MEAN, PEAK, AND CUMULATIVE SPINAL COMPRESSION ESTIMATES IN FIVE HEAVY INDUSTRIES

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This study reports mean, peak, and cumulative spinal loads using compression-normalized electromyography (CNEMG), compares these levels between industries, and compares them to the NIOSH guidelines. Full-shift (5.5 to 10.3 hours) EMG measurements were made for 105 workers in five heavy industries with portable data loggers. EMG voltage was transformed into units of spinal compression force (Newtons). The mean, peak, and cumulative CNEMG as well as the percentage of work time spent above 3400 N and 6800 N thresholds were calculated. Mean CNEMG (sd) was 1564 N (796), peak was 2721 N (1545), and cumulative was 3.8 $x10^7$ N.sec (2.1 x 10^5). Mean time spent above the 3400 N NIOSH threshold was on average 6.3% of the shift, while mean time spent above the 6800 N threshold was around 1%. Overall, estimated compressions in heavy industry show elevated risks when compared to NIOSH guidelines, warranting control strategies.

Keywords: Spinal Compression, Compression-normalized EMG, Heavy Industry

INTRODUCTION

In British Columbia, back injuries account for approximately 25% of all workers' compensation claims, 23% of work days lost, and 20% of total claims costs. One-quarter of back injury claims are made by workers in five heavy industries: construction, forestry, transportation, warehousing and wood products (WorkSafeBC, 2006). Work tasks and activities in heavy industry often involve considerable time in awkward postures and manual materials handling (Teschke et al. 2007), both of which contribute to muscle activity and to associated spinal compression (Waters et al., 1993). Both peak and cumulative spinal loads have been examined in cyclical manufacturing and assembly tasks (Norman et al. 1998), since these types of work tasks allow for efficient exposure assessment and extrapolation. However, in comparison, little study has been done on non-cyclical tasks, such as those found in resource industries and construction, perhaps because the most precise and accurate exposure assessment methods are harder to apply in these industries.

There are many excellent biomechanical modeling methods that account for asymmetrical, complex motion and dynamic segment/load inertias. Unfortunately, heavy industry presents extensive measurement challenges to researchers (Trask et al., 2007), and these methods are too cumbersome and expensive to be widely applicable in the sampling durations and frequencies required for epidemiological studies. Portable electromyography (EMG) provides a practical alternative to complex biomechanical methods because it can be used to estimate the low back compressive forces throughout the shift (Mientjes et al., 1999; Village et al., 2005). EMG has advantages in that it allows workers to move freely throughout their working environments with minimal interruption. Because EMG can be used to attain full-shift estimates of non-cyclical activities, estimates of mean, peak, and cumulative exposures can be made concurrently.

The goal of this study was to report mean, peak, and cumulative forces using compression-normalized electromyography (CNEMG), to compare these levels between industries, and to compare them to the NIOSH guidelines (Waters 1993).

METHODS

Worker recruitment and sampling strategy

This analysis was undertaken as part of a larger study of the risk factors for low back injury in heavy industry. Workers in construction, forestry, transportation, wood products, and warehousing with a lost-time workers' compensation board (WCB) claim for a back injury in 2001 were contacted by phone; 75% agreed to participate. Employers were then contacted for permission to visit the worksite and make full-shift exposure measurements; 75% of employers gave permission. Up to four additional co-workers were recruited from each work site; these were non-management, non-administrative workers on the same shift. Where possible, workers were measured for a second shift between 1 to 439 days after the first measurement. In total, 105 individuals were measured in this study, with repeated measurements on 27% of workers.

EMG Data Collection

Continuous full-shift (5.5 to 10.3 hours) EMG measurements were made with portable data loggers (Mega P4 3000, Mega Electronics, Finland) using disposable Ag-AgCl electrodes over the erector spinae at approximately the level of L4/L5. Data collected at 1000 Hz were filtered with an 8-500 Hz band pass filter; the rms averaged values were stored at 100 ms intervals and downloaded onto a laptop computer during work breaks.

