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Method for quantitatively assessing physical risk factors during variable noncyclic work

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Objectives Assessing exposure to physical risk factors during variable noncyclic work can be problematic. The purpose of this study was to modify an existing data reduction method for directly quantifying physical exposures during variable noncyclic work.

Methods Myoelectric activity of the finger flexors of two groups of workers, heavy equipment operators (N=25) and mechanics (N=25), was sampled to determine the intensity and duration of forceful exertions during normal tasks. Data were reduced with a modification of the exposure variation analysis (EVA), called clustered EVA (CEVA), using three intensity and two duration categories. A two-way, mixed-effects, repeated-measures analysis of variance evaluated the percentage of sampled work time in each CEVA category.

Results CEVA was able to quantify variable noncyclic work, and it contrasted the work of the two groups, with simple effects significantly different for all the exposure categories. The mechanics performed high-intensity short-duration contractions 9.1% of the time, whereas the operators had similar contractions only 1.8% of the time. Conversely, the operators used low-intensity contractions of prolonged duration over 81% of the time, compared with only 43% for the mechanics.

Conclusions CEVA is a useful modification of EVA for contrasting the noncyclic work typical of understudied industries like construction. A simplification of electromyography with summary measures such as CEVA provides a comprehensible, yet accurate measure of forceful exertions during worktasks.

Key terms construction work, electromyography, exposure assessment, force, musculoskeletal disorders.

Work-related upper-extremity musculoskeletal disorders are common in manufacturing industries (1–3). Although few studies of upper-extremity musculoskeletal disorders have been carried out among construction workers, the prevalence and incidence appear to be high (4–6). Certain construction worker groups may be at greater risk of developing upper-extremity musculoskeletal disorders than other groups are. For example, the prevalence of carpal tunnel syndrome in apprentice-level operators of heavy equipment (drivers of heavy construction equipment such as bulldozers) has been reported to be approximately 7–8% (5), compared with a general population prevalence of 2.7% (7). In contrast, apprentice-level heavy equipment mechanics have a corresponding prevalence of 27%. The contrasting prevalence of carpal tunnel syndrome between heavy equipment operators and mechanics may be associated with differences in exposure to work-related physical (mechanical) risk factors, such as forceful exertion.

Assessing exposure to physical risk factors during construction work can be problematic in that such exposure can be over- or underestimated (8, 9), since subjective and observation methods are commonly used (10, 11). Investigators that use these methods typically do not report the influence of rest on the total exposure pattern. More frequent rest periods may be present in

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some construction work, in contrast to frequently cyclic manufacturing work. Although there is cyclic construction work, it can also be highly variable, have cycles of prolonged duration, or be entirely noncyclic (10, 12). Thus it is possible that a risk factor like forceful exertion may not affect a construction worker in the same way it does those performing cyclic work.

In contrast, direct methods of exposure assessment, such as electromyography (EMG), are able to quantify exposure more accurately and precisely, especially with prolonged sampling periods (13). However, prolonged EMG sampling generates considerable amounts of data, and there are few efficient methods of reducing such data in a way that is informative yet easily understandable by researchers and nonresearchers alike (12). The development of exposure assessment methods usable for researchers and nonresearchers is a current priority of the National Occupational Research Agenda for Musculoskeletal Disorders (NORA) in the United States (12). One data reduction method that has been used for EMG is exposure variation analysis (EVA) (14). When used with EMG, EVA describes the intensity of muscular activity used during a period of work, as well as the length of time (duration) at each intensity level. This method has the benefit of measuring multiple exposure dimensions simultaneously, also a NORA priority (12). However, the method has infrequently been used to assess noncyclic work (15, 16), and it is complex to analyze statistically (17, 18). In addition, EVA has limited utility for nonresearchers since the array of values is difficult to interpret and the graphs are challenging to visualize.

In general, there is a paucity of quantifiable exposure data on risk factors for understudied industries such as construction (12, 19). The long-term objective of this research was to further the understanding of risk factors in order to establish causal relationships between occupational exposure and musculoskeletal disorders, as well as to develop and evaluate possible ergonomic intervention. The purpose of this study was to modify an existing data reduction method for directly assessing physical exposures during variable noncyclic work. Researchers or nonresearchers can use this modification to quantify exposure to physical risk factors.

