finger pinch | <i>How long do you spend in the following posture during a typical day of work: pinch objects with your thumb and forefinger.</i> | 33 128 | 34 738 | 0.69 | 0.71 | 0.30 | 0.00 |
| Work outdoors | <i>How long do you spend working outdoors during a typical day of work?</i> | – | 35 187 | – | – | – | – |

Within-job pooled variance between full cohort (symptomatic + asymptomatic workers) and asymptomatic cohort. Linear mixed model (β estimates and p values). Included are descriptions of CONSTANCES exposure questions.

Expert-rated assessments are often used in the construction of JEMs for industry-specific studies of chemical risk factors, and rely on assessors with accurate knowledge of rated jobs. For general population studies, knowledge of many different jobs is required, and individual assessors may or may not have direct knowledge of the very broad range of jobs. Inter-rater agreement has been reported as fair to moderate when ranking job categories in a general population JEM for risk factors for lower limb MSD.⁷ Other studies have found substantial variation between raters in assigning exposures.¹²

Direct measurement of worker exposures and detailed observational assessments are precise, but may misclassify exposures in jobs where exposures vary over a longer time than the period of observation.^{13 14} Direct measurement and observation are expensive and time-consuming, potentially limiting their application to larger groups of workers.^{15 16}

Alternatively, JEMs can be constructed using self-reported exposures, which make use of workers' knowledge of their jobs. Reported exposures from all workers are then pooled and exposures assigned at the job level. Use of a JEM to combine self-reported exposures at the job level reduces information biases due to individual variation in reporting. The use of self-reported physical exposures provides an efficient method to estimate cumulative exposure.² Although this approach has been used in a few studies of work-related psychosocial,^{3 17} physical²⁻⁴ and chemical exposures,⁵ there are fewer general population JEMs built primarily from self-reported data for a large range of physical risk factors.

The aim of this study was to create a general population JEM based on self-reported physical exposure estimates within a large prospective cohort study. This JEM will contribute to the growing array of JEMs for physical risk factors, enabling large-scale studies of associations between workplace exposures and chronic diseases, including MSD. In this paper, we report: (1) The creation of a new JEM. (2) A validation of its ability to create homogeneous exposure groups (HEGs). (3) A comparison between different exposure metrics to express job-level exposures.

METHODS

JEM data source

Physical exposure data were obtained from the Cohorte des consultants des Centres d'examen de santé (CONSTANCES) project, a large (expected n=200 000) prospective French cohort study investigating occupational and social determinants of health in the general population.¹⁸ CONSTANCES was designed to create a representative sample of French salaried workers.

Detailed information on CONSTANCES is available at: www.constances.fr. CONSTANCES participants answered questions estimating 27 different physical risk factors in each participant's current job. Exposure questions were patterned after the Samarbetsprogram mellan Arbetslivsinstitutet, LO, TCO och SACO (SALTSA) criteria¹⁹ and other sources.²⁰ Overall intensity of physical workload was assessed with the Borg Rating of Perceived Exertion Scale, ranging from 6 (no effort at all) to 20 (exhausting). Questions pertaining to the duration or frequency of performing specific actions, including postures, repetitive motion and the use of vibrating tools, were evaluated on a 4-point Likert Scale (text of each question listed in table 1). Generally, the Likert Scale was formatted with the following anchor points: 'Never or nearly never', 'Rarely (<2 hours per day)', 'Often (2 to 4 hours per day)' and 'Always or nearly always'. Questions pertaining to regular handling, moving or carrying loads asked participants to report whether they handle objects greater than 1 kg (yes/no), and if yes, asked the frequency of handling objects based on different ranges of weights, following the 4-point Likert Scale above.

JEM development

We used data from the first 81 425 CONSTANCES participants. Reported job titles were assigned a French 4-digit Profession et Catégorie Sociale (PCS) job code using the SiCore automated coding system.²¹ The PCS classification system involves three nested levels of classification, from the 1-digit socioprofessional job categories (table 2) to the 4-digit PCS job code. This assignment resulted in 418 PCS job codes. Participants who were not currently working (n=35 466), those who did not report a job title or who were not assigned a PCS job code through automatic coding (n=10 396), and those who had missing exposure data (n=30), were excluded.

To produce reliable estimates, we required a minimum of 10 valid responses for each risk factor within each PCS job code. PCS jobs with fewer than 10 responses were grouped with other similar PCS jobs to create adequately sized groups (a minimum of 10 valid responses for each exposure for each PCS code). This method has been previously applied in grouping American standard occupational classification (SOC) codes.²² To create groups of similar jobs, we first used PCS to ISCO-88 (International Standard Classification of Occupations) crosswalk (Codage Assisté des Professions et Secteurs d'activité) and an existing French autocoding system tool.²³ Many PCS codes share a single ISCO-88 code, thus creating natural groupings. To group the remaining PCS job codes with few respondents, we used an ISCO-88 to ISCO-08 crosswalk, and an ISCO-08 to

SOC crosswalk. All such groupings were reviewed, and PCS job codes that were not successfully grouped via crosswalks were grouped manually based on consensus opinions from three of the authors (BAE, AD, AMD). PCS codes with a small sample size that could not be meaningfully merged with other jobs were excluded (n=7 participants). After all exclusions and job code grouping, the JEM comprised 27 physical exposures assigned to 407 PCS codes from 35 526 eligible participants.

