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Brief Report

The Estimated National Burden of Physical Ergonomic Hazards Among US Workers

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Purpose *To estimate the national burden of physical ergonomic hazards among working adults in the US.*

Methods *We estimated the population prevalence of and the total number of workers who are exposed to physical ergonomic hazards, such as vibration, working in cramped space, kneeling, body bending or twisting, climbing, and repetitive motions using Occupational Information Network (O*NET) data and the Occupational Employment Statistics (OES) from the U.S. Bureau of Labor Statistics (BLS) stratified by occupation title.*

Results *Repetitive motion was the most prevalent of all ergonomic hazards (27% of US workers are estimated to be exposed continually). Bending or twisting of the body more than half their time at work was also common, involving over 32 million US workers (25% of US workforce). Kneeling, crouching, stooping, or crawling was another ergonomic hazard that 14 million US workers perform more than half their time at work. Almost 4 million workers climb ladders, scaffolds, poles, etc. for more than half their time at work. We estimate that over 13 million workers (10% of US workforce) were exposed to cramped workspace that requires getting into awkward positions every day. Finally, about 3.5 million workers (2.7% of US workforce) were estimated to be exposed to whole body vibration every day.*

Conclusion *A large portion of the US work force is exposed to ergonomic hazards known to be associated with musculoskeletal disorders (MSDs). The occupations with the highest prevalence of each ergonomic hazard may be deserving of prompt efforts toward prevention of MSDs.* Am. J. Ind. Med. 54:395–404, 2011. © *2010 Wiley-Liss, Inc.*

KEY WORDS: O*NET; OES; musculoskeletal disorders

INTRODUCTION

Musculoskeletal disorders (MSDs) are prevalent in US workers [Leigh and Miller, 1998] and their impact is pervasive [Stewart et al., 2003]. The evidence on MSDs, including back pain, in relation to workplace factors has been thoroughly reviewed by the U.S. National Institute for Occupational Safety and Health (NIOSH)/Centers for Disease Control and Prevention (CDC) [Bernard, 1997] and the Institute of Medicine of the National Research Council [National Research Council, 2001]. Physical ergonomic hazards are work activities and/or workplace conditions that pose a biomechanical stress to the workers. Such hazards identified from previous studies include repetitive motions; forceful exertions, including dynamic motions; segmental and whole-body vibration; maintaining awkward postures of the neck, wrists, arms, trunk, and lower extremities; contact stress (i.e., compression of sensitive

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body tissue from occasional, repeated, or continuous contact with hard or sharp objects); lifting, lowering, pushing, carrying, and pulling loads of excessive weight; and exposing extremities to temperature extremes [Nordin et al., 1997].

Identifying work processes or individual workers exposed to high levels of specific hazardous agents in particular industries or job categories is important because it enables timely intervention that will prevent occupational illness and its attendant morbidity and mortality [Wegman et al., 1975; Froines et al., 1989]. Information about the distribution of ergonomic hazards by type of work across the U.S. workforce is needed in conjunction with estimating the burden of MSDs attributed to such physical ergonomic hazards. The National Occupational Exposure Survey (NOES) conducted by NIOSH in 1981–1983 provided descriptive data of potential exposure agents and health and safety conditions in American workplaces [Seta et al., 1988]. Factors surveyed in NOES included exposure to work conditions associated with passive or awkward postures, lifting, arm or shoulder transport movements, and hand-wrist manipulation. One analysis of these data showed that 2.0 million workers were exposed to hand-wrist manipulations and 1.9 million workers to passive or awkward postures [Wegman and Fine, 1990]. Even though the NOES data provide information on the distribution of work factors related to MSDs in a wide variety of workplaces, the survey was implemented almost 30 years ago and is unlikely to represent the distribution of current ergonomic exposures.

The objective of this study is to estimate the approximate magnitude of occupational exposure to various known physical ergonomic hazards using two independent data sources: O*NET and the Occupational Employment Statistics (OES).

