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ORIGINAL ARTICLE

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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'examens 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.

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'examens de santé, CONSTANCES).
- ► JEMs may also be useful for clinical or compensation assessments among individuals when more detailed exposure data are not available.

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, or their combination: direct exposure measurements in a subset of the population,[10] direct observations of workers,[10] expert ratings of exposure[1] and self-reported exposures from individual workers in different jobs.[11]

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

Exposure variable	Description	N (asymp)	N (full)	Within-job variance (asymp)	Within-job variance (full)	β estimate	P value
Physical intensity	*How would you describe the intensity of the physical efforts of your work during a typical day?*	26 821	34 788	6.13	6.65	0.85	0.00
Stand	*During a typical day of work: are you standing?*	29 597	35 017	0.55	0.56	0.09	0.00
Repetition	*On a typical day of work: do you repeat the same actions more than two times to four times per minute?*	26 424	34 297	0.97	1.05	0.27	0.00
Change tasks	*On a typical day of work: can you interrupt your work or change tasks or activities for 10 min or more each hour?*	26 581	34 520	1.11	1.13	−0.11	0.00
Rest eyes	*During a typical day of work: can you rest your eyes for a few seconds outside of work breaks?*	31 848	34 510	1.00	1.01	−0.18	0.00
Kneel or squat	*During a typical day of work: do you kneel or squat?*	29 574	34 963	0.51	0.55	0.18	0.00
Bend trunk	*During a typical day of work: do you lean forward or sideways regularly or for prolonged periods?*	30 853	34 920	0.62	0.66	0.27	0.00
Drive machinery	*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)?*	29 385	34 984	0.15	0.16	0.01	0.09
Drive car or truck	*On a typical day of work: do you drive a vehicle (automobile, truck, bus, ambulance, motorcycle, etc) on public roads, excluding commuting?*	29 357	34 951	0.49	0.50	0.04	0.00
Handle objects 1–4 kg	*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?*	31 116	34 644	1.34	1.38	0.25	0.00
Handle objects >4 kg	*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?*	28 306	34 555	0.91	0.98	0.21	0.00
Carry loads <10 kg	*How much time do you spend doing the following tasks or activities: carry a load that weighs less than 10 kg?*	28 240	34 475	0.83	0.89	0.19	0.00
Carry loads 10–25 kg	*How much time do you spend doing the following tasks or activities: carry a load that weighs 10 kg to 25 kg?*	28 297	34 568	0.54	0.60	0.17	0.00
Carry loads >25 kg	*How much time do you spend doing the following tasks or activities: carry a load that weighs more than 25 kg?*	28 271	34 533	0.41	0.45	0.14	0.00
Use vibrating tools	*On a typical day of work, do you use: vibrating tools or place your hand(s) on vibrating machines?*	28 437	34 747	0.16	0.19	0.06	0.00
Use computer screen	*During a typical day of work, do you use: a computer screen or control panel?*	31 017	34 792	0.55	0.56	0.01	0.19
Use keyboard or scanner	*During a typical day of work, do you use: a keyboard, a mouse, or similar device (optical pen, scanner) to enter data?*	28 437	34 735	0.61	0.63	−0.01	0.98
Bend neck	*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?*	32 048	34 732	1.14	1.14	0.36	0.00
Arms above shoulder	*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?*	32 712	34 834	0.41	0.43	0.23	0.00
Reach behind	*How long do you spend in the following posture during a typical day of work: reaching regularly for items behind your back?*	29 482	34 839	0.30	0.34	0.15	0.00
Arms abducted	*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?*	32 634	34 758	0.49	0.52	0.24	0.00
Bend elbow	*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?*	33 722	34 703	0.55	0.57	0.45	0.00
Rotate forearm	*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?*	32 647	34 786	0.26	0.28	0.15	0.00

continued

Table 1 continued

Exposure variable	Description	N (asymp)	N (full)	Within-job variance (asymp)	Within-job variance (full)	β estimate	P value
Bend wrist	*How long do you spend in the following posture during a typical day of work: bending the wrist?*	32 599	34 721	0.50	0.53	0.30	0.00
Press base of hand	*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?*	33 127	34 736	0.19	0.20	0.11	0.00
Finger pinch	*How long do you spend in the following posture during a typical day of work: pinch objects with your thumb and forefinger.*	33 128	34 738	0.69	0.71	0.30	0.00
Work outdoors	*How long do you spend working outdoors during a typical day of work?*	–	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] physical[2–4] 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'examens 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) criteria[19] 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 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.

Table 2 Eligible participants from the Cohorte des consultants des Centres d'examens 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.