Participants and methods

Participants

The sample for this cross-sectional field study consisted of 24 heavy equipment mechanics and 24 heavy equipment operators recruited from union training centers, heavy equipment contractors that perform scraping and grading work, and heavy equipment service centers in the states of Iowa and Illinois in the United States. The contractors were a sample of convenience recruited from companies that the investigators have previously worked with and companies that permitted sampling of their workers. For each contractor, the worksites were selected on the basis of accessibility for the investigators. Four mechanic shops and four contractors participated, and the sampling occurred at 10 distinct worksites. At each worksite, all the operators and mechanics were given an opportunity to participate. A total of 55 operating engineers were contacted, 2 refused to participate, and the EMG data were erroneous for 5 others. All the participants had at least 3 years' experience in their respective trade group and were currently employed. Since EMG of the finger flexors was sampled, any persons with conditions such as a history of carpal tunnel surgery, wrist fracture, or rheumatoid arthritis were excluded from participation. The Institutional Review Board at the University of Iowa approved the study. The workers received monetary compensation for participating in the study.

Heavy equipment contractors, who perform scraping and grading work, level large areas of land and move earth for highways, parking lots, housing developments, or golf courses. In order of frequency, earth scrapers, bulldozers, and loaders are found at these worksites. Although the researchers did not purposefully control the heavy equipment type, 12 scraper, 9 bulldozer, and 3 loader operators were involved in the study. It was noted that most of the heavy equipment was new (no more than 10 years old). Heavy equipment mechanics work either in the shop or travel to worksites as a part of a mobile crew. They perform all the maintenance and repair of heavy equipment using hand tools, pneumatic tools, and hoists. Only shop mechanics were evaluated in this study.

Questionnaire

The participants completed a questionnaire on demographics, work history, medical history, and hobbies (4, 5, 20). The questionnaire items have shown good test-retest reliability (21). The demographic questions included date of birth, height, weight, gender, and handedness. The work history questions included factors such as an estimate of the percentage of time spent performing their primary task (operating heavy equipment or repairing heavy equipment) and the number of years as a heavy equipment operator or mechanic. Certain work characteristics were calculated from the responses (eg, hours off per year). The medical history questions were related to the exclusion criteria, and any persons with hand numbness or tingling filled out a hand survey and marked a diagram (22).

The mean demographic and work characteristics for the 48 operating engineers are shown in table 1. The average age of the operating engineers in this study was 40.4 (SD 12.1) years, the operators being approximately 7 years older than the mechanics. All of the participants were men. The only female operators seen at the worksites were dump truck drivers, and there were no female mechanics employed at any of the shops. The operators drove heavy equipment about 84% of the workday, the rest of the time being spent greasing the equipment and taking planned or unplanned breaks. The mechanics repaired heavy equipment 71% of the workday; their other tasks involved finding parts in catalogs, reading repair manuals, or taking unscheduled breaks. Operators spent 306 more hours per year performing their primary task than mechanics did. Although the operators worked almost 13 more hours a week than the mechanics, they took over five times as many days off a year since their work is highly seasonal and can be limited by adverse weather conditions. However, there was minimal difference in the time-weighted-average total hours worked in a year between the groups.

Direct exposure assessment

The electromyographic (EMG) activity of the finger flexors, measured with the use of a standard electrode location for the flexor digitorum superficialis muscle (23), was sampled from the dominant arm of the mechanics and from the right arm of the operators.

Table 1. Subject demographics and work characteristics for the heavy equipment mechanics and operators.[a, b, c]

	Mechanics (N=24)		Operators (N=24)	
	Mean	SD	Mean	SD
Demographics				
Age (years)	36.8	7.6	44.1	14.5
Weight (kg)	90.5	11.5	95.3	18.0
Height (m)	1.8	0.1	1.8	0.1
Body mass index (kg/m^2)	27.8	3.5	29.5	5.0
Work characteristics				
Years at current trade	15.6	7.4	18.6	14.3
Work hours				
Per day	9.5	1.2	12.1	1.3
Per week	47.5	6.2	60.3	6.5
Per year	2365.8	315.1	2360.8	519.7
Primary task				
Per day (%)	71.1	10.4	83.6	16.4
Per year (hours)	1673.2	335.0	1979.2	559.4
Days off per year	12.6	7.8	67.1	28.6
Hours off per year	120.0	83.5	798.8	333.1

[a] Male gender: mechanics 24 (100%), operators 24 (100%).
[b] Right-handed: mechanics 21 (87.5%), operators 23 (95.8%).
[c] Hand numbness/tingling: mechanics 3 (12.5%), operators 1 (4.2%).