JEM participant inclusion: full cohort versus asymptomatic cohort

We conducted preliminary analyses to determine whether exposure data from both symptomatic and asymptomatic workers should be included in the JEM. Since workers with symptoms of MSD may overestimate physical exposures compared with asymptomatic workers,^{24 25} reporting bias is a potential concern. Symptomatic workers were defined as those reporting a pain level of 6 or more (on a scale from 0 to 10) in one or more of six body regions in the previous 7 days. We first used linear mixed models to compare self-reported exposure levels between symptomatic and asymptomatic individuals. Separate models were produced for *each* of 26 risk factors (the variable *work outdoors* was not analysed, we expected this risk factor was unrelated to physical pain). A second analysis examined whether a JEM consisting of only asymptomatic workers led to more favourable HEGs than a JEM with both symptomatic and asymptomatic participants (full cohort); for this analysis, the within-job pooled variance was compared between the full cohort and the asymptomatic cohort for each risk factor.

All statistical analyses were carried out with R statistical software (R Foundation for Statistical Computing, Vienna, Austria). The significant main effect was set at an α level of 0.05.

JEM evaluation

We computed descriptive statistics to assess the demographics of the cohort, the overall distributions of each of the 27 risk factors, and proportion of symptomatic and asymptomatic participants. To better enable interpretation of JEM-assigned exposure estimates and comparison with exposures based on other methods, the ordinal questionnaire responses were recoded to time-based variables (ie, minutes of activity per day). We selected the median value of the questionnaire time interval: 0 min (rating of 0 on the 5-point ordinal scale), 5 min (rating of 1 = 'Never or nearly never'), 60 min (rating of 2 = 'Rarely (<2 hours per day)'), 180 min (rating of 3 = 'Often (2 to 4 hours per day)') and 360 min (rating of 4 = 'Always or nearly always').

Validity of JEM classification

We assessed the homogeneity of exposures classified by PCS codes by calculating within-job and between-job variance, which is a common approach to determine if workers within the same job title were uniformly exposed.²⁶ We performed non-parametric multivariate analysis of variance (NPMANOVA) to compare within-job and between-job exposure variance for all 27 exposures. NPMANOVA is a robust alternative to multivariate analysis of variance, and computes the sums of squares using metric distance matrices.²⁷ Since there was a relatively large number of dependent variables (27 risk factors), we selected Manhattan distances, which is the sum of the absolute value of the differences among vector coordinates. Manhattan distances are particularly appropriate for high-dimensional data,²⁸ providing significantly higher relative contrast between different points and a more meaningful indication of proximity than Euclidean distance metrics. Because the process of merging

Table 2 Eligible participants from the Cohorte des consultants des Centres d'examen de santé (CONSTANCES) population cohort study (n=35 526)

| | n | %* |
|--|--------|-------|
| Socioprofessional category | | |
| Farmers | 13 | 0.04 |
| Craftsmen, traders and entrepreneurs | 534 | 1.50 |
| Executives and higher intellectual professions | 12 192 | 34.32 |
| Intermediate professions | 11 039 | 31.07 |
| Salaried employees | 8008 | 22.54 |
| Manual workers | 3740 | 10.53 |
| Sex | | |
| Male | 15 800 | 44.47 |
| Female | 19 726 | 55.53 |
| Age | | |
| 18–24 years old | 763 | 2.15 |
| 25–34 years old | 6470 | 18.21 |
| 35–44 years old | 9162 | 25.79 |
| 45–54 years old | 10 617 | 29.89 |
| 55–64 years old | 6546 | 18.43 |
| 65 years and older | 1968 | 5.54 |
| Musculoskeletal symptoms (pain in the past 7 days and current pain level 6 or more) | | |
| Hand | 1656 | 6.06 |
| Knee | 2576 | 9.29 |
| Neck | 2744 | 9.81 |
| Elbow | 1009 | 3.76 |
| Lower back | 4151 | 14.74 |
| Shoulder | 2166 | 7.85 |
| One or more regions | 8181 | 23.03 |

*Per cent of non-missing responses.

jobs reported in 'JEM development' resulted in overlapping job groups, we first combined overlapping PCS codes to create 229 mutually exclusive job groupings. Each exposure was then scaled by rank transformation; the Manhattan distance between two groups was then the sum of the absolute differences between ranks among the 27 exposures. Univariate Kruskal-Wallis tests were performed for each of the 27 exposure variables to evaluate between-job and within-job variance for each exposure variable.

To help visualise within-PCS and between-PCS job code groupings, we created a multidimensional scaling (MDS) plot with confidence ellipses to depict the Manhattan distances between exposure vectors. The radii of the confidence ellipses represent the upper 95% confidence bound of within-group distances from the group centres computed from Monte Carlo simulations.

