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ORIGINAL ARTICLE

Incident CTS in a large pooled cohort study: associations obtained by a Job Exposure Matrix versus associations obtained from observed exposures

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ABSTRACT

Background There is growing use of a job exposure matrix (JEM) to provide exposure estimates in studies of work-related musculoskeletal disorders; few studies have examined the validity of such estimates, nor did compare associations obtained with a JEM with those obtained using other exposures.

Objective This study estimated upper extremity exposures using a JEM derived from a publicly available data set (Occupational Network, O*NET), and compared exposure-disease associations for incident carpal tunnel syndrome (CTS) with those obtained using observed physical exposure measures in a large prospective study.

Methods 2393 workers from several industries were followed for up to 2.8 years (5.5 person-years). Standard Occupational Classification (SOC) codes were assigned to the job at enrolment. SOC codes linked to physical exposures for forceful hand exertion and repetitive activities were extracted from O*NET. We used multivariable Cox proportional hazards regression models to describe exposure-disease associations for incident CTS for individually observed physical exposures and JEM exposures from O*NET.

Results Both exposure methods found associations between incident CTS and exposures of force and repetition, with evidence of dose–response. Observed associations were similar across the two methods, with somewhat wider CIs for HRs calculated using the JEM method.

Conclusion Exposures estimated using a JEM provided similar exposure-disease associations for CTS when compared with associations obtained using the 'gold standard' method of individual observation. While JEMs have a number of limitations, in some studies they can provide useful exposure estimates in the absence of individual-level observed exposures.

Key messages

What is already known about this subject?

- For some study designs, job exposure matrices (JEM) offer a cost-efficient way of assessing exposures, and can be applied to existing data sets that contain job titles and disease outcomes but no other exposure data.

What are the new findings?

- Physical exposures estimated from a JEM produced similar associations with carpal tunnel syndrome compared with those obtained using the 'gold standard' method of individual observation.
- O*NET, a publicly available data set in the USA, can provide useful physical exposure values for examining some exposure-disease relationships.

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

- Because of their low cost and ease of use, general-population JEMs may be useful for calculating burden of exposure at a population level, and for targeting surveillance or intervention efforts.
- Their applicability to past exposures may be useful for clinical or compensation assessments among individuals when more detailed exposure information is lacking.

INTRODUCTION

Exposure assessment of biomechanical factors is critical for both epidemiologic studies and workplace risk assessments for occupational musculoskeletal disorders.[1 2] Observations, video analysis and direct measurements are reliable and precise, but these approaches are also time consuming and expensive and are difficult to apply in studies of large populations.[3 4] Questionnaire-based exposure assessments are easier to administer to large groups of workers and their employers, but may be less accurate due to both non-differential misclassification and differential misclassification (eg, recall bias), particularly if perception of exposures may be altered by health status.[5] While prospectively obtained observed or directly measured individual-level physical exposure data are considered the 'gold standard' for occupational exposure assessment for epidemiological studies of acute health effects, these methods are difficult to apply in studies of chronic health outcomes, and usually cannot be applied to studies of past exposures.

In the absence of directly measured individual-level exposure data, a job exposure matrix (JEM) is commonly used in occupational studies to estimate study participants' exposures to chemical and physical risk factors based on job titles, industry information and population exposure data.[6] JEMs are increasingly used to estimate work-related physical exposures for studies of musculoskeletal disorders, and are a topic of current research interest.[7–14] Occupational Network (O*NET), a publicly available American database, describes physical and mental requirements of occupations based on the US Standard Occupational Classification (SOC) through exposure estimates assigned by experts and through self-reported exposures by individual workers across different jobs. Several recent studies have used O*NET-based physical exposure estimates to evaluate relationships between workplace exposures and chronic disease outcomes.[12 15 16]

While several studies have been performed to validate physical exposure JEMs,[10 11 17 18] there is still a need to validate new and existing JEMs to assess their usefulness for future research.[19] The primary purpose of the current study was to evaluate the validity of a physical exposure JEM derived from O*NET by comparing exposure-disease associations for incident carpal tunnel syndrome (CTS) obtained using this JEM versus associations obtained using directly observed individual measures of physical exposures in a well-characterised, previously studied cohort of US workers. We hypothesised that associations with incident CTS based on JEM exposure estimates would be of similar magnitude but less precise than those based on individual-level observed exposure estimates.