Although upper-extremity musculoskeletal disorders have not been directly associated with this muscle group, it was chosen because the finger flexor tendons travel through the carpal tunnel and increased force on these tendons has been shown to increase carpal tunnel pressure (24, 25). A surface EMG electrode with dual 8-millimeter diameter bipolar silver-silver chloride surfaces, an interelectrode distance of 22 millimeters, and onsite preamplification with a gain of 35 (EQ Inc, Chalfont, PA, USA) was interfaced with a portable data logger collection system (Tattletale Model 5F-LCD, Onset Computer Corp, Pocasset, MA, USA). The data logger was modified to allow onboard rms (root-mean-square) processing capability using an 100-millisecond time constant, a gain of 1000, bandwidth of 40–4000 hertz, and common-mode rejection of 87 decibels at 60 hertz with a 30-hertz sampling rate. The EMG was normalized to the highest myoelectric activity during three maximal voluntary contractions (%MVE) of the handgrip using a Smedley-Type lightweight hand dynamometer (Preston, Jackson, MI, USA) in the standard position (26). Each maximal grip contraction was held for 5 seconds, and the participants were given at least 1 minute to rest between contractions. Longer rest times were not practical because of the need to return the participant to work as soon as possible.

Signal quality was monitored on a laptop computer with a computer program modified for field measurement of EMG (Testpoint Version 4, Capitol Equipment Corporation, Billerica, MA, USA) before and after the data logger was attached. The EMG signals were sampled at 100 hertz with a 12-bit analog-to-digital PCMCIA card (KPCMCIA-12AIAO-C, Keithley Instruments Inc, Cleveland, OH, USA) connected to a laptop personal computer. All of the EMG sampling occurred at the operators' and mechanics' worksites.

The EMG data were reduced in real-time on the data logger by an EVA program written in TXBASIC (Onset Computer Corp, Pocasset, MA, USA). Eight intensity levels and seven duration levels were used for a total of 56 cells (figures 1 and 2). Clustered exposure-variation analysis (CEVA), a new modification of EVA, was used to reduce the EMG data further (27). The intensity and duration levels were combined to create three intensity levels and two duration levels for a total of six cells or clusters (table 2). The specific boundaries were chosen to contrast effectively between low, moderate, and high intensities of exertion, as well as to be somewhat comparable to boundaries used by other researchers (28, 29).

After the preparation time, approximately 10 minutes, the participants returned to their normal worktasks for 1 hour, while EMG was simultaneously recorded. Although the time of day for sampling was based on convenience, a reasonable distribution of work throughout

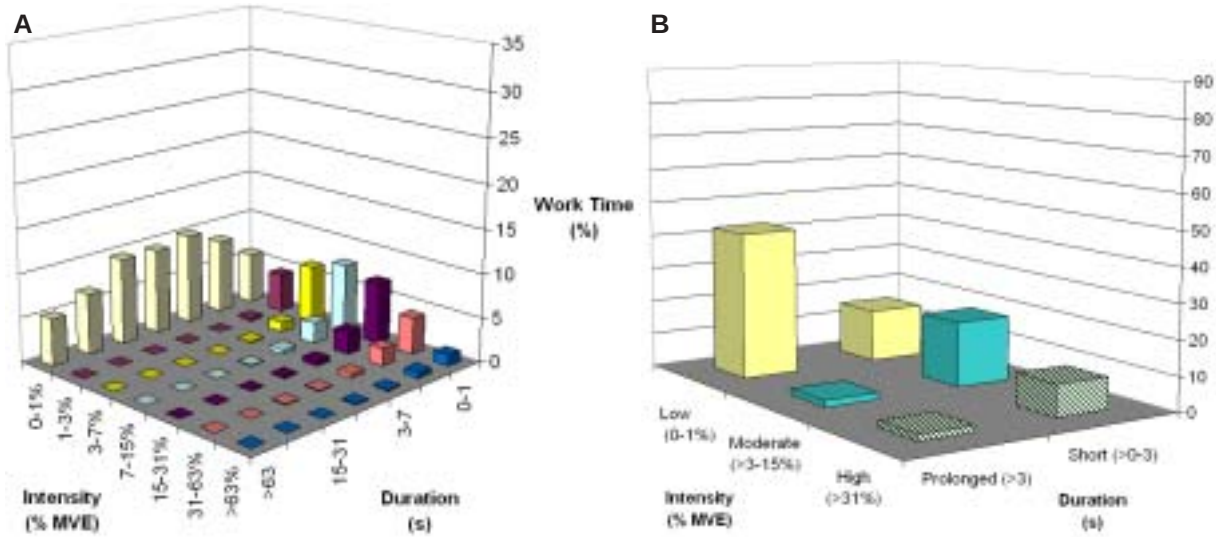

Figure 1. Mechanic's exposure variation analysis (EVA) (A) and clustered exposure variation analysis CEVA (B).

