HHS Public Access
Author manuscript
Am J Ind Med. Author manuscript; available in PMC 2022 May 26.

Published in final edited form as:
Am J Ind Med. 2020 January ; 63(1): 51–59. doi:10.1002/ajim.23064.

Musculoskeletal Symptoms Associated with Workplace Physical Exposures Estimated by a Job Exposure Matrix and by Self-Report

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Abstract

Background: A job exposure matrix (JEM) is an efficient method to assign physical workplace exposures based on job titles. JEMs offer the possibility of linking work exposures to outcome data from national health registers that contain job titles. The French CONSTANCES JEM was constructed from self-reported physical work exposures of asymptomatic workers participating in a large general population study. We validated this general population JEM by testing its ability to demonstrate exposure-outcome associations for MSD symptoms.

Methods: The CONSTANCES JEM was evaluated by assigning exposure estimates to a validation sample of new participants in the CONSTANCES study (final n = 38,730). We used weighted kappas to compare the level of agreement between JEM-assigned and self-reported exposures across job codes for each of 27 physical exposure variables. We computed prevalence ratios (PR) and 95% confidence intervals using Poisson regression models adjusted for age and sex for pain at 6 body locations associated with work exposures estimated via individual self-report and by the JEM.

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Authors' contributions: BAE, AD, AMD designed the study, obtained funding, and reviewed and edited the paper. AD and YR obtained the study data. MY and SBP contributed to data analysis and data visualization. All authors contributed to interpreting the data, and to drafting and formatting the manuscript

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Institution and Ethics approval and informed consent: Institution and ethics approval was obtained from Washington University in St. Louis; Consent was obtained from all participants as part of the CONSTANCES project.

Disclosure (Authors): The authors declare no conflicts of interest.

Results: Agreement between individual self-reported and JEM-assigned exposures ranged from $\kappa = 0.16$ to 0.71; generally, the level of agreement was fair to good. We observed consistent and significant associations between pain and both self-reported and JEM-assigned exposures at all body locations.

Conclusions: The CONSTANCES JEM replicated known associations between physical risk factors and prevalent MSD symptoms. Physical exposure JEMs can reduce some types of information bias, and open new avenues of research in the prevention of MSDs and other health conditions related to workplace physical activities.

Keywords

Job Exposure Matrix; Musculoskeletal Disorders; Workplace Physical Exposures; Exposure Assessment; Hand Pain

Introduction

Musculoskeletal disorders (MSD) remain the most common and costly chronic condition arising from work-related causes, representing more than a third of all reported occupational diseases in the US, Japan, and Nordic Countries.[1] In 2015, 43% of 44,000 surveyed workers in 35 European countries reported back pain, 42% reported pain in the neck and upper limbs, and 29% reported musculoskeletal pain in the hip or lower extremities.[2] In France, there were over 270,000 compensated cases of MSD between 1996 and 2006.[3] MSD poses a significant economic burden, with the majority of overall costs considered as indirect costs attributed to absence from work, loss of potential earnings, hiring and training of new employees, and reduced productivity levels and quality of work.[3] These burdens underscore the need for effective prevention strategies to mitigate the risk of musculoskeletal disorders and symptoms; improved methods of workplace exposure assessment are necessary to effectively assess and prevent musculoskeletal disorders related to workplace exposures.[4]

A job exposure matrix (JEM) is an efficient and effective method for assigning workplace exposure values based on job titles, enabling large-scale studies of associations between physical exposures and chronic diseases, including MSD. Although individual level direct measurement or observation of worker exposures are considered more precise, they are time consuming, expensive, and may misclassify exposures that vary over a longer time period than the window of exposure assessment.[5] Individual self-reported exposure data are less expensive and may integrate exposures over a longer period but may be less precise than direct measurement or be more prone to recall or reporting bias by participants with concurrent symptoms.[6] Many sources of disease outcome data such as national health registers contain job titles but no other individual level exposure data; JEMs offer the possibility of linking work exposures to these outcome data. JEMs for workplace physical activities have been the focus of much recent work, and have been constructed from direct measurement and observation,[7] expert-rated assessment,[8] and from self-reported exposures.[9]

Recently, we constructed a general population JEM from self-reported physical work exposures in a large general population cohort study of salaried workers in France (Cohorte des consultants des Centres d’examens de santé – CONSTANCES).[10] In our previous studies, we found that this CONSTANCES JEM created homogenous exposure groups that could discriminate physical work exposures between different jobs,[11] and that there was substantial agreement between this French JEM and an existing American JEM.[12] To further validate the CONSTANCES JEM, this study tested the ability of the CONSTANCES JEM to demonstrate known exposure-outcome associations for MSD symptoms at multiple body locations by applying the JEM to a new sample of participants (validation sample) from the same cohort. We first compared the level of agreement between self-reported exposures and JEM-assigned exposure estimates within the validation sample cohort. We then compared exposure-outcome associations for MSD symptoms using self-reported and JEM-assigned exposures. These comparisons will contribute to the growing body of research on JEMs for assessment of physical exposures, and will inform large-scale epidemiological research of MSD and other conditions related to workplace physical activities within the CONSTANCES population study (expected n = 200,000 participants) and potentially within other cohorts.