METHODS

The US Department of Labor's O*NET database is the primary source of descriptive information on occupations and is used by workers or students interested in finding or changing careers [Mariani, 1999]. It is also used by employers, policymakers, and educators. It is the replacement for the Dictionary of Occupational Titles. O*NET contains several hundred variables representing occupation descriptors that provide details on the type of work involved in a given occupation and the characteristics of workers engaged in that occupation. The O*NET provides a common language for defining work attributes and work content to form a classification system that can be applied across occupational groups (see www.onetcenter.org). The O*NET database offers a rich source of information to impute occupational exposures and has been used for this purpose in occupational health research [Man et al., 2007; Meyer et al., 2007, 2009; d'Errico et al., 2007; Alterman et al., 2008; Bell et al., 2008; Cifuentes et al., 2008; Boyer et al., 2009]. Some validity analyses of O*NET data have been reported in a few recent studies [Hadden et al., 2004; Cifuentes et al., 2007; Lapolice et al., 2008], suggesting that the use of O*NET data is largely generalizable to the US workforce.

Data collection for O*NET is ongoing and began in 1999. The most recent version of O*NET (v14.0) contains 831 occupations for most domains with a mixture of O*NET job analyst and incumbent ratings. O*NET 14 data were collected from July 2004 through June 2009. Data were collected by surveying job incumbents using standardized questionnaires. The O*NET data provide several hundred rating scales, based on responses by the sampled workers on the O*NET questionnaires. To reduce the burden on incumbent respondents, the scale questions have been organized into four questionnaires, each containing a different set of questions. The sampled job incumbents for each occupation are randomly assigned one of the four questionnaires.

Physical ergonomic hazard variables were obtained from the O*NET's work context questionnaire that asks about the job incumbent's working conditions. Incumbents were asked how often they are exposed in their current job to (1) cramped work space that requires getting into awkward positions and (2) whole body vibration (e.g., from operating a jack hammer or earth moving equipment). Respondents answered on a scale of 1–5: (1) never, (2) once a year or more but not every month, (3) once a month or more but not every week, (4) once a week or more but not every day, and (5) every day or almost every day. Incumbents were also asked how much time they spend in their current job: (1) climbing ladders, scaffolds, poles, etc., (2) kneeling, crouching, stooping, or crawling, (3) bending or twisting their body, and (4) making repetitive motions. Respondents answered using a different 1–5 scale: (1) never, (2) less than half the time, (3) about half the time, (4) more than half the time, (5) continually or almost continually. Climbing ladders, scaffolds, poles, etc. was included as an ergonomic hazard because it is known to produce mechanical stress on the body [Bloswick and Chaffin, 1990]. However, it is also known as a fall hazard [Lipscomb et al., 2006].

We identified the 10 occupation categories with the highest prevalence of exposure to each ergonomic hazard. The prevalence of each of four ergonomic hazards (i.e., (a) climbing ladders, scaffolds, poles, etc.; (b) kneeling, crouching, stooping, or crawling; (c) bending or twisting their body; and (d) making repetitive motions) were measured by combining the proportions in the top two scales (more than half the time and continually or almost continually). For the other two ergonomic hazards (i.e., (a) working in a cramped space requiring awkward positions and (b) whole body vibration), the prevalence was measured by the proportion in the top scale (every day or almost every day). The prevalence of each of these two hazards was determined by the proportion of occupation category

incumbents exposed to the respective ergonomic hazard everyday or almost every day.

The OES survey is a semi-annual mail survey administered by the US Bureau of Labor Statistics (BLS) and designed to produce estimates of employment and wages for about 800 specific occupations. The OES survey covers all full- and part-time wage and salary workers in nonfarm industries. The survey does not include the self-employed, owners, and partners in unincorporated firms, workers in private households, or unpaid family workers. The OES program surveys approximately 200,000 establishments every 6 months, as such assembling a sample of 1.2 million establishments over 3 years. In this analysis, we used the May 2008 OES estimates which are based on all data collected from establishments in the May 2008, November 2007, May 2007, November 2006, May 2006, November 2005 semi-annual samples. The nationwide response rate for the May 2008 survey was 78.25% based on establishments and 74.28% based on employment. Additional information on sampling and estimation methodology is available elsewhere [BLS, 2009]. Annual average numbers of employment by 2000 Standard Occupation Codes (SOC) for the year 2008 provided by the OES were used in the analysis. The year 2008 was chosen because it was the most recent year of complete data at the time of this analysis.