Transformation to spinal compression: compression-normalized EMG

EMG voltage was transformed into units of spinal compression force (Newtons) using a linear calibration equation based on reference calibration postures performed at the beginning of the shift. The first reference contraction involved standing upright with the hands by the sides. The second involved a static 45^{o} forward trunk flexion while holding an 11.5 kg weight. The reference contractions were performed twice for 5 seconds at the beginning of each shift. For these positions, spinal compression was estimated using a computer-based link-segment model (Ergowatch 4D WATBAK, Waterloo University, Canada). The estimated spinal compression (in Newtons) and the muscle activity (in uV) for each position were used to generate a linear calibration equation. This process yielded a continuous estimate of “compression-normalized EMG” (CNEMG) for the whole work day. This is similar to the compression normalization methods used by Mientjes et al. (1999) and Village et al. (2005).

Statistical analysis and comparison to guidelines

Full-shift EMG was summarized into three metrics for each work shift: the arithmetic mean, the 90th percentile as an estimate of ‘peak’ loads, and cumulative exposure. Since shifts lengths varied in this population, cumulative spinal loads were calculated without normalizing to a standard day length to reflect the variation in daily dose. Standardizing cumulative exposure to a constant shift length would generate a rank order of exposures identical to that of the mean exposures.

The mean and peak CNEMG levels were compared to levels approximating NIOSH guidelines (3400 N and 6800 N) (NIOSH 1994), and the percentage of work time spent above each threshold was calculated. Differences between industries in mean, peak, cumulative, and percent time exceeding thresholds were tested using one-way ANOVA in SPSS V 11.5 (SPSS Inc., Chicago, Illinois, USA).

RESULTS

Compression-normalized EMG in heavy industry

The rank order of mean, peak, and cumulative CNEMG exposures was similar across industries (Table 1). Mean CNEMG ranged from 1269 N (654) in transportation to 1771 N (593) in construction. Variability in mean CNEMG among workers within each industry meant that the observed differences were not significant between industries. There was less variation in peak CNEMG, which ranged from 2338 N (1679) in transportation to 3066 N (1065) in construction. Cumulative CNEMG showed a somewhat different ranking, lowest in transportation at 3.2 $x10^{7}$ N.sec (2.4 x ^{5}), and highest in forestry at 4.4 $x10^{7}$ N.sec (2.0 $x10^{5}$).

Comparisons to NIOSH guidelines

Mean time spent above the 3400 N threshold was on average 6.3% for all workers (Table 2); wood products had the greatest time above this threshold at 10% while transportation had the least at 3.7%. Wood products also had the most time spent above the 6800 N threshold at 2%; construction had the least time above 6800 N at 0.16%. Although construction had the highest mean and peak CNEMG values, it had the lowest standard deviations, and therefore did not represent the worst case for time spent above NIOSH recommended limits.

DISCUSSION

Finding compression-normalized EMG values that exceed NIOSH guidelines in a heavy industrial working population is not surprising, especially given that these workers spend substantial time performing manual materials handling (MMH) activities and in non-neutral postures (Teschke et al. 2008). It should be noted that the 'peak' values reported in this paper are actually 90th percentile values, so 10% of the exposure values in a day were higher than these levels. Point measures of 'worst-case' exposures during complex or dynamic movement are likely to produce much larger estimates (as confirmed in table 2). However, because the 99th and 100th percentiles are vulnerable to instantaneous EMG noise and artifact, 90th percentile is often used as a conservative estimate of peak levels (Mientjes et al. 1999; Moller et al. 2004).