Materials and Methods

CONSTANCES Job Exposure Matrix and JEM Cohort

CONSTANCES consists of a randomly selected representative sample of the French adult population (18 – 69 years old), including individuals living and working in diverse settings, individuals from different regions and population density areas, and individuals that represent a broad range of socioeconomic status and occupations.[10] Participants were recruited over a several year period and attended an interview and examination by a study physician at one of 17 Health Screening Centers located in different regions of France. Baseline health and occupational exposure data were collected from self-administered questionnaires.[10] Detailed information on CONSTANCES is available at: www.constances.fr.

We created a JEM for 27 physical risk factors relevant to MSD using self-reported physical exposure data obtained from currently employed workers in the first 81,425 CONSTANCES participants, who were recruited between 2012 and 2015.[11] On the baseline questionnaire, participants rated the duration of performing different workplace physical activities at given levels of intensity and frequency on 4- or 5- point ordinal scales. Overall physical intensity was assessed using Borg's rating of perceived exertion (RPE) 6–20 ordinal scale.[13] Self-reported job titles were assigned a French 4-digit PCS (Profession et Catégorie Sociale) job code using an automated coding system.[14]

To create the JEM from the initial 81,425 CONSTANCES participants, we excluded those who were not currently working, those with missing exposure or job title data, and those who were not assigned a 4-digit French PCS job code by the automated coding system, resulting in 35,526 active workers with exposure data linked to 407 unique PCS codes (the "CONSTANCES JEM cohort"). Briefly, the CONSTANCES JEM was created by assigning the bias-corrected means of self-reported exposures provided by workers within each PCS code as the exposure for that job code. For jobs with few workers, we collapsed similar jobs to achieve a minimum number of 10 workers per job title estimate. For each exposure, we also used the self-reported exposure estimates only from workers without musculoskeletal pain in relevant body areas, to avoid potentially biased reporting of current job exposures due to current pain. We found that excluding symptomatic workers lowered within-job variance of reported exposures and led to more homogenous exposure groups.[11] We also found that expressing JEM-assigned estimates using a bias-corrected mean[15] gave group estimates that better reflected the distribution of individual-level exposures and resulted in more homogenous exposure groups at the job level.[11] We calculated bias-corrected means using empirical quantile mapping (EQM) methods, which adjusted JEM mean values falling within every 1% quantile range to correspond with their respective 1% quantiles of the individual-level self-reported values.[15] When developing the JEM, this method resulted in more homogenous exposure groupings. Detailed information on the development and evaluation of the CONSTANCES JEM, including distributions of individual-level and group-level exposure estimates and their differences using median, mean, and bias-corrected mean have been previously published.[11] Informed consent was obtained from all participants as part of the CONSTANCES project; institution and ethics approval for this study was obtained from Washington University in St. Louis.

Validation Cohort

The second wave of 69,782 CONSTANCES participants, recruited to the study from 2015 to 2017, formed the validation sample to evaluate whether the CONSTANCES JEM can replicate known exposure-outcome associations in a worker group whose data were not used in the creation of the JEM. From this cohort of new participants, we excluded individuals who were not currently employed, or whose reported job titles were not assigned one of the 407 4-digit PCS codes used in the JEM, leaving 38,730 participants as the "Validation cohort."

Statistical Analysis

Comparison of Level of Agreement between self-reported exposures and JEM-assigned exposure estimates—For each of the 27 physical exposure variables, we calculated weighted kappa and 95% upper and lower limits between individual self-reported exposure values and JEM-assigned bias-corrected mean exposure estimates. This analysis was performed across all PCS codes for the validation sample cohort (n = 38,730).

Associations between self-reported exposures, JEM-assigned exposure estimates, and musculoskeletal pain.—From the 27 JEM physical exposure variables, we selected *a priori* those exposures thought to be most relevant to MSD pain specific to each of six body locations: hand, elbow, shoulder, low back, knee, and neck. For each body location, we graded the *a priori* selected exposures based on the expected strength of their association with MSD pain: strong association, some association, and possible association. This analysis was performed for the outcomes of current pain (definition: >5 rating on a 0–10 self-reported ordinal scale in the previous 7 days) and/or chronic musculoskeletal pain (pain occurring 30 or more days within the previous year) at the six body locations. We computed prevalence ratios (PR) and 95% confidence intervals using Poisson regression models with robust sandwich estimators adjusted for age and sex for both individual self-reported exposures and JEM-assigned exposures. We analyzed two models for all exposures: a continuous model using the full scale of the exposure values and a dichotomous model where exposures were split at the median exposure value. For two of the variables ("Use computer screen" and "Use keyboard or scanner"), the median value was at the maximum scale rating, and therefore high exposure reflects the maximum value whereas low exposure reflects exposures less than the maximum. We did not adjust for multiple comparisons.