The occupation categories found in O*NET have more detailed codes compared to those in OES. Both data systems have a six-digit SOC code, but the O*NET codes also have a two-digit suffix (in OES, the two-digit suffix is always .00). For example, Nuclear Technicians is an occupation with one SOC code but two different detailed O*NET-SOC codes, as follows:

19-4051.00 Nuclear Technicians (the SOC code/category).
19-4051.01 Nuclear Equipment Operation Technicians (a detailed O*NET-SOC code/category).
19-4051.02 Nuclear Monitoring Technicians (a detailed O*NET-SOC code/category).

The O*NET program collects data on each detailed O*NET code/category [The National Center for O*NET Development, 2009]. There were 56 SOC-level categories that have one or more detailed O*NET-SOC occupation subcategories. The proportion of workers exposed to ergonomic hazards in these 56 SOC-level categories was derived from the average of each occupation's subcategories.

Data Analysis

The basic approach was to estimate the number of workers exposed to ergonomic hazards by occupation category, then to sum the number of workers in each occupation category to estimate the national burden of various physical ergonomic hazards. Because O*NET uses a scale to measure each ergonomic hazard within each occupational category, it was not necessary to partition exposures into "high" or "low" levels. The estimated total number of workers exposed to ergonomic hazards by occupation involved obtaining the prevalence of the ergonomic hazard from O*NET and using OES to determine the number of workers employed in each occupation. The total number of workers exposed to each ergonomic hazard was estimated on the basis of occupation categories, using the following equation:

$$P_{hazard} = \sum_{i=1}^{n} (T_i P_i) \quad (1)$$

where P_{hazard} is the total number of US workers occupationally exposed to a specific ergonomic hazard, T_i the number of workers employed in ith occupation, and P_i the proportion of workers occupationally exposed to a specific ergonomic hazard in ith occupation.

RESULTS

A total of 28,084 subjects provided data in O*NET 14. A total of 81 O*NET-SOC subcategories from the 831 occupations in O*NET were pooled into the appropriate SOC-level categories resulting in the same total of 750 SOC categories found in OES.

Overall, approximately 60 million US workers spend more than half their time in their job making repetitive motions. One in four US workers (26.8%) makes repetitive motions continually or almost continually at their job (Fig. 1a). Over 32 million workers (25% of US workforce) were estimated to be exposed to body twisting or bending for more than half their time at work (Fig. 1b). Over 14 million workers were estimated to kneel, stoop, or crawl more than half their time at work (11%) and over 4 million workers climbed ladders, scaffolds, poles, or other apparatuses more than half their working day (Fig. 1c,d). We estimate that over 13 million workers (10% of US workforce) were exposed to cramped work space that requires getting into awkward positions every day and about 3.5 million workers (2.7% of US workforce) were exposed daily to whole body vibration (Fig. 1e,f).

Six of the 10 occupation categories with the highest prevalence of making repetitive motions for more than half the working day included service-related occupations, such as dental hygienists (100%), hairdressers (100%), and dancers (99%) (Table I). Workers in construction and mining had the highest prevalence of bending or twisting their body over half their working day (Table II). Maids and housekeeping cleaners were one of the 10 occupation categories with the highest prevalence of bending or twisting their body for more than half their working time (88.5%, representing over 800,000 persons). The 10 occupation categories with the