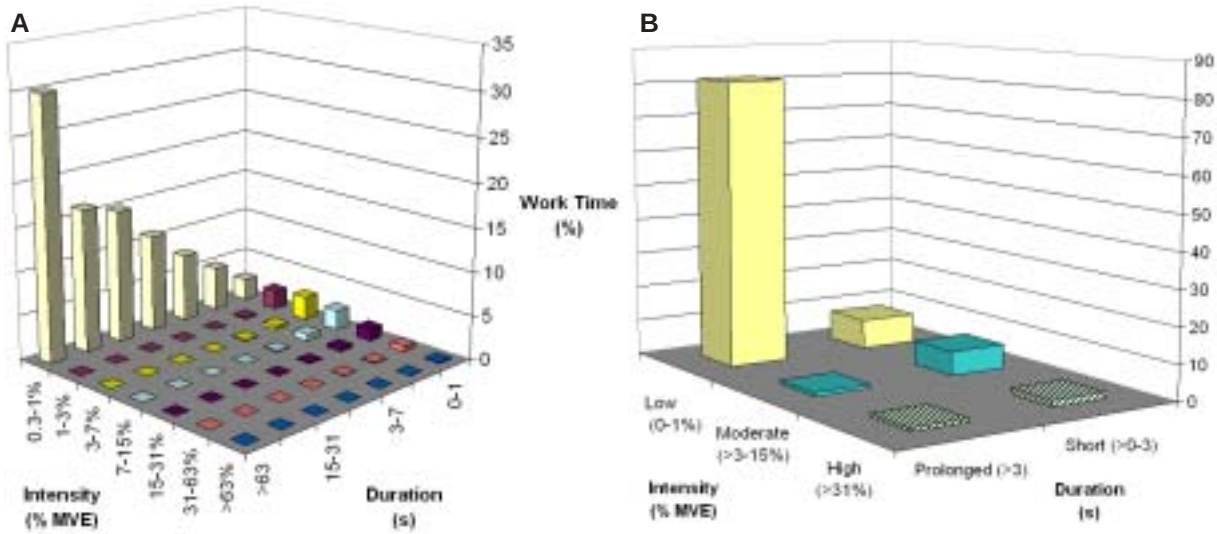

Figure 2. Operator's exposure variation analysis (EVA) (A) and clustered exposure variation analysis (CEVA) (B).

the day resulted, the range of the sampling start times being 0700 to 1545 for the operators and 0857 to 1435 for the mechanics. The mechanics were sampled for a mean of 0.95 hours and the operators for 1.14 hours.

Only dayshift mechanics and operators were sampled. The sampling only occurred during actual work and did not include breaks or lunch times. However, sampling continued for unscheduled but typical rest time; for example, when operators were waiting for dump trucks or when mechanics were talking to a colleague.

Table 2. Clustered exposure variation analysis (CEVA) boundaries (%MVE = percentage of maximal voluntary exertion; s = seconds).

CEVA category	Intensity (%MVE)	Duration (s)
High intensity and prolonged duration	>31	>3
High intensity and short duration	>31	>0–3
Moderate intensity and prolonged duration	>3–15	>3
Moderate intensity and short duration	>3–15	>0–3
Low intensity and prolonged duration	>0–1	>3
Low intensity and short duration	>0–1	>0–3

Statistical analysis

Means and standard deviations were used to describe the groups' questionnaire data. Univariate analyses and tests of assumptions were also conducted for the CEVA exposure category variables (30). A two-way mixed-effects repeated-measures analysis of variance (ANOVA) evaluated the percentage of sampled worktime in each CEVA category (31). Trade group was considered a between-participants factor with two fixed levels, operators and mechanics. The CEVA category was a within-participant factor with six fixed levels of clusters. The interaction between trade group and exposure category was considered a fixed factor as well. The participants were considered to be a random factor nested within the trade group factor.