JEM exposure metrics

When reporting JEM-assigned exposure values, studies have used different exposure metrics.^{29 30} MSD-focused JEMs have typically reported arithmetic means¹ and medians,³¹ therefore we reported both metrics. We also corrected the JEM mean value using empirical quantile mapping (EQM) methods³² to adjust the group-level data to better reflect the distributions of individual-level exposure estimates. Using EQM, JEM mean values falling within every 1% quantile range were adjusted to reflect respective 1% quantiles of the individual-level self-reported values; this adjusted JEM mean is referred to as *bias-corrected mean*.

To compare exposure metrics, we calculated the within-job variance, between-job variance and r^2 values for these three

Table 3 Descriptive statistics of 27 risk factor variables in job exposure matrices (JEMs)

| Exposure variable | Scale | N | Mean | SD | P05 | P25 | Med | P75 | P95 | Minutes/day | | R ² |
|-------------------------|-------|-------|------|------|-----|-----|-----|-----|-----|-------------|-----|----------------|
| | | | | | | | | | | Mean | SD | |
| Physical intensity | 6–20 | 26821 | 9.80 | 3.20 | 6 | 7 | 9 | 12 | 15 | – | – | 0.39 |
| Stand | 1–4 | 29597 | 2.59 | 1.12 | 1 | 2 | 2 | 4 | 4 | 168 | 143 | 0.55 |
| Repetition | 1–4 | 26424 | 1.75 | 1.09 | 1 | 1 | 1 | 2 | 4 | 90 | 130 | 0.18 |
| Change tasks | 1–4 | 26581 | 2.94 | 1.11 | 1 | 2 | 3 | 4 | 4 | 204 | 142 | 0.10 |
| Rest eyes | 1–4 | 31848 | 3.10 | 1.13 | 1 | 2 | 4 | 4 | 4 | 232 | 145 | 0.19 |
| Kneel or squat | 1–4 | 29574 | 1.58 | 0.91 | 1 | 1 | 1 | 2 | 4 | 62 | 101 | 0.39 |
| Bend trunk | 1–4 | 30853 | 1.66 | 0.97 | 1 | 1 | 1 | 2 | 4 | 70 | 107 | 0.35 |
| Drive machinery | 1–4 | 29385 | 1.10 | 0.46 | 1 | 1 | 1 | 1 | 2 | 15 | 51 | 0.27 |
| Drive car or truck | 1–4 | 29357 | 1.41 | 0.88 | 1 | 1 | 1 | 1 | 4 | 46 | 99 | 0.29 |
| Handle objects 1–4 kg | 0–4 | 31116 | 1.03 | 1.46 | 0 | 0 | 0 | 2 | 4 | 69 | 119 | 0.36 |
| Handle objects >4 kg | 0–4 | 28306 | 0.80 | 1.24 | 0 | 0 | 0 | 2 | 4 | 48 | 100 | 0.38 |
| Carry loads <10 kg | 0–4 | 28240 | 0.72 | 1.15 | 0 | 0 | 0 | 1 | 3 | 39 | 89 | 0.36 |
| Carry loads 10–25 kg | 0–4 | 28297 | 0.58 | 0.94 | 0 | 0 | 0 | 1 | 3 | 24 | 69 | 0.37 |
| Carry loads >25 kg | 0–4 | 28271 | 0.51 | 0.83 | 0 | 0 | 0 | 1 | 2 | 17 | 57 | 0.36 |
| Use vibrating tools | 1–4 | 28437 | 1.11 | 0.47 | 1 | 1 | 1 | 1 | 2 | 17 | 55 | 0.30 |
| Use computer screen | 1–4 | 31017 | 3.15 | 1.12 | 1 | 2 | 4 | 4 | 4 | 240 | 146 | 0.55 |
| Use keyboard or scanner | 1–4 | 28437 | 3.11 | 1.15 | 1 | 2 | 4 | 4 | 4 | 231 | 149 | 0.52 |
| Bend neck | 1–4 | 32048 | 2.45 | 1.11 | 1 | 1 | 3 | 3 | 4 | 149 | 133 | 0.08 |
| Arms above shoulder | 1–4 | 32712 | 1.39 | 0.73 | 1 | 1 | 1 | 2 | 3 | 38 | 74 | 0.23 |
| Reach behind | 1–4 | 29482 | 1.27 | 0.57 | 1 | 1 | 1 | 1 | 2 | 26 | 53 | 0.05 |
| Arms abducted | 1–4 | 32634 | 1.39 | 0.79 | 1 | 1 | 1 | 1 | 3 | 41 | 85 | 0.21 |
| Bend elbow | 1–4 | 33722 | 1.42 | 0.85 | 1 | 1 | 1 | 1 | 4 | 45 | 91 | 0.23 |
| Rotate forearm | 1–4 | 32647 | 1.22 | 0.62 | 1 | 1 | 1 | 1 | 3 | 25 | 66 | 0.30 |
| Bend wrist | 1–4 | 32599 | 1.36 | 0.79 | 1 | 1 | 1 | 1 | 3 | 40 | 87 | 0.22 |
| Press base of hand | 1–4 | 33127 | 1.14 | 0.49 | 1 | 1 | 1 | 1 | 2 | 17 | 51 | 0.23 |
| Finger pinch | 1–4 | 33128 | 1.45 | 0.88 | 1 | 1 | 1 | 1 | 4 | 48 | 97 | 0.13 |
| Work outdoors | 1–4 | 35187 | 1.38 | 0.78 | 1 | 1 | 1 | 1 | 3 | 38 | 81 | 0.31 |