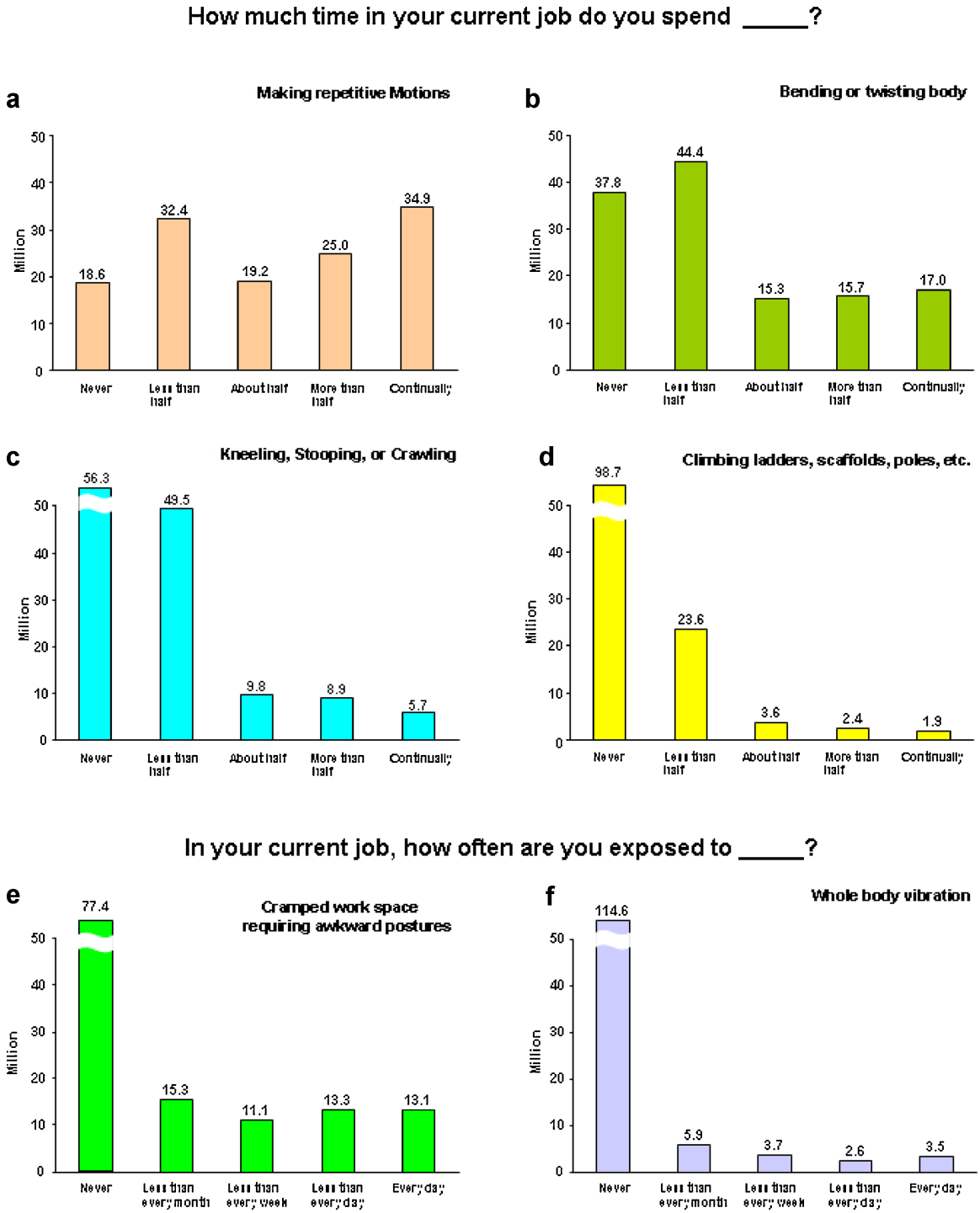

FIGURE 1. Estimated numbers of US workers with exposure to physical ergonomic hazards. How much time in your current job do you spend _? **a**: Making repetitive motions; (**b**) bending or twisting body; (**c**) kneeling, stooping, or crawling; (**d**) climbing ladders, scaffolds, poles, etc. In your current job, how often are you exposed to _? **e**: Cramped work space requiring awkward postures and (**f**) whole body vibration. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

highest prevalence of kneeling, crouching, stooping, or crawling were mostly construction-related occupations including tile and marble setters (94%), carpet installers (91%), and reinforcing iron workers (72%) (Table III). All of the 10 occupation categories with the highest prevalence of climbing for more than half their time were construction-related occupations, such as insulation workers (88%), paperhangers (87%), and roofers (69%) (Table IV). Machine

TABLE I. The 10 Occupation Categories Whose Workers Reported the Highest Prevalence of Making Repetitive Motions for More Than Half the Time in Their Current Job, United States, 2004–2009