The main effects of the trade group, the CEVA exposure category, and the interaction between group and exposure category were evaluated with general linear models. However, an a priori assumption was that the CEVA exposure categories would significantly differ since the possibility of equal worktime spent in each exposure category seemed remote. In addition, interactions were assumed to occur between the group and exposure categories. The primary analyses were simple effects of trade group and CEVA category. The study-wise alpha level was 0.05, with appropriate Bonferroni corrections.

Results

Direct exposure assessment data

The assumption of normality was robust to violation because of the sample size (30). Sphericity of the exposure category effect was violated, and the appropriate F-tests were adjusted with a Huynh-Feldt epsilon of 0.235. Since the variances were heterogeneous for two CEVA categories, a more restrictive experimentwise alpha level of 0.01 was used. The Bonferroni adjusted alpha level appropriate for significance was 0.001.

Table 3. Percentage of worktime spent by mechanics and operators in each CEVA category. (CEVA = clustered exposure variation analysis)

CEVA category	Trade group			
	Mechanics		Operators	
	Mean	SD	Mean	SD
High intensity and prolonged duration	1.87	0.86	1.02	0.04
High intensity and short duration	9.11	5.99	1.77	1.05
Moderate intensity and prolonged duration	1.87	1.03	1.08	0.15
Moderate intensity and short duration	18.84	6.45	6.83	5.78
Low intensity and prolonged duration	42.85	19.97	81.46	16.76
Low intensity and short duration	15.40	4.82	8.47	5.94

The CEVA means and standard deviations are shown in table 3. A value of 1 was added to all of these CEVA values, since some of the participants did not spend any time performing high-intensity, prolonged-duration contractions. Therefore, the total worktime could be greater than 100% in table 3. Examples of CEVA graphs for each group illustrate the differences in exposure between the two trades (figures 1 and 2). The simple effects of group differed significantly for all the CEVA categories at $P \leq 0.001$. Both groups of workers spent most of their worktime in the low-intensity, prolonged-duration CEVA category. However, the operators spent almost twice the time in this category as the mechanics did ($P<0.001$). While the mechanics performed more low-intensity contractions of short duration, the operators had more prolonged-duration, low-intensity contractions. The mechanics were exposed to work that required high-intensity muscular contraction at both prolonged and short muscle-contraction durations. Short-duration contractions occurred 9.1% of the time for the mechanics and only 1.8% of the time for the operators ($P<0.001$).

The mechanics were also exposed to activities that required more moderate-intensity muscle contraction of the flexor forearm than the operators, regardless of the muscle contraction duration (table 3). Almost 21% of the mechanics' sampled time was used performing moderate-intensity contractions, contrasted to 8% for the operators ($P<0.001$). The moderate-intensity, short-duration contractions showed highly significant differences ($P<0.001$) between the groups.

Although the difference was significant, the percentage of worktime spent at prolonged duration at the high and moderate intensity levels were essentially similar for the mechanics and operators. Less informative, the main effect of group for the CEVA values was significant ($F=43.00$, $P<0.001$) as was the main effect of the CEVA exposure category ($F=306.97$, $P<0.001$) and interaction ($F=49.03$, $P<0.001$). In addition, the simple effect of the CEVA exposure category for the mechanics was significant ($F=56.54$, $P<0.001$), as for the operators ($F=352.85$, $P<0.001$).

Discussion

CEVA appears to be a useful modification of the original EVA method for contrasting noncyclic work, typical of understudied industries like construction (12). Summary measures (32) like CEVA reduce the EMG data to a simpler, more statistically and visually

manageable array that is easy for researchers and non-researchers alike to comprehend. The visual clarity of CEVA graphs, compared with EVA graphs, is shown in figures 1 and 2. Ease-of-use is a priority for exposure assessment methods according to NORA (12). An alternate method of evaluating EVA has been reported by Jansen et al (18), who describe overall exposure patterns observed in the data. Conversely, the intent of CEVA is to contrast the exposure obtained from groups of workers or worktasks with a priori defined clusters. Reduction of the data into fewer categories with CEVA allows the exposure estimates to be used as potential predictor variables in models of the relationship between physical exposures and upper-extremity musculoskeletal disorders or to evaluate interventions.