Results

The validation sample cohort shared similar demographics as the cohort used for the creation of the JEM (Table I). Most striking are similarities in the distribution of workers by broad socio-professional job categories (i.e., the first digit PCS code) and nearly identical distribution based on sex. In both cohorts, the largest number of workers represented senior civil servants, senior managerial staff, and higher intellectual professions, as well as workers representing associate professionals in teaching, health, and administration. We found that in both the JEM cohort and validation sample cohort, there was a higher distribution of female (55%) than male workers (45%). In the validation sample cohort, 14.7% of the 38730 participants reported current low back pain followed by neck pain (9.9%) and knee pain (8.6%). 9113 participants (26.5%) of the validation sample cohort reported current pain at one or more body locations. Of the 38730 participants, 23.9% reported chronic low back pain (occurring 30 days or more in the previous year); 45.4% of the validation sample reported chronic pain at one or more body locations. Workers in the validation sample were somewhat younger than the CONSTANCES JEM cohort, with a slightly higher proportion of the cohort between 25 and 44 years of age. The validation sample also had a lower proportion of workers who were 65 years or older.

Table II shows mean and median exposure values for each exposure variable; to help interpret ordinal scale ratings, we recoded exposure ratings to a time-based value using the median value of the time interval indicated in the CONSTANCES questionnaire, as previously described.[11] Time-based exposure values were generally consistent between the validation sample and the JEM cohort.

Comparison of Level of Agreement between self-reported exposures and JEM-assigned exposure estimates

Overall, agreement between individually self-reported and JEM-assigned exposures was fair to good as shown in Table III. Weighted kappa values ranged from $\kappa = 0.16$ (variable: "Reach Behind") to 0.71 (variable: "Use Computer Screen"). Based on Altman's (1991) interpretation, six exposure variables demonstrated good agreement (variables: "Physical Intensity", "Stand", "Handle Objects 1–4 kg", "Handle Objects >4kg", "Use Computer Screen", and "Use Keyboard or Scanner"), fifteen exposure variables demonstrated moderate agreement, five variables demonstrated fair agreement, and one variable demonstrated poor agreement (Table III). In our previous study, the amount of variance explained by PCS job code was different between risk factor variables; "Reach Behind" led to a low explained variance whereas "Use Computer Screen" resulted in high explained variance.[11]

Associations between self-reported exposures, JEM-assigned exposure estimates, and musculoskeletal pain.

We calculated prevalence ratios of musculoskeletal pain at six body locations (Table IV: (a) hand, (b) elbow, (c) shoulder, (d) low back, (e) knee, (f) neck) using self-reported and JEM-assigned exposure estimates. Generally, we observed consistent and significant exposure-outcome relationships for both self-reported and JEM-assigned exposure estimates in both continuous and dichotomous models for all six body locations. Effect sizes from JEM estimates were marginally attenuated compared to effect sizes from self-report. Generally, we observed that longer exposure durations were associated with higher prevalence of musculoskeletal pain. However, two variables ("Use Computer Screen" and "Use Keyboard or Scanner") were significantly *protective* of hand and neck pain using both self-reported and JEM-assigned estimates for continuous and dichotomous models. JEM estimates resulted in somewhat lower (more protective) point estimates for both hand and neck pain.

Discussion

After assigning CONSTANCES JEM exposure estimates to a large validation sample of CONSTANCES participants, we first evaluated the agreement between exposure values obtained from individual self-report and from JEM-assigned estimates. Of the 27 physical exposure variables, 21 variables demonstrated moderate to good agreement. Second, we evaluated associations of self-reported and JEM-assigned exposure estimates with current musculoskeletal pain at six body locations; both exposure estimation methods demonstrated significant exposure-outcome associations with musculoskeletal symptoms, with generally similar results. These findings support the conclusion that a general population JEM for physical exposures, including this CONSTANCES JEM, can be an effective method to estimate workplace exposures.

The CONSTANCES JEM was created using self-reported data from asymptomatic workers; retaining their data created favorable homogenous exposure groups.[11] In the validation sample, individual self-reports include exposures from symptomatic and asymptomatic workers. There is the possibility that workers with musculoskeletal pain might have overestimated their exposures compared to workers without symptoms.[6] On the other hand, it is also possible that higher exposures were accurately reported by workers with MSD symptoms due to actual exposure differences between workers within the same job. A recognized limitation of JEMs is that they do not capture exposure variability within the same job.[16]