Exposure rating values recoded to a time-based value based on the following conversion:

| No (for 5-point Likert Scales) | Rating of 1: never or almost never | Rating of 2: rarely (>2 hours per day) | Rating of 3: often (2–4 hours per day) | Rating of 4: almost always |
|--------------------------------|------------------------------------|--|--|----------------------------|
| 0 min | 5 min | 60 min | 180 mins | 360 mins |

Kruskal-Wallis test for each exposure (r²) reported for 27 risk factor variables to determine amount of variance explained by Profession et Catégorie Sociale job code.

exposure metrics for all 27 physical exposures. Within-job variance was defined as the average of the squared deviation from group metric values (equation 1). Between-job variance was the average of the squared deviation of metric values from the global mean (equation 2).

$$\text{Within – job variance} = \frac{1}{N - K} \sum_{j=1}^K \sum_{i=1}^N \left(X_{ji} - \tilde{X}_j \right)^2 \quad (1)$$

$$\text{Between – job variance} = \frac{1}{K-1} \sum_{j=1}^K n_j \left(\tilde{X}_j - \bar{X} \right)^2 \quad (2)$$

where \tilde{X}_j is the estimated metric value for the jth group.

JEM exposure estimate versus individually reported exposures

For each physical risk factor, we created residual plots of the differences between individually reported exposures and exposures estimated by each of the three JEM metrics. We calculated the average of differences, the average absolute difference, and difference in variance between individually reported and JEM-estimated exposure values.

RESULTS

JEM development

Eligible participants represented 407 PCS job titles nested within six broad socioprofessional categories. Twenty-three per cent of the cohort reported musculoskeletal pain in one or more body regions (table 2). A linear mixed model compared exposure values between symptomatic and asymptomatic participants; 23 of 26 risk factors demonstrated statistically significant differences (table 1). Positive β coefficients from these models indicated that symptomatic individuals reported higher exposure values than asymptomatic individuals within the same PCS job code. Of the 26 linear mixed models, 21 exposure variables had statistically significant positive β estimates. Eleven exposure variables had β estimates greater than 0.2. Negative β estimates indicated that symptomatic workers reported lower exposures than asymptomatic workers. Significant negative β estimates were observed with two variables: *change task* ($\beta = -0.11$) and *rest eyes* ($\beta = -0.18$).

The asymptomatic cohort (range 0.15 to 6.13) demonstrated lower within-job variance than the full cohort (range 0.16 to 6.65), resulting in more favourable HEGs (table 1). As a result, only exposure estimates from asymptomatic workers were included in the JEM.