Occupation	2000 SOC code	Estimated total number of US workers	Number of workers in sample	Estimated proportion with exposure (SE)[a]	Estimated number of exposed workers
Dental hygienists	29-2021	173,090	31	100.0 (1.1)	173,090
Hairdressers, hairstylists, and cosmetologists	39-5012	355,990	17	100.0 (8.2)	355,990
Dancers	27-2031	11,370	34	98.9 (8.4)	11,246
Tire builders	51-9197	21,740	17	97.6 (6.6)	21,225
Shampooers	39-5093	15,570	33	97.6 (10.8)	15,195
Roof bolters, mining	47-5061	4,950	33	97.1 (7.5)	4,804
Mine cutting and channeling machine operators	47-5042	9,190	21	96.6 (7.8)	8,876
Court reporters	23-2091	17,930	35	96.6 (2.7)	17,313
Correspondence clerks	43-4021	13,450	19	96.5 (13.0)	12,978
Shoe machine operators and tenders	51-6042	4,910	21	96.2 (8.1)	4,723

SOC, Standard Occupation Code; SE, standard error.
[a]Exposure was defined as those who answered "more than half the time" or "continually or almost continually" to the question, "how much time in your current job do you spend making repetitive motions?"

operators related to mining, construction, or transportation had the highest prevalence of exposure to cramped work space that requires getting into awkward positions, which includes continuous mining machine operators (93 %), roof bolters (80%), and shuttle car operations (69%) (Table V). Daily exposure to whole body vibration was found to be most prevalent among operators of machines, vehicles, or equipment used in various industrial sectors (Table VI). Operating engineers had the third highest prevalence of daily exposure to whole body vibration (73%).

DISCUSSION

In this analysis, we provided magnitude estimates of a range of physical ergonomic hazards which are known to represent risk of MSDs to the back, knees, and other joints. We used two nationally representative surveys whose data permit the comparison of many occupations in the US. The predominant ergonomic exposure among US workers was to repetitive motions. Body bending and twisting was also common. Overall, construction workers had high exposure to

TABLE II. The 10 Occupation Categories Whose Workers Reported the Highest Prevalence of Trunk Bending and Twisting for More Than Half the Time in Their Current Job, United States, 2004–2009

Occupation	2000 SOC code	Estimated total number of US workers	Number of workers in sample	Estimated proportion with exposure (SE)[a]	Estimated number of exposed workers
Refractory materials repairers, except brick masons	49-9045	2,450	24	99.4 (12.6)	2,437
Manufactured building and mobile home installers	49-9095	8,290	15	97.9 (12.0)	8,113
Roof bolters, mining	47-5061	4,950	33	94.9 (6.8)	4,698
Insulation workers, floor, ceiling, and wall	47-2131	28,390	22	94.6 (6.8)	26,865
Brick masons and block masons	47-2021	106,270	18	94.1 (12.8)	100,032
Continuous mining machine operators	47-5041	10,920	21	90.5 (10.6)	9,879
Maids and housekeeping cleaners	37-2012	917,120	28	88.5 (7.3)	811,193
Tapers	47-2082	31,850	27	87.2 (9.9)	27,764
Shoe machine operators and tenders	51-6042	4,910	21	86.4 (4.8)	4,242
Dental hygienists	29-2021	173,090	31	85.7 (8.2)	148,286

SOC, Standard Occupation Code; SE, standard error.
[a]Exposure was defined as those who answered "more than half the time" or "continually or almost continually" to the question, "how much time in your current job do you spend bending or twisting your body?"

TABLE III. The 10 Occupation Categories Whose Workers Reported the Highest Prevalence of Kneeling, Crouching, Stooping, or Crawling More Than Half the Time in Their Current Job, United States, 2004–2009

Occupation	2000 SOC code	Estimated total number of US workers	Number of workers in sample	Estimated proportion with exposure (SE)[a]	Estimated number of exposed workers
Manufactured building and mobile home installers	49-9095	8,290	15	96.9 (11.9)	8,031
Tile and marble setters	47-2044	51,210	25	94.4 (8.5)	48,332
Carpet installers	47-2041	34,390	25	91.4 (12.8)	31,432
Floor layers, except carpet, wood, and hard tiles	47-2042	14,250	15	78.1 (15.2)	11,124
Helpers—electricians	47-3013	104,050	19	76.0 (6.6)	79,036
Helpers—roofers	47-3016	18,730	29	74.8 (6.6)	14,001
Dancers	27-2031	11,370	34	74.0 (4.6)	8,412
Reinforcing iron and rebar workers	47-2171	28,620	21	72.2 (9.2)	20,675
Insulation workers, floor, ceiling, and wall	47-2131	28,390	22	71.3 (6.5)	20,234
Mobile heavy equipment mechanics, except engines	49-3042	125,930	29	67.2 (5.4)	84,600