Table 1: Mean, peak (90th percentile), and cumulative CNEMG for five industries and for all industries combined

CNEMG	Construction	Forestry	Transportation	Warehousing	Wood products	All industries
	Newtons (sd)					
Mean (sd)	1771 (593)	1727 (760)	1269 (654)	1444 (755)	1653 (1076)	1564 (796)
Peak (sd)	3066 (1065)	2911 (1247)	2338 (1679)	2531 (1574)	2821 (1945)	2721 (1545)
	N.sec (sd)					
Cumulative	3.7 x10^7 (1.7 x 10^5)	4.4 x10^7 (2.0x10^5)	3.2 x10^7 (2.4 x 10^5)	3.6 x10^7 (2.7 x 10^5)	3.9 x10^7 (2.1x10^5)	3.8 x10^7 (2.1x 10^5)

Table 2: Percent time spent above NIOSH recommended guidelines

% time above	Construction	Forestry	Transportation	Warehousing	Wood products	All industries
3400 N (sd)	5.1% (0.7%)	7.5% (0.77%)	3.7% (0.7%)	5.7% (0.8%)	10.3% (2%)	6.3% (1.1%)
6800 N (sd)	0.16% (0.04%)	0.65% (0.07%)	0.84% (0.3%)	0.69% (0.1%)	2.0% (0.5%)	0.90% (0.3%)

Comparison to NIOSH guidelines

The guidelines that form the NIOSH lifting index were developed based on combined biomechanical, physiological, and psychophysical criteria and were developed to be protective for the bulk of the working population (Waters et al. 1993). Although the *percentage of time* spent above a NIOSH guidelines have not been explicitly compared to risk for back injury, *any* excedance of the NIOSH guidelines is considered to introduce elevated risk (Waters et al.,1993) and presents an opportunity for improvement. The data presented in this paper represent only biomechanical exposures, and the physiological demands of the work are also likely to contribute to risk in a way undetected by comparison to NIOSH guidelines.

Even more telling is the fact that the risk for back injuries in heavy industry is consistent with the excedances of the NIOSH guidelines. Postural exposures and manual materials handling were high in this group (Teschke et al. 2008), NIOSH guidelines were exceeded over 6% of working time, back injury claims in these industries were elevated (WorkSafeBC, 2006) and the majority (77%) of these workers reported low back pain in the past 6 months (Trask et al., 2008). Together, these facts make a compelling argument for controlling exposures in these industries.

Limitations of CNEMG

The CNEMG methodology has some inherent limitations that must be acknowledged when considering the results. The method described in this paper uses only one muscle location for measurement. Although this was the most practical for workers wearing safety equipment and performing frequent bending, co-contraction is an important source of spinal compression and is not accounted for in the exposures presented. Furthermore, CNEMG is known to be less accurate during non-symmetrical lateral bending or twisting or combined movement tasks (Mientjes, 1999). The biomechanical model used to transform EMG volts to Newtons of spinal compression was static and sagittal, as were the reference postures. This could also introduce a source of error since workplace tasks are generally dynamic and frequently asymmetrical. However, despite these challenges, an occupational field study of long-term care nurses successfully showed a relationship between CNEMG and injury reporting (Village et al., 2005), indicating that CNEMG has predictive validity.

Despite the limitations, making exposure assessment in the working environments of heavy industry presents necessary choices and tradeoffs. What is lost in the accuracy of each individual estimate is gained in the low relative cost which allows for over 100 full-shift measurements to be made. Direct measurement of exposure to low back risk factors in heavy industry is challenging, with inclement, dusty, or vibrating environments, very high mobility requirements, extreme postures, confined spaces, and unpredictable task schedules or work methods (Trask et al., 2007). Although it may represent a compromise in terms of accuracy when compared to more advanced biomechanical methods, CNEMG allows for investigation of tasks and jobs that would be impossible to measure using video-based methods or motion-capture methods, and with higher objectivity and precision than observation or self-report. In this respect, CNEMG represents a quantitative 'middle ground' on the spectrum of exposure assessment which ranges from qualitative job title data to the most involved lab-based biomechanical methods.

Conclusion

CNEMG provided a feasible way to measure risk factors for back injury in heavy industry. When comparing CNEMG levels to NIOSH guidelines, there were non-trivial excursions above exposure thresholds. Overall, estimated low back compressive forces in heavy industry are in a range that would be considered high risk when compared to NIOSH guidelines, although there was variability across industries. Particularly in wood products and forestry, the percentage of time exceeding guideline thresholds suggests that controlling exposure through engineering or administrative interventions is needed.

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