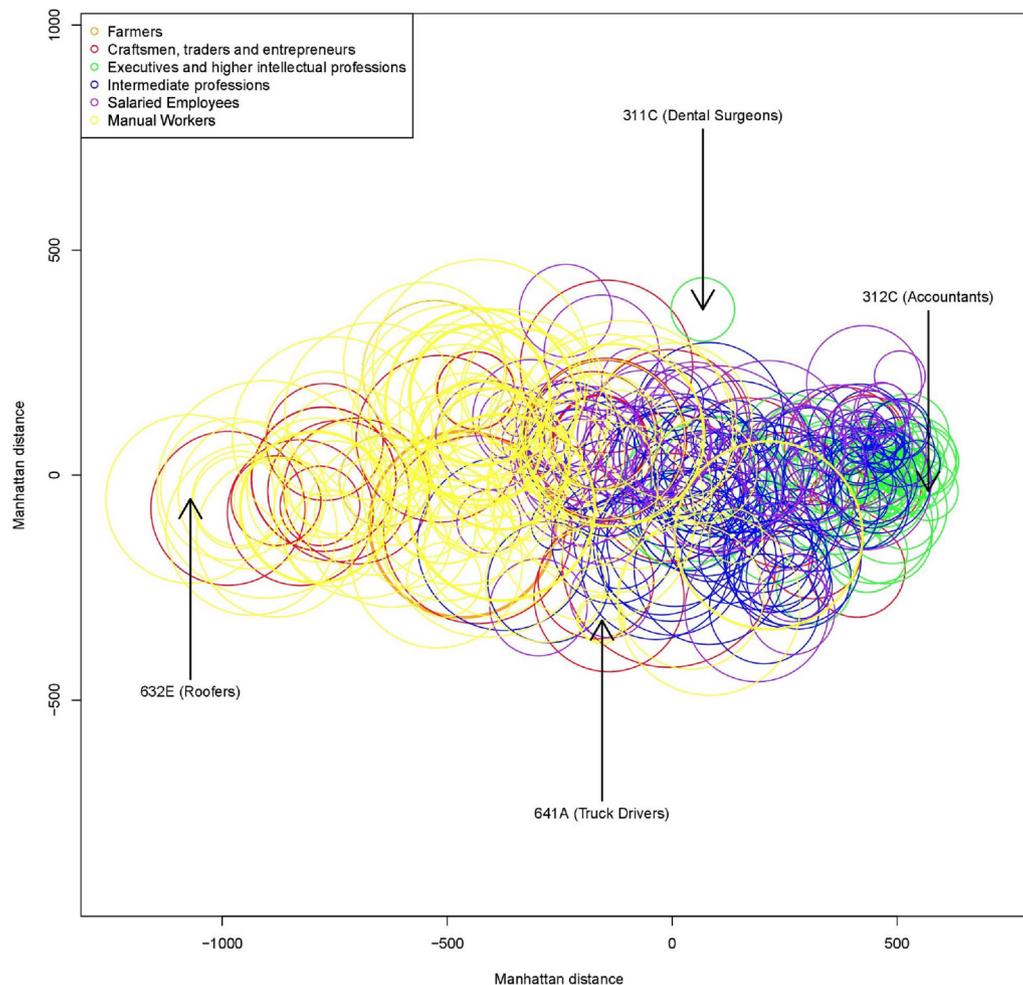


Figure 1 Multidimensional scaling plots of exposure vectors for all PCS codes with 95% confidence ellipses based on Monte Carlo simulations. Colour coded by PCS subgroup (first digit of PCS). PCS, Profession et Catégorie Sociale.

JEM evaluation

As expected for the general population in an industrialised country, the risk factors with the highest mean and median duration of daily activity were related to computer or office work, with much lower daily durations of heavy lifting or hand exertion (table 3). Examining individually reported exposures at the level of the job, NPMANOVA analysis showed significantly higher *between-job* variance than *within-job* variance among the 27 exposures (229 PCS groupings; $F(228,21989)=67.18$, $p<0.0001$). PCS job codes explained 41.4% of the variance in individual self-reported exposures in the overall model. The univariate analysis (table 3) for each risk factor variable revealed r^2 values ranging from 5% (*reaching for items behind back*) to 55% (*standing*). This indicates that the amount of variance explained by PCS job codes was different between risk factor variables; of the 27 risk factors, 12 variables achieved r^2 greater than 30%, while three variables resulted in explained variance less than 10%. Despite the large range of explained variance, all univariate models were statistically significant (all $p<0.0001$) indicating a relationship between exposures estimated by PCS code and self-reported exposure variables among asymptomatic workers.

Taking all reported risk factors into account, we observed non-overlapping relationships between individual PCS codes (shown by ellipses in figure 1), indicating separation between

different jobs. We also noted clustering of PCS codes within the same socioprofessional categories (represented by colour).

JEM exposure metrics

We observed minimal differences between the three exposure metrics (mean, median, bias-corrected mean) based on the within-job variance (online supplementary table 1). Trends indicate a comparable within-job variance using the means (variance=0.15 to 6.13), medians (variance=0.18 to 6.73) and bias-corrected means (variance=0.22 to 7.62). In contrast to the *within-job* variance, the bias-corrected mean (variance=25.60 to 1193.55) showed markedly higher *between-job* variance than means (variance=2.35 to 492.03) or medians (variance=5.93 to 764.15). R^2 values of the 27 physical risk factors ranged from 0.06 to 0.57 (JEM mean), 0.17 to 0.64 (JEM median) and 0.38 to 0.65 (JEM bias-corrected mean). Thus, compared with means or medians, use of bias-corrected means resulted in more HEGs at the job level (greater contrast of within-job and between-job variance), and explained more of the variance in individually reported exposures.

Examination of residual plots shows increasing differences between individually reported versus group-level exposure estimates with increasing exposure level (eg, figure 2; for all physical risk factors see online supplementary figures 1–27). JEM-assigned exposure estimates were attenuated as the exposure level