METHODS

Study population

The study cohort consisted of pooled data from six prospective studies of workplace risk factors for upper extremity musculoskeletal disorders. Details of the pooled cohort have been described elsewhere.[20–23] Briefly, study participants were full-time employees, 18 years of age or older, who performed hand-intensive activities, and were employed in industries such as manufacturing, production, service and construction. In total, 4321 workers were recruited across the six study sites and followed between 2001 and 2010. At enrolment, all study participants completed baseline questionnaires and underwent physical examinations that included median and ulnar electrodiagnostic studies (EDS) across the wrist.[23] Individual workplace exposure assessments included interviews to identify primary work tasks, videotaped recordings of workers performing their usual work tasks and measurements of hand forces used to complete each task. Video analysis of work tasks provided estimates of hand force, repetitiveness in tasks and temporal exertion patterns for repetition, hand exertions, duty cycle and posture as described in a previous publication.[24] The Institutional Review Board at each study site approved relevant study protocols, and all participants provided written informed consent.

Outcome

The primary study outcome was incident CTS of the dominant hand that included both (1) symptoms of tingling, numbness, burning or pain in the thumb, index finger or long finger, and (2) abnormal EDS consistent with median neuropathy at the wrist. Median neuropathy criteria included (A) peak median sensory latency >3.7 ms or onset median sensory latency >3.2 ms at 14 cm, (B) motor latency >4.5 ms, or (C) transcarpal sensory difference of >0.85 ms (difference between median and ulnar nerve sensory latency across the wrist). All electrodiagnostic values were temperature adjusted to 32°C. Those meeting the case definition at baseline were excluded. Participants eligible to become an incident case of CTS were followed from study enrolment until the case definition of CTS was met or the end of follow-up. The end of follow-up was the earliest of either: (1) the last data collection point or (2) the onset of symptoms if symptomatic with no subsequent EDS reading was available to complete case definition.

Exposure assessment

We estimated the physical exposures of each participant using two different methods: observed exposures of individual workers in our large prospective study, and a JEM using O*NET-assigned exposures at the level of the job title.

Exposure assessment based on observation of individual workers (individually observed)

Individually observed exposure estimates were obtained from exposure assessments of each worker based on observations and measurements at the worksite by trained observers and detailed video analysis of the worker performing their tasks. During the worksite observations, worker and observer-estimated hand force was determined by using the Borg CR-10 rating scale.[25] The observer-estimated hand activity level (HAL) was based on the HAL rating scale.[26] Detailed video analysis was performed to determine the frequency and duty cycle of repetition for forceful hand exertions and all hand exertions, and the duration of selected wrist postures, as described more fully in prior publications.[2 22 24] In brief, video estimates of repetition was defined as the total number of exertions per minute and also the number of forceful exertions (≥9N pinch force or ≥45N of power grip force or a Borg CR-10 ≥2) per minute. Force estimates were based on measurements gathered during the worksite assessment about the force required for the task, the weights of parts or tools, or force matching.[2] Duty cycle, or the per cent of work time that the hands were exerting force, was determined for all hand exertions (% time all exertions) and forceful hand exertions (% time forceful exertions). Each worker was assigned the observed exposures for their job held at the time of enrolment. For workers who performed multiple tasks in their job, we obtained estimates of the proportion of time spent in each task from workers and their supervisors. The 'observed' exposure value accounted for the proportion of daily work time in each observed task using a time-weighted average approach.

Exposure assessment based on O*NET (O*NET JEM)

At baseline, information about each worker's current job was collected including job title, company name, job start date and work-related tasks. SOC codes were assigned to each job for each worker using the job title selection feature provided by the O*NET online database (http://www.onetonline.org) and selecting the occupational code that best matched the primary tasks and employer information. Assigned job codes were independently reviewed by two raters, with differences resolved by consensus. Job codes were assigned while blinded to case status. To ensure appropriate matches between job titles and SOC codes, one rater from each research study site reviewed the final job code assignments.