CEVA and subsequent analysis differ from EVA in several ways. In contrast to previous studies that have evaluated solely the intensity categories, or the intensity and duration categories separately (15, 16, 33), we assumed an interaction. In other words, all muscular contractions must have a corresponding duration of contraction. This intensity–duration interaction is important to consider since temporal variables are infrequently evaluated (12). Although the duration of muscle contraction is part of EVA, these categories have been excluded from the statistical analyses (16). CEVA also differs in that it is a summary measure (32) that is not intended to describe the entire exposure pattern, as EVA is. Instead, the clusters of CEVA represent separate characteristics of the exposure. In comparison to EVA, not all of the data were used to form the six CEVA categories. Mathiassen (34) suggested that deleting a row or column from the EVA array would promote statistical independence. However, the CEVA intensity levels >1–3% and >15–31 %MVE were omitted to allow greater contrast between the groups. EVA and CEVA also differ in the methods that are used to analyze data. A multivariate ANOVA is often used to evaluate EVA (34–36), while a mixed repeated-measures ANOVA is used for CEVA. The initial use of a repeated-measures ANOVA prevented the circular analyses that often occur when the less powerful multivariate ANOVA is used (37, 38). Mixed models are appropriate for use with summary measures (32), and we appropriately adjusted for the lack of sphericity in the data.

The boundaries for the CEVA intensity categories were somewhat comparable to those used by other researchers (28, 29). For example, Fallentin et al (29) defined "hard" or "very hard" force as greater than 29% of a maximal voluntary contraction, a level comparable with the high-intensity CEVA category. In contrast, Fallentin et al defined "somewhat hard" force as 10–29 %MVE, while "moderate" intensity was 3–15% in our study. However, there is no clear consensus in the literature for the percentage of maximal strength considered "hard," "moderate," or "low" (1, 28). Regardless, not all of the CEVA categories provided meaningful data in our study. For example, minimal time was spent in the high- or moderate-intensity cluster at prolonged durations of exertion (table 3). Further evaluation using different cluster boundaries, groups of workers and muscle groups, and other types of work is necessary.

The results of this study indicate that heavy equipment mechanics use their flexor forearm muscles at greater contraction intensities than operators do. The mechanics used high-intensity contractions 3.5 times, and moderate intensity contractions 2.5 times, more often than the operators did. In our study, the mechanics and operators both spent most of their worktime using low-intensity contractions of the flexor forearm. The pattern of more time spent at low intensity levels was expected since the work of both operators and mechanics has frequent pauses. For example, operators must often wait for a loader, and mechanics look up parts in catalogs. However, in our study, the operators spent almost 32% more time working at low-intensity levels than the mechanics did. Indeed, operators spent almost 90% of their time using their flexor forearm at levels less than 1 %MVE.

Other studies have reported low-intensity levels during work. A study of flexor forearm load during automobile assembly tasks found that much of the sampled worktime was spent at low-intensity levels (16). Although EVA was used in the study, no univariate analyses were provided for comparative purposes. Another study evaluated myoelectric activity of the flexor carpi radialis muscle during the simulated operation of heavy forestry equipment with two types of joysticks (15). Low levels were reported with the median level of the amplitude probability distribution function 2–4 %MVE. Again, EVA univariate analyses were not reported.

In our study, the low exertion levels found among the operators may have been due to the newer hydraulic equipment that was operated. Many of the vehicles had modern joystick linkage mechanisms. These mechanisms are either "pilot-operated" or "electronic rheostat", both of which substantially reduce the operating force. The operating force for these newer mechanisms has been measured to be less than 5 newtons (Wilder D, personal communication). In contrast, direct mechanical linkages were used in older heavy equipment, and the forces on the arm were undoubtedly greater. The low exertion levels found in our study also concur with the results from a laboratory simulation study on heavy equipment joysticks (39). Operators used minimal flexor forearm force to move joysticks with summed fingertip forces of less than 4 newtons. Additional evidence that the results of our study are valid was provided by in-cab videotaping of scraper and bulldozer operation

(27). The videotape analysis indicated frequent, prolonged periods in which the operator was simply resting his hand on the joystick. The validity of the data was also verified, since the mechanics and operators were routinely sampled on the same day with the same equipment; yet the CEVA results differed remarkably between the two groups. The visual similarities of the EVA and CEVA graphs within each group indicated that a consistent estimate of exposure was obtained.