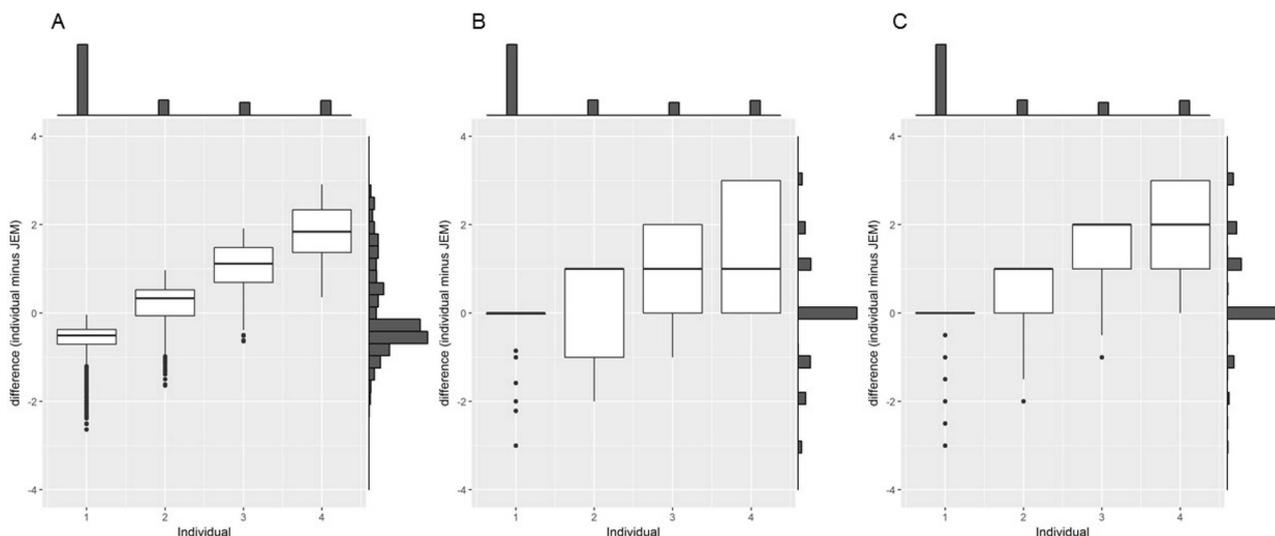


Figure 2 Example of box plots of the differences between individual-level reports and group-level exposure estimates (individual JEM) at each exposure intensity level for three exposure metrics: (A) JEM mean, (B) JEM bias-corrected mean and (C) JEM median. Distributions of individual (top axis) and JEM (right axis) are plotted. Bias-corrected mean determined using empirical quantile mapping (EQM) methods. The exposure variable in this example is 'Repetition'.

increased; this effect was most pronounced when assigning individual exposure values based on group-level mean values. Use of the bias-corrected mean led to smaller differences at all exposure levels compared with the JEM mean and median plots. A representative example of these box plots for JEM mean, bias-corrected mean and median exposure metrics is shown in figure 2.

When using job means, the mean differences were near-zero for all exposure variables (-0.002 (*repetition*) to 0.003 (*drive car or truck*)); job medians led to a mean difference ranging from -0.27 (*rest eyes*) to 0.40 (*repetition*) (online supplementary table 2). JEM bias-corrected mean ranged between -0.05 (*handle objects 1–4kg*) and 0.007 (*repetition* and *drive car or truck*). The bias-corrected mean also led to lower variance differences compared with JEM median values.

DISCUSSION

Assessment of workplace physical exposures is critical for the prevention of MSD and other conditions that may be affected by workplace physical activity.^{33 34} The purpose of this study was to develop and evaluate a JEM using individual-level self-reported physical exposure data from a prospective general population cohort study in France. After clustering the PCS codes into 229 groups, we found significantly higher *between-job* variance than *within-job* variance among all 27 exposures tested. Our MDS plot (figure 1) supported the interpretation that the CONSTANCES JEM created HEGs, with distinct separation of exposures between jobs and some clustering of exposures within broad job categories. We also found that using a bias-corrected mean led to the most favourable HEGs while best approximating individual-level exposure reports at the level of the job.

The CONSTANCES JEM was constructed using self-reported data from asymptomatic workers. Symptomatic study participants reported higher workplace physical exposures than asymptomatic participants; previous studies have shown differential reporting of exposures by symptomatic workers due to higher perception of exposures²⁴ or altered work behaviours.³⁵ It is also possible that higher exposures were accurately reported by those with MSD symptoms, because of actual exposure differences between individuals within the same jobs. While using

only the exposures reported by asymptomatic workers created more HEGs, this approach somewhat reduced the overall mean exposures estimated for each job. Future analyses will compare this JEM with other JEMs created from expert-rated exposure estimates or direct measurement, and internal comparison with a new cohort of CONSTANCES participants, to investigate the impact of excluding exposure data from symptomatic workers.

Several metrics have been used to express the central tendency in JEMs. For example, median exposure values were used in a study constructing a JEM to study workplace psychosocial factors,³¹ means were used in a JEM for shoulder disorders based on expert-rated job exposure estimates¹ and geometric means were used in a JEM for magnetic field exposures.³⁶ In this study, we compared bias-corrected mean to the arithmetic mean and median exposure values. We observed that bias-corrected mean values led to comparable within-job variance but larger between-job variance and therefore more homogeneous exposure measures at the job level. These methodological differences show a need to further investigate the ability of different exposure metrics to approximate individual-level exposures. Our results suggest that use of EQM methods may correct biases and better reflect the shape of the underlying exposure distribution.

Although we demonstrated that the CONSTANCES JEM, based on self-reported physical exposure data, may be an effective tool to estimate individual workers' job exposures, there are several potential limitations to this JEM relating to the source population, the coding of job titles and the ordinal nature of the self-reported exposure estimates. The CONSTANCES study does not include self-employed workers, who are affiliated with other health insurance funds in France.¹⁸ This raises the question of the generalisability of the JEM. However, the source population represents more than 85% of the general population, including individuals living and working in diverse settings, individuals from different regions and different population density areas, and individuals that represent a broad range of socioeconomic status and occupations.¹⁸ We developed this JEM using a traditional non-gendered approach. Given evidence that sex and gender influence the reported frequency and magnitude of awkward postures and physical workload within the same

job title and task,³⁷ future work will evaluate the differences in individual-level reports within each PCS group, and consider sex-specific/gender-specific stratification.

Reported job titles in our study were assigned a standardised PCS job code using the automated SiCore coding system. This process coded 87% of provided job titles, consistent with coding results in previous surveys.³⁸ Accuracy of the SiCore system has been shown to be greater than 90%.³⁸ Manual coding of the currently uncoded jobs will allow future adjustments to the CONSTANCES JEM in case these uncoded jobs were substantively different from those automatically coded.