Exposure-outcome associations using JEMs have previously been compared to associations using "gold standard" directly measured or observed exposures. Friesen et al.[17] compared a JEM constructed from expert-ratings with direct measurement for exposure to carcinogens. Solovieva et al.[18] validated a gender-specific JEM for workplace psychosocial factors in the study of depression and low back pain. For physical exposures, Dale et al.,[19] compared exposure-outcome associations for incident of carpal tunnel syndrome using a JEM created from American O*NET physical demands data and directly observed physical work exposures in a large American worker cohort. In Dale et al.,[19] effect sizes of exposures categorized by ergonomic dimension (e.g., force intensity, repetition, duration) were similar between O*NET JEM values and direct observation, however the precision of the exposure-outcome associations using JEM estimates was lower based on wider 95% confidence intervals. In this study, we compared the CONSTANCES JEM to individual self-report between similar population samples and identical exposure variables. The point estimates of JEM-assigned estimates were marginally attenuated compared to individual self-report; JEMs usually do not take into account variability of exposures within job codes since a single value is assigned to each job code. Using a JEM to assign a single exposure estimate for each code may then result in non-differential misclassification of exposures and may consequently attenuate risk estimates towards the null.[16] However, in both continuous and dichotomous Poisson regression models, we observed substantially similar, statistically significant associations for the same variables in all body locations using both exposure methods.

Generally, our *a priori* selected variables demonstrated meaningful positive associations with musculoskeletal pain, with the exception of variables estimating computer use and the outcomes of hand pain and neck pain. Studies focused on office workers report mixed results on associations between computer use and musculoskeletal symptoms.[20–22] Our results indicated that computer use was significantly protective for hand and neck pain, which is consistent with a previous study on two large general population cohorts (France and United States of America) that observed no association between computer work and new cases of carpal tunnel syndrome.[23] In general population studies, office workers are compared to workers in other job sectors, who are more highly exposed to other physical factors such as repetition, forceful exertions, vibration, and awkward postures.

There are several limitations to our study. First, we investigated the exposure-outcome associations based on the prevalence of MSD pain; results of our cross-sectional study may be influenced by the healthy worker survivor effect, leading to an underestimation of the risk of MSD pain in high-exposure jobs. Future studies on the incidence of MSD symptoms may provide better indications of MSD risk. Second, our case definition of MSD symptoms was based on reporting a rating of more than 5 on a pain scale between 0 (no pain or discomfort) and 10 (most pain imaginable) in the previous 7 days or occurring more than 30 days within the previous year. The pain scale used in CONSTANCES was based on the Nordic musculoskeletal questionnaire,[24] which has been shown to be a useful tool for surveillance of MSD when exploring symptoms in the previous year.[25] The pain threshold value was set at the median rating, which has been used as a threshold value for pain.[26–28] The prevalence of pain at each region, and probably the effect sizes, would be expected to change if a different threshold value were used. Third, self-reported symptoms may be influenced by differences in worker pain thresholds, cultural influences, and psychosocial factors at work.[1] However, self-reports have also been shown to be highly correlated with physical examinations and measures.[1] Fourth, the CONSTANCES study does not include self-employed workers who are affiliated with other health insurances funds in France.[10] This potential selection bias may raise the question of generalizability of our results within the source population. However, the sample represents more than 85% of the general population, representing a diverse range of occupations, socioeconomic status, and living environments.[10] Lastly, we dichotomized both outcome and exposure data for ease of presentation of multiple exposure-outcome relationships. Future analyses will be needed to determine the shape of these relationships and the presence of threshold effects.

There are several study strengths. We observed consistent exposure-outcome associations using JEM-assigned exposure estimates with self-reported exposure data, indicating that a JEM is a reasonable exposure assessment method to predict prevalent MSD symptoms in a general population cohort. Self-reported data are susceptible to information biases due to individual variation in reporting, and to potentially biased reporting when symptoms and exposures are reported at the same time in cross-sectional studies. A JEM based on self-report minimizes these potential information biases as it consists of pooled exposure data from all workers, and assigns exposures at the job level. A JEM constructed from self-reported exposures makes use of workers' knowledge and provides a method to estimate cumulative exposure.[29] Unlike self-reported data, a JEM can also be applied retroactively to assign past exposures based on job titles that can then be used to study current or future chronic diseases.[30,31] There is potential in using JEMs outside their countries of origin or to complement existing JEMs that might lack particular exposures; recently, we found that physical exposure estimates from this French JEM can be applied to an American JEM, and vice versa.[12] However, further cross-national comparisons are needed to fully realize this rapidly expanding area of occupational epidemiology research.[32]

JEMs are simple, cost-effective, and useful tools that provide a source of workplace exposure data, particularly for epidemiological studies that lack individual-level exposure data. Our results suggest that the CONSTANCES JEM based on self-reported physical exposures from asymptomatic workers replicates known associations between physical risk factors and prevalent MSD symptoms. Physical exposure JEMs, such as the CONSTANCES JEM, open avenues of research in the prevention of MSDs and other health conditions related to workplace physical activities.

Funding:

Grant sponsor: US National Institute for Occupational Safety and Health; Grant number: NIOSH R01OH011076; Grant sponsor for CONSTANCES: French National Research Agency; Grant number: ANR-11-INBS-0002; Grant sponsor for CONSTANCES: Caisse Nationale d'Assurance Maladie des Travailleurs Salariés (CNAMTS); Grant sponsor for CONSTANCES: Institut de Recherché en Santé Publique/Institut Thématique Santé Publique; Grant sponsor for CONSTANCES: 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).