A substantial amount of the time at low-intensity levels could be considered gaps or true rest using the gap definition proposed by Hansson et al (40). Thus operators are able to rest their flexor forearm to a much greater extent during the workday than mechanics are; this finding would suggest that the potential for upper-extremity musculoskeletal disorders, such as carpal tunnel syndrome or tendonitis, is less for operators. Indeed, Rosecrance et al (5) reported a substantially lower prevalence of carpal tunnel syndrome for heavy equipment operators than for mechanics. In contrast, the shorter breaks for mechanics may produce fatigue, limit recovery periods, and increase susceptibility to upper-extremity musculoskeletal disorders (41).

With the exception of rest durations or gap analyses (42), the duration of muscle contraction has rarely been reported as a separate predictor variable for upper-extremity musculoskeletal disorders (28, 43). Fransson-Hall et al (43) reported that persons with a higher prevalence of forearm and wrist symptoms used longer holding times during the manual assembly of automobiles. In contrast, the mechanics in our study spent a greater percentage of worktime using contractions of short duration at high and moderate intensities. These short-duration contractions probably occurred during episodic tool use or during brief efforts when parts were being positioned. If the high- and moderate-intensity contractions of short duration are associated with the high prevalence of carpal tunnel syndrome among mechanics, the contrasting findings between our study and that of Fransson-Hall et al (43) suggest that the etiology of upper-extremity musculoskeletal disorders may differ between highly variable work and cyclic work.

Although our study was not epidemiologic in nature, the questionnaire results provide important information on the differences in work exposure between the two groups. The operators worked over 2.5 more hours a day than the mechanics and spent approximately 15% more time performing their primary task, which is approximately 300 more hours a year. However, the workhours per year were similar for the two groups of workers. In addition, operators take many more days off per year than mechanics, and this time allows for more healing time if injured. Mechanics spend 77% of the day repairing equipment that involves lifting heavy parts, using hand and power tools (most with smooth handles), and working in oily or greasy environments. Thus mechanics may spend an inordinate amount of their workday gripping tools or parts at high or moderate intensities in an attempt to overcome slippery surfaces.

The group-based exposure sampling strategy used in our study adequately contrasted between groups that performed variable noncyclic work. Although task evaluation has been recommended for highly variable noncyclic work (44), it may be unreasonable to state a priori which task has the most effect on the development of upper-extremity musculoskeletal disorders. In addition, task evaluation may not consider the effect of brief, intermittent rest periods on the total exposure profile. In our study, the sampling continued during these unscheduled rest periods and therefore allowed a more complete profile of exposure. Since evidence exists that cumulative load may contribute to upper-extremity musculoskeletal disorders such as carpal tunnel syndrome (45, 46), intervention should seek to reduce overall exposure. Although misclassification of exposure could have potentially occurred since a single sampling period for 1 hour was used (44), the misclassification would have been nondifferential and the effect of the bias would have been towards the null (47). Even in cases of high within-group variability, exposure measurements are useful if the group differences are even greater (48). In the current study, the two trade groups were significantly different for each CEVA category.

The investigators have previously reported the reliability of CEVA (49). Participants in the reliability study performed trials of repetitive hand gripping using a force dynamometer. Each trial consisted of a combination of gripping tasks at low and high exertion intensities with long- and short-duration holds. The test-retest reliability was assessed by having the participants perform the gripping tasks in the same order at a later time, with a mean intraclass correlation of 0.82. The participants also performed the same gripping tasks in a different order to assess "superposition." The reliability of these superposition trials was high as well.

Our study had some potential limitations. The generalizability of the results may have been limited since EMG was sampled from only one muscle group. A single muscle group was sampled to minimize contractor burden since the use of heavy equipment is billed at high hourly rates. In addition, we sampled the muscle group that potentially has the most effect on carpal tunnel pressure and was most appropriately evaluated with surface EMG. Motion artifact and cross-talk between muscle groups is often a concern with field studies using EMG. However, studies using the same electrodes (50–52) and pilot studies using the data logger system indicated that the effects were inconsequential (Anton D, unpublished data).

In summary, our study is one of the few that has attempted to evaluate variable noncyclic work with direct exposure assessment methods. CEVA is a direct method that easily evaluates and accurately quantifies exposure to forceful exertion, qualities that comply with current NORA priorities (12). This measurement tool also shows promise as an assessment method for other physical risk factors, such as awkward postures, in cyclic or noncyclic work environments. CEVA results obtained from data loggers can be used by researchers and those in industry to evaluate risk factors and to eventually reduce the burden of work-related musculoskeletal disorders.

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