Using the SOC code assigned to each job, physical work exposure variables for each job held by each participant were extracted from the O*NET databases.[15] A total of five items describing physical exposures of hand force and repetition of the upper extremity were selected from three different O*NET databases (work activities, work context and work abilities). The selected physical exposure items were (A) dynamic strength, (B) static strength, (C) handling and moving objects, (D) time spent making repetitive movements, and (E) time spent using the hand to handle, control, or feel objects. The ordinal score for each of these exposures was assigned to each participant's SOC code following methods described in our prior publications.[15 16] Workers who were given multiple SOC codes for their baseline job to account for multiple tasks or job rotation were assigned time-weighted average scores for each O*NET exposure variable, proportional to the time spent in each task associated with a different SOC code.

Statistical analysis

Multivariable Cox proportional hazards models were used to evaluate relationships between baseline physical work exposures and incident CTS. We computed adjusted HRs and 95% CIs with the following a priori-selected covariates included in final models: age, gender, body mass index (BMI) and study site. Each model included a single exposure. Given that exposure data were collected and expressed on different scales and units within and between the observed and JEM data, we examined three different models for each exposure: dichotomous exposure values split at the median value, exposure tertiles and continuous exposure values. Assigning exposure values at the group level using a JEM inherently results in intracluster dependence, which can lead to inaccurate estimates of SEs. To account for this, we applied robust sandwich estimators derived by Lin and Wei[27] to each model. All analyses were performed using the SAS software package, V.9.4.[28]

RESULTS

Of the 4321 workers from the original pooled cohort, we excluded all workers from one study site (n=1107) because the exposure assessments did not include the necessary detailed data used for the individual observational assessment method. Of the remaining 3214 workers, we excluded those who had undergone carpal tunnel release surgery (n=37), workers who met the CTS case definition at baseline (n=327) and workers who were lost to follow-up (n=331). A total of 113 workers were missing observed or O*NET exposure data and an additional 13 workers were missing covariate data, leaving 2393 workers at risk for incident CTS in the analytical cohort.

Characteristics of the study population

The study population was 52.2% female, with a mean age of 40.8 and mean BMI of 28.3. A total of 195 cases of CTS occurred during follow-up. Based on 5005 total years of follow-up (median 2.0 years, range 1.1–2.8 years), the incidence rate of CTS was 3.9 per 100 person-years. Table 1 shows the distribution of occupations in the cohort. Forty SOC codes with 10 or more workers in each contained 87% of the cohort, with the largest groups being assembly workers and moulding and casting workers. Ninety additional SOC codes each contained fewer than 10 workers.

Table 1 Frequency of jobs held (n=2393 workers)

SOC_code	Title	n
51-2092.00	Team assemblers	799
51-2022.00	Electrical and electronic equipment assemblers	135
51-9195.07	Molding and casting workers	118
45-2092.01	Nursery workers	90
51-4031.00	Cutting, punching, and press machine setters, operators, and tenders, metal and plastic	85
51-6031.00	Sewing machine operators	84
53-7063.00	Machine feeders and offbearers	81
51-2031.00	Engine and other machine assemblers	66
53-7064.00	Packers and packagers, hand	43
51-3022.00	Meat, poultry, and fish cutters and trimmers	42
51-9061.00	Inspectors, testers, sorters, samplers, and weighers	39
51-9123.00	Painting, coating, and decorating workers	33
51-6011.00	Laundry and dry-cleaning workers	30
51-7021.00	Furniture finishers	27
43-9061.00	Office clerks, general	26
51-4121.06	Welders, cutters, and welder fitters	25
51-4081.00	Multiple machine tool setters, operators, and tenders, metal and plastic	22
51-4121.07	Solderers and brazers	22
51-7011.00	Cabinetmakers and bench carpenters	21
43-5071.00	Shipping, receiving, and traffic clerks	20
51-4122.00	Welding, soldering, and brazing machine setters, operators, and tenders	18
51-9121.00	Coating, painting, and spraying machine setters, operators, and tenders	18
31-9093.00	Medical equipment preparers	17
51-3021.00	Butchers and meat cutters	17
53-7051.00	Industrial truck and tractor operators	17
51-7041.00	Sawing machine setters, operators, and tenders, wood	16
43-4051.00	Customer service representatives	15
43-6014.00	Secretaries and administrative assistants, except legal, medical, and executive	15
53-1021.00	First-line supervisors of helpers, laborers, and material movers, hand	15
43-6011.00	Executive secretaries and executive administrative assistants	14
45-2041.00	Graders and sorters, agricultural products	14
51-7042.00	Woodworking machine setters, operators, and tenders, except sawing	14
53-7062.00	Laborers and freight, stock, and material movers, hand	14
29-2052.00	Pharmacy technicians	13
51-4041.00	Machinists	13
43-5081.04	Order fillers, wholesale and retail sales	12
51-1011.00	First-line supervisors of production and operating workers	12
51-9022.00	Grinding and polishing workers, hand	11
29-2055.00	Surgical technologists	10
51-9198.00	Helpers—production workers	10
Other	Includes 90 different SOC codes, each with fewer than 10 workers	300