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Table I.

Characteristics of the Validation cohort of CONSTANCES Participants (N = 38,730) compared to the CONSTANCES JEM Cohort (N = 35526).

	n	%*	JEM Cohort %*
Socio-Professional Category			
Farmers	15	0.04	0.04
Craftsmen, traders and entrepreneurs	605	1.56	1.50
Executives and higher intellectual professions	13087	33.79	34.32
Intermediate professions	12960	33.46	31.07
Salaried Employees	7801	20.14	22.54
Manual Workers	4262	11.00	10.53
Sex			
Male	17329	44.74	44.47
Female	21401	55.26	55.53
Age			
18–24 years old	970	2.50	2.15
25–34 years old	8951	23.11	18.21
35–44 years old	11875	30.66	25.79
45–54 years old	10531	27.19	29.89
55–64 years old	6221	16.06	18.43
65 years and older	182	0.47	5.54
Musculoskeletal Symptoms (Current: Pain in past 7 days & current pain level 5 or more)			
Hand	1791	5.66	
Knee	2738	8.55	
Neck	3211	9.94	
Elbow	1048	3.36	
Lower back	4762	14.70	
Shoulder	2502	7.85	
1 or More Regions	9113	26.53	
Musculoskeletal Symptoms (Chronic: Pain in past year, occurring 30 or more days)			
Hand	4775	13.22	
Knee	6533	17.80	
Neck	6317	17.02	
Elbow	3228	9.04	
Lower back	8942	23.96	
Shoulder	5967	16.27	
1 or More Regions	17478	45.40	
Musculoskeletal Symptoms (Current and/or Chronic Pain)			
Hand	5300	14.24	
Knee	7305	19.44	
Neck	7406	19.65	
Elbow	3487	9.42	

	n	%*	JEM Cohort %*
Lower back	10267	27.10	
Shoulder	6651	17.73	
1 or More Regions	19337	50.19	

*Proportion of individuals within cohort

Table II.

Descriptive Statistics of JEM Values for Twenty-Seven Risk Factor Variables in the Validation Sample (N = 38730)

Exposure Variable	Scale	N^	Mean	SD	P05#	P25#	Med^^	P75#	P95#	Minutes/Day* Mean	Minutes/Day* SD
Physical intensity	6–20	37661	10.13	3.41	6	7	10	13	16	---	---
Stand	1–4	38109	2.66	1.13	1	2	3	4	4	172	144
Repetition	1–4	37116	1.81	1.12	1	1	1	3	4	84	125
Change tasks	1–4	37229	2.85	1.12	1	2	3	4	4	197	141
Rest eyes	1–4	37257	2.98	1.17	1	2	3	4	4	220	148
Kneel or squat	1–4	38053	1.63	0.96	1	1	1	2	4	62	102
Bend trunk	1–4	37983	1.71	1.00	1	1	1	2	4	70	107
Drive machinery	1–4	38135	1.12	0.49	1	1	1	1	2	16	52
Drive car or truck	1–4	38115	1.40	0.87	1	1	1	1	4	44	97
Handle objects 1–4 kg	0–4	37422	1.05	1.47	0	0	0	2	4	66	117
Handle objects >4 kg	0–4	37264	0.86	1.28	0	0	0	2	4	46	98
Carry loads <10 kg	0–4	37211	0.76	1.17	0	0	0	1	3	36	85
Carry loads 10–25 kg	0–4	37277	0.63	0.99	0	0	0	1	3	24	68
Carry loads > 25 kg	0–4	37325	0.55	0.87	0	0	0	1	2	16	56
Use vibrating tools	1–4	37652	1.13	0.50	1	1	1	1	2	16	51
Use computer screen	1–4	37772	3.13	1.12	1	2	4	4	4	238	145
Use keyboard or scanner	1–4	37734	3.03	1.18	1	2	4	4	4	227	150
Bend neck	1–4	37602	2.38	1.11	1	1	2	3	4	137	130
Arms above shoulder	1–4	37784	1.40	0.74	1	1	1	2	3	37	73
Reach behind	1–4	37779	1.26	0.57	1	1	1	1	2	23	50
Arms abducted	1–4	37657	1.39	0.79	1	1	1	1	3	39	81
Bend elbow	1–4	37587	1.40	0.83	1	1	1	1	4	41	87
Rotate forearm	1–4	37733	1.22	0.62	1	1	1	1	3	24	63
Bend wrist	1–4	37674	1.36	0.79	1	1	1	1	3	37	83
Press base of hand	1–4	37710	1.13	0.48	1	1	1	1	2	16	48
Finger pinch	1–4	37699	1.39	0.83	1	1	1	1	4	41	88
Work outdoors	1–4	38285	1.37	0.77	1	1	1	1	3	37	79

^Non-missing responses

#P05/P25/P75/P95 are 5th, 25th, 75th, 95th percentiles, respectively.