JEM exposure metrics

When reporting JEM-assigned exposure values, studies have used different exposure metrics.[29 30] MSD-focused JEMs have typically reported arithmetic means[1] and medians,[31] therefore we reported both metrics. We also corrected the JEM mean value using empirical quantile mapping (EQM) methods[32] 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 Mean	Minutes/day SD	R^2
Physical intensity	6–20	26 821	9.80	3.20	6	7	9	12	15	–	–	0.39
Stand	1–4	29 597	2.59	1.12	1	2	2	4	4	168	143	0.55
Repetition	1–4	26 424	1.75	1.09	1	1	1	2	4	90	130	0.18
Change tasks	1-–4	26 581	2.94	1.11	1	2	3	4	4	204	142	0.10
Rest eyes	1–4	31 848	3.10	1.13	1	2	4	4	4	232	145	0.19
Kneel or squat	1–4	29 574	1.58	0.91	1	1	1	2	4	62	101	0.39
Bend trunk	1–4	30 853	1.66	0.97	1	1	1	2	4	70	107	0.35
Drive machinery	1–4	29 385	1.10	0.46	1	1	1	1	2	15	51	0.27
Drive car or truck	1–4	29 357	1.41	0.88	1	1	1	1	4	46	99	0.29
Handle objects 1–4 kg	0–4	31 116	1.03	1.46	0	0	0	2	4	69	119	0.36
Handle objects >4 kg	0–4	28 306	0.80	1.24	0	0	0	2	4	48	100	0.38
Carry loads <10 kg	0–4	28 240	0.72	1.15	0	0	0	1	3	39	89	0.36
Carry loads 10–25 kg	0–4	28 297	0.58	0.94	0	0	0	1	3	24	69	0.37
Carry loads >25 kg	0–4	28 271	0.51	0.83	0	0	0	1	2	17	57	0.36
Use vibrating tools	1-–4	28 437	1.11	0.47	1	1	1	1	2	17	55	0.30
Use computer screen	1-–4	31 017	3.15	1.12	1	2	4	4	4	240	146	0.55
Use keyboard or scanner	1–4	28 437	3.11	1.15	1	2	4	4	4	231	149	0.52
Bend neck	1–4	32 048	2.45	1.11	1	1	3	3	4	149	133	0.08
Arms above shoulder	1–4	32 712	1.39	0.73	1	1	1	2	3	38	74	0.23
Reach behind	1–4	29 482	1.27	0.57	1	1	1	1	2	26	53	0.05
Arms abducted	1–4	32 634	1.39	0.79	1	1	1	1	3	41	85	0.21
Bend elbow	1–4	33 722	1.42	0.85	1	1	1	1	4	45	91	0.23
Rotate forearm	1–4	32 647	1.22	0.62	1	1	1	1	3	25	66	0.30
Bend wrist	1–4	32 599	1.36	0.79	1	1	1	1	3	40	87	0.22
Press base of hand	1–4	33 127	1.14	0.49	1	1	1	1	2	17	51	0.23
Finger pinch	1–4	33 128	1.45	0.88	1	1	1	1	4	48	97	0.13
Work outdoors	1–4	35 187	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 (r^2) 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).

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

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

where $\widetilde{X}_j i$ is the estimated metric value for the j^{th} 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* (β=−0.11) and *rest eyes* (β=−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.