SOC, Standard Occupational Classification.

Distribution of physical exposures

Table 2 shows the distribution of time-weighted exposures among study participants. The median for the O*NET-derived strength variables indicated modest levels of job requirement for *dynamic strength* (median=2.00; IQR=0.62 on a 0–7 point scale) with an anchor of 'use pruning shears to trim a bush' and *static strength* (median=2.71; IQR=1.12 on a 0–7 point scale) with a score of 1 meaning 'push an empty shopping cart' and 4 meaning 'pull a 40-pound [18.2 kg] sack of fertilizer across the lawn.' The median value for *time spent making repetitive motions* was 3.94 (IQR=0.50 on a 0–5 point scale), equivalent to 'more than half of the time'. The median value for *handling and moving objects* was similar to 'load boxes on an assembly line' (median=5.42; IQR=0.98 on a 0–7 point scale), and the median value for *time spent using your hands to handle, control, or feel objects* was 4.45 (IQR=0.76 on a 1–5 point scale).

Peak force values for the individually observed values were measured on the Borg scale (median=3.00 on a 0–10 point scale).

Table 2 Distribution of time-weighted exposures by assessment method

Type	Assessment method	Exposure	Scale	Min	Q1	Median*	Q3	Max
Force intensity	Observed	Observer peak Borg	0–10	0.00	1.22	3.00	4.00	10.00
	O*NET	Dynamic strength	0–7	0.00	1.63	2.00	2.25	3.00
	O*NET	Static strength	0–7	0.00	2.13	2.71	3.25	3.88
HAL repetition rate	Observed	Observer HAL	0–10	0.00	3.50	4.50	6.00	10.00
	O*NET	Time spent making repetitive motions	0–5	1.79	3.66	3.94	4.16	4.87
	O*NET	Time spent using your hands to handle, control, or feel objects	1–5	1.70	3.98	4.45	4.74	4.96
Forceful exertions	Observed	% forceful exertions	0–100	0.00	3.34	16.38	36.96	100.00
	Observed	Repetitions/minute forceful exertions	Continuous	0.00	0.67	3.81	10.23	95.72
	O*NET	Handling and moving objects	0–7	0.15	4.63	5.42	5.61	6.42

*Higher scores indicate higher exposure level.
HAL, hand activity level; O*NET, Occupational Network.

Observed repetition was assessed by the HAL (median=4.50 on a 0–10 point scale). Forceful exertion was measured by the % forceful exertions (median=16.38) and repetitions/minute of forceful exertions (median=3.81).

Physical exposures and incident CTS

HRs, 95% CIs and SEs for incident CTS are shown in table 3. For both JEM-derived and observed exposure variables, continuous models showed statistically meaningful associations for all exposure variables except for observed HAL. Dichotomous models showed HR in the range of 1.2–1.78 when using JEM exposure variables, and 1.28–1.74 when using individually observed values. The JEM variables of static strength and time spent using hands to handle and control objects did not attain statistical significance, nor did the observed values of HAL and repetitions per minute of forceful exertion. Models using tertiles of exposure showed dose effects between the upper and middle tertiles for most exposure variables. HR for the highest versus the lowest tertile of exposure ranged from 1.31 to 1.80 for JEM exposures and from 1.32 to 2.10 for observed values.