^^Med = median

*Exposure rating values re-coded to a time-based value based on the following conversion:

No [for 5pt 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 mins	5 mins	60 mins	180 mins	360 mins

Table III.

Agreement between Self-Reported and JEM-Assigned Exposure Estimates (Bias-Corrected Mean). Weighted kappa and 95% Lower (LL) and Upper Limits (UL).

Exposure Variable	Weighted kappa	95% LL	95% UL
Physical intensity	0.64	0.64	0.65
Stand	0.70	0.70	0.71
Repetition	0.43	0.42	0.44
Change tasks	0.30	0.29	0.31
Rest eyes	0.43	0.42	0.44
Kneel or squat	0.59	0.58	0.60
Bend trunk	0.57	0.57	0.58
Drive machinery	0.47	0.45	0.49
Drive car or truck	0.55	0.54	0.56
Handle objects 1–4 kg	0.61	0.60	0.62
Handle objects >4 kg	0.62	0.61	0.63
Carry loads <10 kg	0.56	0.55	0.57
Carry loads 10–25 kg	0.57	0.56	0.58
Carry loads > 25 kg	0.55	0.53	0.57
Use vibrating tools	0.52	0.50	0.54
Use computer screen	0.71	0.70	0.72
Use keyboard or scanner	0.67	0.66	0.68
Bend neck	0.26	0.25	0.27
Arms above shoulder	0.43	0.42	0.44
Reach behind	0.16	0.14	0.18
Arms abducted	0.41	0.40	0.42
Bend elbow	0.45	0.43	0.46
Rotate forearm	0.51	0.49	0.53
Bend wrist	0.40	0.39	0.42
Press base of hand	0.39	0.36	0.41
Finger pinch	0.28	0.26	0.29
Work outdoors	0.58	0.57	0.60

Range of kappa Values	Altman's (1991) Interpretation
<0.20	Poor
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Good
0.81 – 1.00	Very Good

Table IV.

Exposure-Response Associations between Self-Reported Exposure Values, JEM-Assigned Exposure Estimates (Bias-Corrected Mean), and Current and/or Chronic Musculoskeletal Pain at 6 Body Locations: (A) Hand, (B) Elbow, (C) Shoulder, (D) Low Back, (E) Knee, (F) Neck. Poisson Regression Models with Robust Sandwich Estimators Adjusted for Age and Sex. Continuous – Full Scale (1-unit increase) and Dichotomized (Split at Median) Models. *A Priori* Expectations of Association Strengths and Prevalence Ratios (95% CI).

(A) Hand Pain

Exposure Variable	*A Priori* *	Self-Report (Full)			JEM (Full)			Self-Report (Dich.)			JEM (Dich.)		
		PR	95% CI		PR	95% CI		PR	95% CI		PR	95% CI	
			Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
Physical intensity	++	1.10	1.09	1.10	1.07	1.06	1.08	1.65	1.57	1.74	1.46	1.39	1.54
Repetition	++	1.24	1.21	1.26	1.22	1.20	1.24	1.59	1.51	1.67	1.57	1.49	1.65
Handle objects 1–4 kg	++	1.21	1.19	1.23	1.17	1.15	1.19	1.72	1.64	1.81	1.43	1.36	1.51
Handle objects >4 kg	++	1.24	1.22	1.26	1.20	1.18	1.22	1.72	1.64	1.81	1.55	1.47	1.63
Carry loads <10 kg	++	1.25	1.23	1.28	1.21	1.19	1.24	1.72	1.64	1.81	1.55	1.48	1.63
Carry loads 10–25 kg	++	1.29	1.26	1.31	1.25	1.22	1.28	1.72	1.64	1.81	1.54	1.46	1.62
Carry loads > 25 kg	++	1.31	1.28	1.34	1.24	1.21	1.27	1.72	1.64	1.81	1.53	1.46	1.61
Use vibrating tools	++	1.42	1.37	1.47	1.34	1.29	1.40	2.07	1.92	2.23	1.81	1.67	1.96
Use computer screen	+	0.86	0.84	0.88	0.83	0.81	0.85	0.78	0.74	0.82	0.74	0.70	0.78
Use keyboard or scanner	+	0.88	0.86	0.90	0.84	0.82	0.85	0.80	0.76	0.84	0.75	0.71	0.79
Bend elbow	+	1.36	1.33	1.39	1.30	1.27	1.34	1.83	1.74	1.93	1.70	1.61	1.79
Rotate forearm	++	1.39	1.35	1.43	1.35	1.31	1.40	1.84	1.73	1.96	1.72	1.61	1.83
Bend wrist	++	1.43	1.40	1.47	1.30	1.27	1.34	2.10	1.99	2.21	1.72	1.63	1.82
Press base of hand	++	1.40	1.35	1.45	1.41	1.35	1.47	1.87	1.74	2.02	1.86	1.72	2.01
Finger pinch	++	1.28	1.25	1.31	1.15	1.12	1.18	1.66	1.57	1.75	1.25	1.19	1.32