To aid the interpretation of ordinal scale exposure ratings, we expressed the ordinal values with time-based variables using the median value of the time intervals indicated in the CONSTANCES questionnaire. Future sensitivity analysis will inform the optimal values of these time intervals for assessing exposure-disease associations. In future work, we will also assess this JEM's convergent validity with other multioccupation sources of exposure information. We will compare CONSTANCES JEM exposure estimates with other JEMs. We will also evaluate its predictive validity through its ability to reproduce known exposure-response associations obtained using other exposure methods.

CONCLUSION

JEMs can be constructed using self-reported data; this method of obtaining data uses workers' knowledge of their jobs, while pooling this information at the level of the job reduces information bias. We developed a JEM using self-reported data for 27 physical risk factors. Our results demonstrated the ability of this novel JEM to create HEGs of physical risk factors that discriminated between different jobs. This JEM provides a potentially robust assessment method for assigning current or cumulative workplace physical exposures in general population studies. Although these preliminary results indicate that the developed JEM may be a promising tool for physical exposure assessment in epidemiology studies, there remains a need for further validation, including comparisons with other exposure assessment methods and demonstration of exposure-disease associations using this JEM.

Contributors BAE, AD, YR and AMD designed the study, obtained funding, and reviewed and edited the paper. MY and BAE made significant contributions to the data visualisation, writing and formatting of this manuscript. SP-B was the primary data analyst and made significant contributions to the visualisations. JHA made significant contributions to the conceptualisation, and reviewed and edited the paper.

Funding This study was supported by research funding from the American National Institute for Occupational Safety and Health (NIOSH R01OH011076). The French CONSTANCES cohort is supported by the French National Research Agency (ANR-11-INBS-0002), Caisse Nationale d'Assurance Maladie des travailleurs salariés-CNAMTS, and is funded by the Institut de Recherche en Santé Publique/Institut Thématique Santé Publique, and the following sponsors: Ministère de la santé et des sports, Ministère délégué à la recherche, Institut national de la santé et de la recherche médicale, Institut national du cancer et Caisse nationale de solidarité pour l'autonomie, as well as Institute for research in public health (IRESP, CapacIT project).

Disclaimer The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute for Occupational Safety and Health (NIOSH), nor the sponsors of the CONSTANCES project.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval Washington University in St Louis, USA.

Provenance and peer review Not commissioned; externally peer reviewed.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which

permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

REFERENCES

- 1 Dalbøge A, Hansson GÅ, Frost P, *et al*. Upper arm elevation and repetitive shoulder movements: a general population job exposure matrix based on expert ratings and technical measurements. *Occup Environ Med* 2016;73:553–60.
- 2 Seidler A, Bolm-Audorff U, Heiskel H, *et al*. The role of cumulative physical work load in lumbar spine disease: risk factors for lumbar osteochondrosis and spondylosis associated with chronic complaints. *Occup Environ Med* 2001;58:735–46.
- 3 Hanvold TN, Sterud T, Kristensen P, *et al*. Mechanical and psychosocial work exposures: the construction and evaluation of a gender-specific job exposure matrix (JEM). *Scand J Work Environ Health* 2018.
- 4 Blanc PD, Faucett J, Kennedy JJ, *et al*. Self-reported carpal tunnel syndrome: predictors of work disability from the National Health Interview Survey Occupational Health Supplement. *Am J Ind Med* 1996;30:362–8.
- 5 Post WK, Heederik D, Kromhout H, *et al*. Occupational exposures estimated by a population specific job exposure matrix and 25 year incidence rate of chronic nonspecific lung disease (CNSLD): the Zutphen study. *Eur Respir J* 1994;7:1048–55.
- 6 Solovieva S, Pehkonen I, Kausto J, *et al*. Development and validation of a job exposure matrix for physical risk factors in low back pain. *PLoS One* 2012;7:e48680.
- 7 Rubak TS, Svendsen SW, Søballe K, *et al*. Total hip replacement due to primary osteoarthritis in relation to cumulative occupational exposures and lifestyle factors: a nationwide nested case-control study. *Arthritis Care Res* 2014;66:1496–505.
- 8 Dembe AE, Yao X, Wickizer TM, *et al*. Using O*NET to estimate the association between work exposures and chronic diseases. *Am J Ind Med* 2014;57:1022–31.
- 9 Svendsen SW, Johnsen B, Fujsang-Frederiksen A, *et al*. Ulnar neuropathy and ulnar neuropathy-like symptoms in relation to biomechanical exposures assessed by a job exposure matrix: a triple case-referent study. *Occup Environ Med* 2012;69:773–80.
- 10 Teschke K, Trask C, Johnson P, *et al*. Measuring posture for epidemiology: comparing inclinometry, observations and self-reports. *Ergonomics* 2009;52:1067–78.
- 11 Johnson JV, Stewart WF. Measuring work organization exposure over the life course with a job-exposure matrix. *Scand J Work Environ Health* 1993;19:21–8.
- 12 Guéguen A, Goldberg M, Bonenfant S, *et al*. Using a representative sample of workers for constructing the SUMEX French general population based job-exposure matrix. *Occup Environ Med* 2004;61:586–93.
- 13 Hansson GA, Balogh I, Byström JU, *et al*. Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. *Scand J Work Environ Health* 2001;27:30–40.
- 14 Zare M, Biau S, Brunet R, *et al*. Comparison of three methods for evaluation of work postures in a truck assembly plant. *Ergonomics* 2017;60:1551–63.
- 15 Trask C, Teschke K, Village J, *et al*. Measuring low back injury risk factors in challenging work environments: an evaluation of cost and feasibility. *Am J Ind Med* 2007;50:687–96.
- 16 Trask C, Mathiassen SE, Wahlström J, *et al*. Cost-efficient assessment of biomechanical exposure in occupational groups, exemplified by posture observation and inclinometry. *Scand J Work Environ Health* 2014;40:252–65.
- 17 Cohidon C, Santin G, Chastang JF, *et al*. Psychosocial exposures at work and mental health: potential utility of a job-exposure matrix. *J Occup Environ Med* 2012;54:184–91.
- 18 Zins M, Goldberg M. CONSTANCES team. The French CONSTANCES population-based cohort: design, inclusion and follow-up. *Eur J Epidemiol* 2015;30:1317–28.
- 19 Sluiter JK, Rest KM, Frings-Dresen MH. Criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders. *Scand J Work Environ Health* 2001;27(Suppl 1):1–102.
- 20 Washington State Department of Labor and Industries. Evaluation tools: Caution and Hazard Zone Checklists. 2000 <http://www.lni.wa.gov/Safety/Topics/Ergonomics/ServicesResources/Tools/default.asp> (Accessed: 15 Sep 2015).
- 21 SiCore RP. un outil et une méthode pour le chiffrage automatique à l'INSÉE". *Le Courrier des Statistiques* 1995;74:65–70.
- 22 Dale AM, Zeringue A, Harris-Adamson C, *et al*. General population job exposure matrix applied to a pooled study of prevalent carpal tunnel syndrome. *Am J Epidemiol* 2015;181:431–9.
- 23 Falcon J. SocialPosition: Social Position Indicators Construction Toolbox. R package version 1.0.1. 2015 <https://CRAN.R-project.org/package=SocialPosition>.
- 24 Viikari-Juntura E, Rautas S, Martikainen R, *et al*. Validity of self-reported physical work load in epidemiologic studies on musculoskeletal disorders. *Scand J Work Environ Health* 1996;22:251–9.
- 25 Balogh I, Ørbaek P, Ohlsson K, *et al*. Self-assessed and directly measured occupational physical activities—influence of musculoskeletal complaints, age and gender. *Appl Ergon* 2004;35:49–56.
- 26 Burdorf A. Sources of variance in exposure to postural load on the back in occupational groups. *Scand J Work Environ Health* 1992;18:361–7.