SOC, Standard Occupation Code; SE, standard error.
[a]Exposure was defined as those who answered "more than half the time" or "continually or almost continually" to the question, "How much time in your current job do you spend kneeling, crouching, stooping, or crawling?"

multiple ergonomic hazards including nonneutral postures of the trunk and leg, and climbing ladders or scaffolds has been shown previously [Schneider and Susi, 1994; Hartmann and Fleischer, 2005]. A high risk of MSDs in US construction workers has been documented in previous studies [Goldsheyder et al., 2002; Forde et al., 2005; Choi et al., 2007]. We also found that operators of various machines, vehicles, and equipment are also at higher risk of exposure to ergonomic hazards such as whole body vibration, and cramped workspace that requires getting into awkward positions. Several service sector occupations were also found to be among those at highest risk of performing repetitive motions at their job (i.e., dental hygienist, hairdressers, and cosmetologists). Repetitive motion exposures have previously been demonstrated to represent an important risk factor for MSDs affecting various parts of the body [Jensen et al., 2000; National Research Council, 2001; Manninen et al., 2002].

To the best of our knowledge, there have been no up-to-date reports that provide national estimates for a range of workplace ergonomic hazards since NOES in 1981. Overall, many of our findings are consistent with previous studies. According to the National Research Council and Institute of

TABLE IV. The 10 Occupation Categories Whose Workers Reported the Highest Prevalence of Climbing Ladders, Scaffolds, Poles, Etc. More Than Half the Time in Their Current Job, United States, 2004–2009

Occupation	2000 SOC code	Estimated total number of US workers	Number of workers in sample	Estimated proportion with exposure (SE)[a]	Estimated number of exposed workers
Insulation workers, mechanical	47-2132	30,150	32	87.7 (6.4)	26,429
Paperhangers	47-2142	4,610	28	86.5 (7.0)	3,987
Painters, construction and maintenance	47-2141	250,310	27	81.8 (8.8)	204,729
Roofers	47-2181	120,200	28	69.3 (9.3)	83,323
Drywall and ceiling tile installers	47-2081	128,740	31	68.6 (12.5)	88,277
Plasterers and stucco masons	47-2161	43,290	25	61.2 (9.2)	26,480
Helpers—electricians	47-3013	104,050	19	58.0 (5.3)	60,297
Derrick operators, oil, and gas	47-5011	23,590	17	56.9 (12.8)	13,413
Helpers—painters, paperhangers, plasterers, and stucco masons	47-3014	19,900	29	56.6 (5.7)	11,255
Helpers—brickmasons, blockmasons, stonemasons, and tile and marble setters	47-3011	53,300	21	56.4 (3.5)	30,035

SOC, Standard Occupation Code; SE, standard error.
[a]Exposure was defined as those who answered "more than half the time" or "continually or almost continually" to the question, "How much time in your current job do you spend climbing ladders, scaffolds, poles, etc?"

TABLE V. The 10 Occupation Categories Whose Workers Reported With the Highest Prevalence of Daily Exposure in Their Current Job to Cramped Work Space, United States, 2004–2009

Occupation	2000 SOC code	Estimated total number of US workers	Number of workers in sample	Estimated proportion with exposure (SE)[a]	Estimated number of exposed workers
Continuous mining machine operators	47-5041	10,920	21	92.7 (4.5)	10,117
Roof bolters, mining	47-5061	4,950	33	80.2 (10.4)	3,969
Mobile heavy equipment mechanics, except engines	49-3042	125,930	29	76.6 (9.9)	96,488
Recreational vehicle service technicians	49-3092	13,400	22	72.7 (—)[b]	9,746
Hoist and winch operators	53-7041	2,810	18	71.4 (16.0)	2,005
Shuttle car operators	53-7111	3,050	29	68.7 (10.2)	2,095
Mine cutting and channeling machine operators	47-5042	9,190	21	60.8 (11.9)	5,588
Helpers—extraction workers	47-5081	25,550	24	59.6 (12.6)	15,238
Automotive service technicians and mechanics	49-3023	649,460	50	59.5 (9.9)	386,665
Historians	19-3093	3,700	17	58.2 (26.5)[c]	2,152

SOC, Standard Occupation Code; SE, standard error.
[a]Exposure was defined as those who answered "everyday" to the question, "In your current job, how often are you exposed to cramped work space that requires getting into awkward positions?"
[b]Standard error is not available since the estimate is based on expert rating.
[c]This estimate may be unreliable because the relative standard error is higher than 30% [Klein et al., 2002].