(B) Elbow Pain

Exposure Variable	*A Priori* *	Self-Report (Full)			JEM (Full)			Self-Report (Dich.)			JEM (Dich.)		
		PR	95% CI		PR	95% CI		PR	95% CI		PR	95% CI	
			Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
Physical intensity	++	1.11	1.10	1.12	1.08	1.07	1.09	1.76	1.65	1.88	1.58	1.48	1.68
Repetition	++	1.29	1.26	1.33	1.27	1.24	1.31	1.73	1.62	1.85	1.71	1.60	1.82
Handle objects 1–4 kg	++	1.23	1.21	1.26	1.19	1.16	1.21	1.75	1.64	1.87	1.47	1.38	1.57

(B) Elbow Pain

Exposure Variable	*A Priori* *	Self-Report (Full) PR	Self-Report (Full) 95% CI Lower	Self-Report (Full) 95% CI Upper	JEM (Full) PR	JEM (Full) 95% CI Lower	JEM (Full) 95% CI Upper	Self-Report (Dich.) PR	Self-Report (Dich.) 95% CI Lower	Self-Report (Dich.) 95% CI Upper	JEM (Dich.) PR	JEM (Dich.) 95% CI Lower	JEM (Dich.) 95% CI Upper
Handle objects >4 kg	++	1.26	1.24	1.29	1.22	1.19	1.24	1.75	1.64	1.86	1.58	1.48	1.68
Carry loads <10 kg	++	1.28	1.25	1.31	1.24	1.21	1.27	1.75	1.65	1.87	1.57	1.48	1.68
Carry loads 10–25 kg	++	1.31	1.28	1.35	1.28	1.24	1.31	1.75	1.64	1.86	1.57	1.48	1.68
Carry loads > 25 kg	++	1.32	1.29	1.36	1.27	1.23	1.31	1.75	1.65	1.87	1.59	1.49	1.70
Use vibrating tools	++	1.42	1.36	1.49	1.38	1.32	1.45	2.03	1.84	2.23	1.95	1.77	2.14
Bend elbow	++	1.49	1.45	1.53	1.34	1.30	1.38	2.23	2.09	2.37	1.83	1.71	1.95
Rotate forearm	++	1.41	1.36	1.46	1.35	1.30	1.41	1.91	1.77	2.07	1.79	1.65	1.94
Bend wrist	++	1.41	1.37	1.46	1.34	1.29	1.38	2.04	1.91	2.18	1.88	1.76	2.01

(C) Shoulder Pain

Exposure Variable	*A Priori* *	Self-Report (Full) PR	Self-Report (Full) 95% CI Lower	Self-Report (Full) 95% CI Upper	JEM (Full) PR	JEM (Full) 95% CI Lower	JEM (Full) 95% CI Upper	Self-Report (Dich.) PR	Self-Report (Dich.) 95% CI Lower	Self-Report (Dich.) 95% CI Upper	JEM (Dich.) PR	JEM (Dich.) 95% CI Lower	JEM (Dich.) 95% CI Upper
Physical intensity	++	1.08	1.07	1.08	1.05	1.04	1.05	1.46	1.39	1.52	1.29	1.24	1.35
Repetition	++	1.18	1.16	1.20	1.16	1.14	1.18	1.41	1.35	1.47	1.39	1.33	1.45
Handle objects 1–4 kg	++	1.15	1.14	1.17	1.11	1.09	1.13	1.47	1.41	1.54	1.26	1.21	1.32
Handle objects >4 kg	++	1.17	1.15	1.19	1.12	1.11	1.14	1.46	1.40	1.53	1.33	1.27	1.39
Carry loads <10 kg	++	1.17	1.16	1.19	1.14	1.12	1.16	1.46	1.40	1.53	1.33	1.28	1.40
Carry loads 10–25 kg	++	1.20	1.18	1.23	1.16	1.14	1.19	1.47	1.40	1.53	1.33	1.27	1.39
Carry loads > 25 kg	++	1.23	1.20	1.25	1.17	1.14	1.19	1.48	1.41	1.54	1.34	1.29	1.40
Use vibrating tools	++	1.25	1.21	1.30	1.23	1.18	1.27	1.56	1.45	1.68	1.50	1.40	1.62
Arms above shoulder	++	1.31	1.28	1.34	1.18	1.14	1.21	1.55	1.49	1.62	1.17	1.12	1.22
Reach behind	+	1.27	1.23	1.31	1.12	1.08	1.16	1.40	1.33	1.47	1.15	1.09	1.21
Arms abducted	+	1.29	1.26	1.31	1.20	1.17	1.23	1.59	1.51	1.66	1.38	1.32	1.44
Rotate forearm	+	1.26	1.22	1.29	1.20	1.16	1.24	1.54	1.46	1.63	1.39	1.31	1.47

