HOW LONG IS LONG ENOUGH? PHYSICAL EXPOSURE ESTIMATES AND SAMPLING DURATION

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This paper explores the representativeness of shorter sampling durations for compression-normalized electromyography (CNEMG) to optimize the tradeoff between expense and measurement accuracy. Shift-long CNEMG data was collected using portable data loggers for 8 workers in heavy industry. Data were re-sampled for 4-hour, 2-hour, and 1-hour durations. The means and 90th percentiles were calculated for each sampling duration and compared using Spearman's correlation coefficient and absolute mean errors. Mean and 90th percentile compression estimates for the full-shift were significantly correlated to means and 90th percentiles for all shorter sampling durations. Although there were no significant differences in means or 90th percentiles between full-shift and shorter durations, the average absolute percent error from full-shift values increased with shorter sampling periods for mean compressions. Increasing sampling durations from 2 to 4 hours show accuracy gains of only 1-2%, but sampling durations one hour or less are likely to produce unacceptable errors (5-15%).
Keywords: EMG, Sampling Duration, Spinal Compression

QUELLE EST LA DURÉE ADÉQUATE? ESTIMATION DES EXPOSITIONS PHYSIQUES ET DURÉE D'ÉCHANTILLONNAGE

Le présent article analyse les représentativités d'échantillonnage de courtes durées d'une électromyographie normalisée de la compression (CNEMG) pour optimiser la compensation entre la charge et la précision de la mesure. Les données CNEMG ont été recueillies dans un quart de travail complet à l'aide d'enregistreurs chronologiques portables chez 8 travailleurs de l'industrie lourde. Ces données ont été rééchantillonnées sur des durées de 4 heures, 2 heures et 1 heure. Les moyennes et les 90^{e} centiles de chaque durée d'échantillonnage ont été calculées et comparées à l'aide du coefficient de corrélation des rangs de Spearman et des erreurs moyennes absolues. La corrélation était significative entre les estimés de la compression de la moyenne et du 90^{e} centile du quart de travail complet et les moyennes et 90^{e} centiles de toutes les périodes de courte durée. Même s'il n'y a pas eu de différences significatives dans les moyennes ou les 90^{e} centiles entre les quarts complets et les périodes de plus courtes durées, l'écart absolu moyen en pourcentage des valeurs du quart de travail complet a augmenté avec les périodes d'échantillonnage plus courtes pour les compressions moyennes. On a observé une augmentation des gains de précision de seulement 1 à 2 % lors des durées d'échantillonnage de 2 à 4 heures; toutefois, les durées d'échantillonnage inférieures à 1 heure semblent produire un taux inacceptable d'erreurs (de 5 à 15 %).
Mots clés : EMG, durée d'échantillonnage, compression médullaire

INTRODUCTION

Spinal compression has been suggested as a universal 'common metric' when describing workload (Wells et al., 1997), and both peak and cumulative spinal compression are related to back injury (Norman et al., 1998). Brief task-based or "worst-case" loading assessments minimize data collector time and equipment rental, but may under-represent exposures since they neglect the temporal variations throughout the work day. There exist several comprehensive biomechanical modeling methods which account for asymmetrical, complex motion and dynamic segment/load inertias. Unfortunately, these methods are too cumbersome and expensive to be widely applicable in industrial environments and in the quantity and frequency required for epidemiological studies. Shift-long electromyography (EMG), which provides a practical alternative to previous methods, allows for measurement of workloads and work pattern variability, and EMG can be used to estimate the spinal compression throughout the shift (Mientjes et al., 1999).The goal of this paper is to explore the representativeness of shorter sampling durations for compression-normalized electromyography (CNEMG) and identify an optimal sampling duration that minimizes expense for large numbers of workers but estimates exposure reasonably accurately.

METHODS

Worker recruitment and data collection

This analysis was undertaken as part of a larger study examining the risk factors for low back injury in 125 employees in heavy industry. From this study population, we selected 8 participants: four from the construction industry, and four from the wood products industry. In construction, job titles included carpenter, paver, and concrete form worker (2). Wood product job titles included green chain worker, spindle sander(2) and chop saw operator. Although the wood products industry tasks were more cyclical with shorter cycle times, the range of work intensity was higher since the maximum loads were greater. Full- shift EMG measurements were made with portable data loggers (Mega P4 3000, Mega Electronics, Finland) using disposable 12mm Ag-AgCl electrodes over the erector spinae at approximately the level of L4/L. Data were collected at 1000 Hz, filtered with an 8-500 Hz band pass filter; and root mean squared values stored at 100 ms intervals on a laptop. EMG data was collected for the full shift excluding breaks (5.5 to 7.5 hours of working time).