- 27 Anderson MJ. A new method for non-parametric multivariate analysis of variance. *Austral Ecology* 2001;26:32–46.
- 28 Aggarwal C, Hinneburg A, Keim DA. On the surprising behavior of distance metrics in high dimensional space. *International Conference on Database Theory*. In: Van den Bussche J, Vianu V, eds. *Database Theory – ICDT*. Berlin, Heidelberg: Springer, 2001.
- 29 Oraby T, Sivaganesan S, Bowman JD, et al. Berkson error adjustment and other exposure surrogates in occupational case-control studies, with application to the Canadian INTEROCC study. *J Expo Sci Environ Epidemiol* 2018;28.
- 30 Cifuentes M, Boyer J, Lombardi DA, et al. Use of O*NET as a job exposure matrix: a literature review. *Am J Ind Med* 2010;53:898–914.
- 31 Solovieva S, Pensola T, Kausto J, et al. Evaluation of the validity of job exposure matrix for psychosocial factors at work. *PLoS One* 2014;9:e108987.
- 32 Amengual A, Homar V, Romero R, et al. A statistical adjustment of regional climate model outputs to local scales: application to Platja de Palma, Spain. *J Clim* 2012;25:939–57.
- 33 Tabatabaeifar S, Frost P, Andersen JH, et al. Varicose veins in the lower extremities in relation to occupational mechanical exposures: a longitudinal study. *Occup Environ Med* 2015;72:330–7.
- 34 Mocevic E, Svendsen SW, Jørgensen KT, et al. Occupational lifting, fetal death and preterm birth: findings from the Danish National Birth Cohort using a job exposure matrix. *PLoS One* 2014;9:e90550.
- 35 Buchholz B, Park JS, Gold JE, et al. Subjective ratings of upper extremity exposures: inter-method agreement with direct measurement of exposures. *Ergonomics* 2008;51:1064–77.
- 36 Noonan CW, Reif JS, Yost M, et al. Occupational exposure to magnetic fields in case-referent studies of neurodegenerative diseases. *Scand J Work Environ Health* 2002;28:42–8.
- 37 Kennedy SM, Koehoorn M. Exposure assessment in epidemiology: does gender matter? *Am J Ind Med* 2003;44:576–83.
- 38 SiCore SP, 1996. The Insee automatic coding system. Proceedings from the Bureau of the Census 1996 Annual Research Conference and Technology Interchange, Arlington, Virginia; March 17–21.