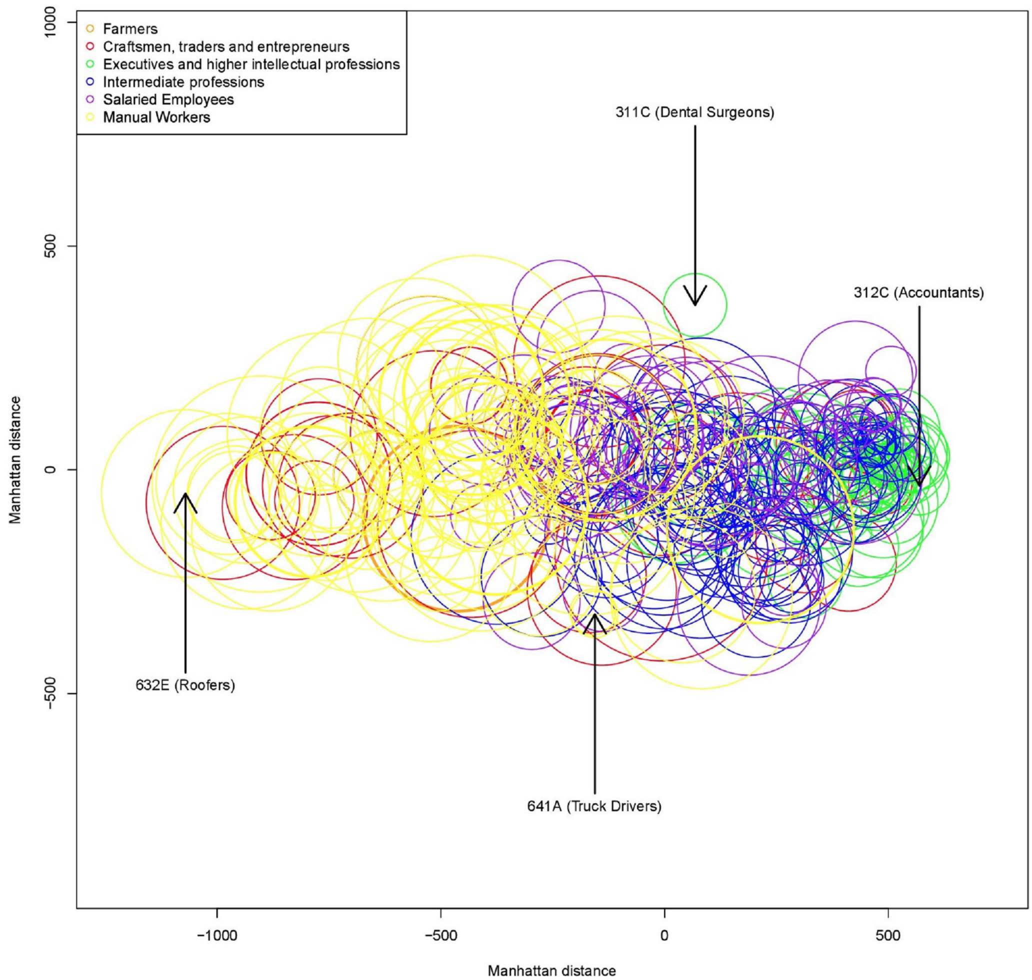

Figure 1 Multidimensional scaling plots of exposure vectors for all PCS codes with 95% confidence ellipses based on Monte Carlo simulations. Colour coded by PCS subgroup (first digit of PCS). PCS, Profession et Catégorie Sociale.

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

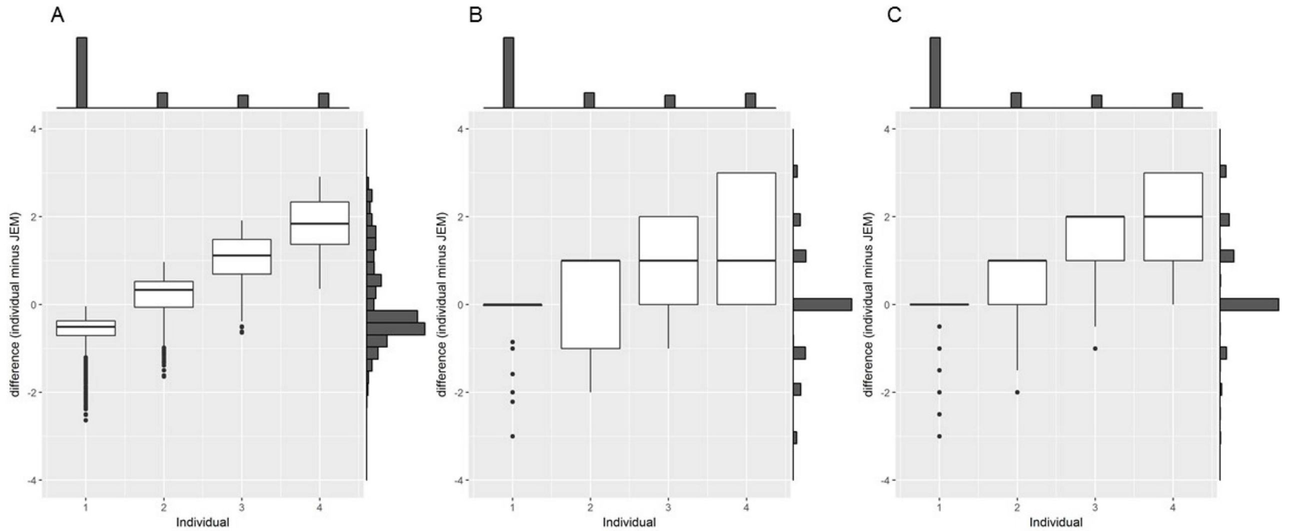

Figure 2 Example of box plots of the differences between individual-level reports and group-level exposure estimates (individual JEM) at each exposure intensity level for three exposure metrics: (A) JEM mean, (B) JEM bias-corrected mean and (C) JEM median. Distributions of individual (top axis) and JEM (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 1–4* kg) 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 exposures[24] 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 estimates[1] 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.

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