Estimation of spinal compression

Continuous EMG measures were used to estimate spinal compression throughout the shift. Before starting work, workers performed two 5-second trials each of four reference postures: standing unloaded, trunk flexed 45^o without a load, trunk flexed 45^o with a 12 kg load, and trunk flexed 60^o with a 12 kg load. For each of 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.

Re-sampling EMG data and statistical analysis

Within each full-shift, the data were re-sampled for shorter durations using random start times. This resulted in four sets of data of varying lengths for each worker: one full-shift segment, .one 4-hour segment, one 2-hour segment, and one 1-hour segment. Mean and 90^{th} percentile CNEMG loading estimates were calculated for each of the four durations. Statistical analysis was performed using SPSS 11.5. The relationship between full shift and the three shorter sampling periods was determined using Spearman's rank correlation coefficient. Generalized Linear Modeling for repeated measures was performed to determine if significant differences existed between the sampling periods. The absolute percent error between full shift and shorter sampling periods was also calculated and compared.

RESULTS

Mean and 90th percentile compression estimates for the full-shift were significantly correlated to mean and 90th percentile estimates for all shorter sampling durations (Table 1). With this limited sample, there were no significant differences between full-shift mean and 90th percentile compression estimates using repeated measures tests. The average absolute percent error from full-shift values increased with shorter sampling periods for mean compressions (Figure 1). Similarly, pooled average errors in 90th percentile spinal compression (not shown) were 2.7% for the 4-hour duration, 4.7% for the 2-hour duration, and 6.1% for the 1-hour duration.

Table 1: Spearman Correlation coefficients for mean and 90th percentile compression estimates between full shift and 4, 2, or 1-hour sampling lengths.

Comparison between:	**Correlation Coefficient for Mean Exposure**	**Correlation Coefficient for 90th Percentile Exposure**
Full shift and 4 hours	0.988*	0.988*
Full shift and 2 hours	0.954*	0.988*
Full shift and 1 hours	0.952*	0.988*

* significantly correlated at $p < 0.001$

Figure 1: Absolute percent error in mean spinal compression at each re-sampling length for construction workers, saw mill workers, and both industries combined .

DISCUSSION

This study shows an excellent correlation on overall mean and 90th percentile exposure estimates, but increasing errors with decreasing sampling lengths. These trends are consistent between the two industries and show a loss of representativeness with decreasing sampling lengths. The loss of accuracy is less marked between 4-hour and 2-hour durations than between the 2-hour and 1-hour duration. Thus, when full shift measurements are not possible, decreasing the sampling length from 4 hours to 2 hours increase the errors only 1-

2%. The type of work being done (cyclical or non-cyclical), the length of the cycle time, the range of work intensity, and other task factors may affect the amount of time required to accurately capture work exposures. For example, cyclical work with short cycle times would require shorter sampling durations than would long-cycle or non-cyclical work.

Limitations

The generalizability of these results is limited by the relatively small sample size and inclusion of only two industries and a handful of job titles. The biomechanical model used was static and sagittal, although workplace tasks are generally dynamic and frequently asymmetrical. The accuracy of a linear calibration equation relating muscle activity to spinal compression, and errector spinae muscle activity as an indicator of spinal loads (an outcome affected by multiple factors) have not been validated for industrial tasks. Nonetheless, this method has been used successfully in occupational field studies of long-term care nurses (Village et al., 2005) and sheep shearing (Marshall et al., 2004).

CONCLUSION

The results from this limited sample suggest that exposure classifications can be maintained with shorter measurement durations, but at the cost of accuracy. Although increasing sampling durations from 2 to 4 hours show accuracy gains of only 1-2%, sampling durations one hour or less are likely to produce unacceptable errors (5-15%). Future work will include re-sampling for the 125 workers from the larger study and statistical modeling to identify workplace and task characteristics which could be identified *a priori* to help guide the choice of measurement duration.

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