DISCUSSION

We evaluated the relationship between physical workplace exposures and incident CTS using two different occupational exposure assessment approaches: a JEM based on values from O*NET, and individual exposure values based on observation and video assessment. For both assessment methods, we observed significant exposure-disease associations between force and repetition exposures and incident CTS, after adjusting for age, gender and BMI. Our results supported our hypothesis showing similar magnitude of effect in the associations between incident CTS and different types of physical exposures when measured by these two methods, although generally the precision of the estimates was lower (CIs were wider) when using the JEM-based exposure. To our knowledge, this paper represents the first comparative evaluation of O*NET physical exposure estimates with observed physical exposures in a prospective study of a work-related musculoskeletal disorder.

This exposure method comparison study was based on data from a large pooled cohort of US workers, who represented a diverse range of industries and occupations. Previous results from this cohort have shown significant exposure-disease associations for CTS with both individually observed and JEM-based exposure methods.[2 15 20] In our earlier cross-sectional studies, observed exposures of force and forceful repetition showed associations with prevalent CTS.[29] Use of job title-based exposure data also found that workers with the highest combined exposures to force and repetition in their jobs had higher prevalence of CTS

Table 3 HRs* and 95% CIs for incident carpal tunnel syndrome

			HR (95% CI)			
			Continuous exposure	Dichotomous exposure†	Trichotomous exposure‡	
Type	Assessment method	Exposure	Per 1-unit increase	(High vs low)	(High vs low)	(Medium vs low)
Force intensity	Observed	Observer peak Borg	1.16 (1.09 to 1.25)	1.38 (1.06 to 1.80)	2.10 (1.47 to 3.00)	1.75 (1.30 to 2.35)
	O*NET	Dynamic strength	1.60 (1.28 to 1.99)	1.64 (1.20 to 2.24)	1.72 (1.06 to 2.79)	1.53 (1.05 to 2.23)
	O*NET	Static strength	1.38 (1.17 to 1.63)	1.20 (0.79 to 1.83)	1.31 (0.88 to 1.95)	1.29 (0.78 to 2.15)
Repetition	Observed	Observer HAL	1.08 (0.96 to 1.22)	1.28 (0.90 to 1.83)	1.32 (0.88 to 2.00)	1.42 (0.96 to 2.11)
	O*NET	Time spent making repetitive motions	1.58 (1.25 to 2.00)	1.42 (1.02 to 1.98)	1.63 (1.12 to 2.37)	1.30 (0.84 to 2.01)
	O*NET	Time spent using your hands to handle, control, or feel objects	1.78 (1.42 to 2.24)	1.36 (0.99 to 1.87)	1.78 (1.22 to 2.61)	1.50 (1.06 to 2.12)
Forceful exertions (duration/rate)	Observed	% duration forceful exertions	1.01 (1.01 to 1.02)	1.74 (1.38 to 2.2)	1.80 (1.33 to 2.43)	1.47 (1.12 to 1.93)
	Observed	Repetitions/minute forceful exertions	1.02 (1.01 to 1.02)	1.38 (0.98 to 1.95)	1.90 (1.31 to 2.75)	1.15 (0.75 to 1.77)
	O*NET	Handling and moving objects	1.30 (1.13 to 1.48)	1.78 (1.37 to 2.31)	1.80 (1.33 to 2.43)	1.47 (1.12 to 1.93)

*Cox proportional hazards regression models with robust sandwich estimators, adjusted for age, gender, body mass index and study site.
†Exposures are dichotomised at the median.
‡Exposures are trichotomised at 33rd and 67th percentiles.
HAL, hand activity level; O*NET, Occupational Network.

compared with the lowest exposed workers.[15] Several prospective studies based on observed measures have been performed in this cohort, and have found strong exposure-response relationships between incident CTS and exposures of peak hand force, forceful hand exertions, the American Conference of Governmental Industrial Hygienists threshold limit value for HAL and forceful repetition rate.[2 20 21] The current study extends the use of job title-derived exposure estimates in showing their utility for demonstrating associations with incident CTS in a large multisite study. Especially striking is the finding that generally similar effect sizes were found when using the JEM exposure estimates and when using the much more labour-intensive exposure estimates based on individual observations.