(D) Low Back Pain

Exposure Variable	*A Priori* *	Self-Report (Full)			JEM (Full)			Self-Report (Dich.)			JEM (Dich.)		
		PR	95% CI		PR	95% CI		PR	95% CI		PR	95% CI	
			Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
Physical intensity	++	1.08	1.08	1.09	1.06	1.05	1.06	1.54	1.48	1.59	1.38	1.33	1.43
Stand	++	1.14	1.13	1.16	1.11	1.09	1.12	1.36	1.32	1.41	1.21	1.17	1.25
Repetition	++	1.18	1.16	1.20	1.17	1.15	1.18	1.43	1.38	1.48	1.43	1.38	1.47
Kneel or squat	+	1.22	1.20	1.24	1.18	1.16	1.20	1.45	1.41	1.50	1.37	1.32	1.41
Bend trunk	++	1.26	1.24	1.28	1.15	1.14	1.17	1.56	1.51	1.61	1.35	1.31	1.40
Drive machinery	++	1.19	1.16	1.22	1.20	1.16	1.23	1.47	1.38	1.56	1.53	1.45	1.63
Drive car or truck	+	1.11	1.09	1.13	1.09	1.07	1.11	1.21	1.16	1.26	1.16	1.12	1.21
Handle objects 1–4 kg	−	1.16	1.15	1.18	1.13	1.12	1.14	1.52	1.47	1.57	1.32	1.28	1.36
Handle objects >4 kg	+	1.19	1.18	1.20	1.15	1.14	1.17	1.52	1.47	1.57	1.42	1.37	1.47
Carry loads <10 kg	+	1.20	1.18	1.21	1.17	1.15	1.18	1.52	1.47	1.58	1.42	1.38	1.47
Carry loads 10–25 kg	++	1.23	1.21	1.25	1.19	1.17	1.21	1.52	1.47	1.57	1.42	1.37	1.47
Carry loads > 25 kg	++	1.25	1.23	1.27	1.20	1.18	1.22	1.52	1.47	1.58	1.42	1.37	1.46
Use vibrating tools	+	1.24	1.20	1.27	1.22	1.19	1.26	1.53	1.45	1.61	1.50	1.42	1.58
Reach behind	+	1.28	1.25	1.31	1.13	1.10	1.16	1.40	1.35	1.46	1.15	1.11	1.20

(E) Knee Pain

Exposure Variable	*A Priori* *	Self-Report (Full)			JEM (Full)			Self-Report (Dich.)			JEM (Dich.)		
		PR	95% CI		PR	95% CI		PR	95% CI		PR	95% CI	
			Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
Physical intensity	++	1.07	1.07	1.08	1.05	1.05	1.06	1.44	1.38	1.51	1.35	1.29	1.41
Stand	+	1.14	1.12	1.16	1.12	1.10	1.14	1.35	1.30	1.41	1.24	1.19	1.29
Repetition	++	1.16	1.14	1.18	1.16	1.14	1.18	1.39	1.33	1.45	1.38	1.33	1.44
Kneel or squat	++	1.21	1.19	1.24	1.17	1.14	1.19	1.44	1.39	1.51	1.36	1.31	1.42
Carry loads <10 kg	−	1.18	1.16	1.20	1.15	1.14	1.17	1.47	1.41	1.54	1.38	1.32	1.43
Carry loads 10–25 kg	++	1.21	1.19	1.24	1.18	1.16	1.20	1.47	1.41	1.53	1.36	1.31	1.42
Carry loads > 25 kg	++	1.22	1.20	1.25	1.18	1.15	1.20	1.47	1.41	1.54	1.36	1.30	1.42

(F) Neck Pain

Exposure Variable	*A Priori* *	Self-Report (Full)			JEM (Full)			Self-Report (Dich.)			JEM (Dich.)		
		PR	95% CI		PR	95% CI		PR	95% CI		PR	95% CI	
			Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
Physical intensity	+	1.05	1.05	1.06	1.02	1.01	1.03	1.29	1.23	1.34	1.12	1.08	1.17
Repetition	+	1.14	1.13	1.16	1.11	1.09	1.13	1.34	1.28	1.40	1.31	1.26	1.36
Bend Trunk	+	1.15	1.13	1.17	1.05	1.02	1.07	1.28	1.23	1.33	1.11	1.06	1.15
Drive Machinery	+	1.09	1.04	1.14	1.13	1.09	1.18	1.17	1.07	1.28	1.29	1.18	1.41
Use computer screen	+	0.98	0.96	1.00	0.94	0.93	0.96	1.01	0.97	1.05	0.95	0.91	0.99
Use keyboard or scanner	+	0.99	0.97	1.00	0.95	0.93	0.97	1.01	0.97	1.06	0.96	0.92	1.00
Bend neck	+	1.26	1.24	1.28	1.06	1.04	1.08	1.57	1.51	1.64	1.13	1.09	1.18

* A priori ranking of exposures based on expected strength of association with MSD pain: ++=strong association, += some association, − = possible association