Medicine Report (2001), the highest risk occupations for MSDs among men were construction laborers, carpenters, and industrial truck and tractor equipment operators, and among women the highest risk occupations were nursing aides/orderlies/attendants, licensed practical nurses, maids, janitor/cleaners. Other high-risk occupations were hairdressers and automobile mechanics, often employed in small businesses or self-employed [National Research Council, 2001]. Unfortunately, because the ergonomic exposure definitions used in the 1981 NOES were substantially different from ours, we were precluded from comparing the estimates between the two surveys.

Given the high prevalence of ergonomic hazards in the US, measures to ameliorate these hazards can dramatically reduce the incidence of MSDs. For example, in jobs where the entire work activity consists of manually handling

TABLE VI. The 10 Occupation Categories Whose Workers Reported the Highest Prevalence of Daily Exposure in Their Current Job to Whole Body Vibration, United States, 2004–2009

Occupation	2000 SOC code	Estimated total number of US workers	Number of workers in sample	Estimated proportion with exposure (SE)[a]	Estimated number of exposed workers
Locomotive firers	53-4012	970	19	89.5 (—)[b]	868
Shuttle car operators	53-7111	3,050	29	76.0 (9.8)	2,319
Operating engineers and other construction equipment operators	47-2073	398,910	40	73.0 (7.5)	291,324
Logging equipment operators	45-4022	27,010	26	72.9 (11.5)	19,685
Fallers	45-4021	7,120	21	68.0 (13.2)	4,839
Derrick operators, oil and gas	47-5011	23,590	17	67.4 (19.0)	15,900
Loading machine operators, underground mining	53-7033	3,670	18	67.0 (14.4)	2,460
Mine cutting and channeling machine operators	47-5042	9,190	21	51.8 (13.0)	4,764
Carpet installers	47-2041	34,390	25	51.5 (20.9)[c]	17,711
Rotary drill operators, oil and gas	47-5012	27,020	27	51.3 (8.8)	13,850

SOC, Standard Occupation Code; SE, standard error.
[a]Exposure was defined as those who answered "everyday" to the question, "In your current job, how often are you exposed to whole body vibration?"
[b]Standard error is not available since the estimate is based on expert rating.
[c]This estimate may be unreliable because the relative standard error is higher than 30% [Klein et al., 2002].

materials, ergonomic interventions consistently reduced both biomechanical exposures and the risk of low back disorders [Marras et al., 2000]. A review of 92 intervention studies concluded that interventions targeted to identify and solve specific ergonomic problems will prove to be most effective and successful in improving musculoskeletal health, especially when the interventions have high commitment from the principal stakeholders such as labor unions and management [Westgaard and Winkel, 1997]. While there are numerous studies that consistently show that organizational interventions to decrease ergonomic exposures result in fewer MSDs, there remains a significant need for more studies to identify the precise physiological stresses from ergonomic exposures that are likely to lead to disease [National Research Council, 2001]. Once identified, targeting interventions to reduce these precise physiological stresses may lead to prevention of MSDs. Until then, the findings of this study may help in prioritizing targeted interventions to reduce the national burden of ergonomic hazards in the US workforce.

Repetitive motions, nonneutral trunk postures, and kneeling, stooping, or crawling were the ergonomic hazards with the highest prevalence and addressing these hazards may produce the largest impacts. A nationwide intervention effort can focus on those occupations with the highest prevalence of ergonomic hazard exposures identified in our study. Since each occupation presents different ergonomic challenges in developing and implementing intervention programs, obtaining occupation-specific information on work conditions, tools, and tasks is an important first step. This effort should include (1) comparing the prevalence of multiple hazards, including force, temporal pattern (e.g., repetitiveness), and duration of the hazard, (2) identifying priorities for specific hazardous ergonomic exposures, and (3) determining the most appropriate intervention measures for each occupation.