While our study did not collect the information required for a formal estimate of the relative costs of obtaining exposure estimates using different methods, the observed data required many hours of researchers' effort for each study subject, including time to travel to a workplace, find and interview each worker and supervisor, perform observations, record video and then to code the videos to assess duration and frequencies of forceful repetitions. In contrast, the JEM required only that the researchers code each subject's job title into an SOC code; exposures for each SOC of interest were then looked up in the O*NET database. Other studies have explicitly examined the cost trade-offs of using different exposure assessment methods and sampling strategies.[30 31] Future work in this area is important, as research resources are limited and the burden of work-related musculoskeletal disorders is large. For some study designs, the modestly lower exposure precision shown in this study is a worthwhile trade-off for the associated gains of speed and lower costs.

Strengths of this study included a diverse and well-characterised study population of workers, and the availability of both individually observed exposure data and job title information that allowed us to link to a national data set of job-based exposure data. A unique contribution of this study is the comparison of associations between work exposures and a disease outcome (incident CTS) using two very different exposure assessment methods. In this paper, we did not address the methodological issues of constructing a JEM from observations or direct measures taken from a subset of the population of interest, and assigning exposures based on group means; this is an alternative means to constructing a JEM that has been well described elsewhere.[4 30 32]

This study also demonstrated limitations of JEM-based exposure methods. While the job-level exposure data from O*NET were relatively easy to obtain compared with individual worker observations, O*NET contains limited physical exposure data relevant to musculoskeletal disorders, lacking for instance variables on grip, pinch, hand/wrist posture and hand vibration. Also, most of the scales on which O*NET is based do not readily translate to more generalisable exposure values such as repetitions per minute or grip force in kilograms. More work is required before findings from associations with O*NET-based exposures can be used to estimate risk in work settings; such work has been done to calibrate expert-derived exposure estimates with a sample of directly measured exposures within a Danish general-population JEM for shoulder disorders.[33] Despite these limitations, our data suggest that JEM can provide a useful method of producing valid exposure estimates for epidemiological studies of work-based physical exposures. While producing an unbiased estimate, use of a JEM is likely to result in non-differential exposure misclassification, which likely weakens the precision of the estimates through measurement error, thus biasing results towards the null.[34–36] The extent of such non-differential bias can be estimated,[36 37] and methods have recently been proposed to perform such bias testing when using JEMs.[38]

Several advantages of JEMs must be considered along with these limitations. Use of a JEM may reduce measurement error from other sources, including observations or worker self-reports of exposures that are biased by the outcome or other factors. As noted above, JEMs are relatively inexpensive to apply. Importantly, they offer a source of job exposure information that can enrich existing data sets that otherwise contain minimal or no information about work exposures, such as large population registries. By showing similar effect sizes between incident CTS and exposure estimated by JEM and those obtained by the presumed 'gold standard' measure of individually observed values, this study further supports the validity and utility of using JEM as a method to estimate workplace physical exposures for epidemiological studies. Such studies have included work-related musculoskeletal disorders and conditions such as hernia and outcomes of disability and sick leave.[39–41] Outside of its research applications, general-population JEM may also be useful for large-scale surveillance studies, and for targeting intervention efforts at a population level. JEM may also be useful in estimating past physical exposures in disability assessments or evaluations of work-relatedness of chronic diseases.

CONCLUSION

In the setting of a large pooled prospective cohort study, we demonstrated the utility of a JEM for estimating some workplace physical exposures using publicly available data linked to standard occupational job codes. We found similar associations between incident CTS and exposures that were estimated using a JEM and exposures estimated by observations on individual workers. JEMs are increasingly used as an exposure assessment method in studies of work-related musculoskeletal disorders and other chronic health outcomes related to different physical workplace exposures. Our study data support the use of JEMs to estimate workplace exposures, allowing them to be added to analyses from a wide variety of registry and other databases containing health outcomes. Future occupational studies should continue to extend the use of JEM and other simple and cost-efficient methods of exposure assessment.

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