There are several limitations that are mostly associated with the use of O*NET. First, most of the occupation-specific O*NET estimates are based on small numbers of observations, almost always <100 workers per occupation. This may hamper the reliability of our occupation-specific estimates. However, with respect to the national estimates of the distribution of physical ergonomic hazards across the entire workforce (as provided in Fig. 1), this limitation is not present due to the large number of subjects in O*NET 14. Secondly, misclassification of exposure arises when using aggregated data because it may mask variability in exposure among different groups and hierarchy within a given occupation such as job tenure, gender, and race/ethnicity. It is impossible to assess whether this issue has led to under- or over-estimation of our estimates. Thirdly, combined measures of multiple exposures were not available in the O*NET database. Usually, the combination of multiple ergonomic exposures creates greater risk, particularly repetitive motions sustained with high force [Armstrong et al., 1993]. We believe that there are a number of occupations in which workers may be exposed to multiple ergonomic hazards that are not necessarily standing out as dominant exposures. For example, construction laborers may often be exposed to various ergonomic hazards, but no single ergonomic hazard constitutes a daily occurrence or exposure for more than half the time. In this regard, we assume that our estimates of the national burden of ergonomic hazards are likely to underestimate the true magnitude because of the lack of information on multiple ergonomic exposures. Also, our estimates do not represent all parameters that are needed for a detailed description of ergonomic hazards (i.e., force and duration of exposures are not captured by O*NET). Our estimates focused on the frequency of the ergonomic hazard. Variables incorporating more specific parameters of exposures could provide better information on priority occupations in future surveillance efforts. Lastly, industry information (i.e., type of business the individual was employed in) is not available in the O*NET database. This prevents us from estimating the burden of ergonomic hazards by US industry sector. Specific analyses at the industry level could increase the precision of national burden estimates by assessing specific physical risk factors at the workplace.

O*NET 14.0 contain information on other ergonomic hazards that were not explored in our analysis. In some cases, the responses to questions were difficult to interpret. For example, the extreme temperature question asked about how often the worker is exposed to very hot (above 90°F) or very cold (under 32°F) temperature. This question may not be useful in identifying occupations with exposure to only extreme heat or only extreme cold. Similar problematic questions include those that ask about inadequate lighting (i.e., too bright or too dim) and walking/running on the job. Two other useful ergonomic variables (i.e., extent of sitting on the job and standing on the job) were not included in our analysis because it was beyond the scope of our study.

Since the two sources of survey data that we used do not contain demographic information such as sex and age, our estimates are not adjusted for these demographic factors. Some possible misclassification may arise due to differential distribution of these factors in the subject populations in the two surveys. In addition, OES does not collect data on self-employed, household, or unpaid family workers. It is not known whether these self-employed or unpaid workers have a higher or lower prevalence of hazardous ergonomic exposures compared to salaried workers in the same occupational categories. It is impossible to know whether these limitations biased our estimates of the proportions of ergonomic hazards in the direction of over- or under-estimation. In addition, the Great Recession that began in 2007 has increased the unemployment rate and may have led to changes in the ergonomic hazards experienced by those who continue to be employed. Due to these changes, our

estimates of the prevalence of ergonomic hazards may not be representative of the true current prevalence. However, real-time estimates of the prevalence of ergonomic hazards would require a redesigned methodology that tracks more closely in time the numbers of workers exposed to workplace ergonomic hazards.

Although the OES estimates are considered representative, we have learned that there are some gaps in the estimates when compared to another data source, such as the Census of Population Survey (CPS). CPS is another representative survey that uses a different survey method and data collection [US Census Bureau, 2006]. Future analysis could include an attempt to replicate our estimates using a different data source to ascertain the total employed population, such as CPS.

CONCLUSION

This study used two nationally representative survey data sets to generate quantitative evidence that a large portion of the US work force is exposed to multiple ergonomic hazards known to present significant health hazards. This study is one of the first to provide nationwide comparisons of exposure to physical ergonomic hazards among different occupations in the US. Several occupations were identified that should be considered for prompt efforts toward prevention of MSDs. As such, our findings might be used to help target national interventions to reduce the burden of these hazards among US workers.

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