Evaluating full-shift low back EMG and posture measurement for epidemiological studies

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Abstract

Occupational exposures to risk factors for low back disorders have been assessed using job titles, self-assessment, observational methods and direct measures. Direct measures are generally recommended as more precise, but their use is limited in large studies. The purpose of this study was to explore the comparability of two direct measurement methods (electromyography and inclinometry) for continuous low back exposures and the ability to distinguish exposures among workers in different industries. Shift-long data on low back muscle activity and posture was collected using EMG and inclinometry from 4 workers in the transportation industry and 4 workers in the wood products industry. Spinal compression summary measures (static, median, peak, cumulative) were estimated and compared by industry and by method. Exposure measures were consistently higher in wood products than in transportation (e.g. EMG-estimated median spinal compression: 1453 N in wood products vs 732 N in transportation). EMG and inclinometer data provided similar estimates for the summary measures (e.g. median spinal compression in wood products: EMG = 1453 N, Inclinometer = 1468 N, r=0.89). Since inclinometer-based estimates of spinal compression appear comparable to those based on EMG and distinguish between exposure groups, inclinometry may be a good surrogate for EMG in large exposure assessment studies.

Keywords: EMG (electromyography), methods development, work related musculoskeletal disorders, low back injury, occupational exposure assessment

1. Introduction

Back injuries are among the most common workplace injuries. Studies suggest that awkward postures and manual materials handling (lifting, pushing, pulling) are leading risk factors for the onset of low back disorders [1]. Occupational exposures to risk factors for low back disorders have been assessed using job titles, self-assessment, observational methods and direct measures. Each method has its own advantages and disadvantages, but direct measurement is generally preferred as it provides precise and usually unbiased measures of magnitude, duration, frequency and patterns of exposure. However, high costs of equipment, time needed to apply and calibrate measurement devices, harsh work environments, and intensive data analysis procedures can limit their practicality in the workplace.

Trunk inclinometers provide an alternative exposure assessment method, one with the potential to estimate spinal loading far more economically than EMG or biomechanical modelling and may therefore be practicable for large epidemiological studies.

Full-shift assessment of EMG and trunk posture allows for continuous, objective estimates of forces and postures over the whole workshift, and facilitates investigations of exposure variability over time. However, a single measure of mean or peak load could represent widely varying job tasks and risks levels; the same mean exposure could represent a constant exposure or highly fluctuating exposure, while a peak level might be reached once or many times during a shift. Use of several summary measures might therefore allow a better determination of risk factors for back injury.

The aims of this study were: 1) to develop and evaluate two automated direct measurement techniques (electromyography and inclinometry) that can be used to collect information on low back exposures over a full work shift in heavy industry; 2) to develop analysis techniques to compare daily exposure measures and patterns by method and by industry, including peak and cumulative spinal loading; and 3) to evaluate the effectiveness of using inclinometry as a predictor of spinal loading in occupational field studies, including comparability with EMG measures and the ability to distinguish exposure by industry. The study was field-based, and involved exposure measurements for employees in two heavy industries: transportation; and wood products.

2. Methods

2.1 Worker recruitment and sampling strategy

As part of a larger study, the British Columbia Workers' Compensation Board identified a random sample of 50 employees in five heavy industries (transportation, warehousing, forestry, wood and paper products, and construction) who had accepted worker's compensation claims for back injury in 2001, who resided in the Greater Vancouver/Sunshine Coast areas, and who agreed to have their information released to researchers. These workers were contacted first by letter, then by telephone and invited to participate. The employers of participating workers were contacted to gain permission to conduct measurements at the worksite. Human subjects procedures were approved by the University of British Columbia's Behavioural Research Ethics Board. From this study population, we selected 8 participants (four from the transportation industry and four from the wood product industry) with work shift measurements using both electromyography and inclinometry.

2.2 Data Collection

Electromyography (EMG) was measured using a portable data collection system with on-board memory (ME3000P4/ME3000P8, Mega Electronics, Finland). Disposable 12mm Ag-AgCl electrodes (Blue Sensor N-00-S, Ambu, Denmark) with a 20 mm interelectrode spacing were placed over the erector spinae at approximately the level of L4/L5, with a ground electrode and preamplifier on the posterior aspect of the iliac crest. Signals were collected at 1000 Hz and filtered internally using an 8-500 Hz band pass filter; and the averaged value was stored at 100 ms intervals. Data were downloaded from the EMG data collection system onto a laptop computer during work breaks.

Continuous posture measurements, in two dimensions relative to gravity, were made using a Virtual Corset inclinometer (VC-323, Microstrain, Inc., Williston, VT). The Virtual Corset is a battery-powered, pager-sized logger with 2 Mb of onboard memory. It was harnessed tightly to the trunk at the approximate level of the T6 spinous process. Lateral flexion (frontal plane) and flexion-extension of the trunk (sagittal plane) were recorded relative to gravity at a rate of 7.6 Hz. Posture was measured and recorded to the logger memory throughout the shift and subsequently downloaded to a laptop computer.

Calibration maneuvers were performed at the beginning and end of each shift: three trunk flexions and one trunk extension, holding each position for 5 seconds. These movements created three phasic signals in the EMG record and provided a means to synchronize to the three movements registered by the Virtual Corset in the time domain. In addition, the upright positions in the calibration maneuvers allowed for the determination and correction of any postural offsets associated with how the Virtual Corset and harness system were mounted to the trunk.

2.2 Signal Processing and Analysis

2.2.1 Estimation of spinal compression

The shift-long EMG data was used to estimate spinal compression, building upon existing methods [2-4]. Before beginning work, workers performed a series of calibration reference postures in order to normalize the EMG signals: standing unloaded, trunk flexion of 45° without a load, 45° with a 12 kg load, and 60° with a 12 kg load. Spinal compression was estimated using a computer-based quasi-dynamic link-segment model (Ergowatch 4D WATBAK, Waterloo University, Canada). The model inputs included individuals' age, sex, height, and weight, as well as joint angles, and force at the hands. The estimated spinal compression (in Newtons) and the muscle activity (in uV) for each position were used to generate a linear calibration equation where the Y-intercept was constrained to be the estimated compression of an unloaded standing posture.

A similar method was used to estimate spinal compression using the Virtual Corset data, using only the unloaded upright and unloaded forward position, flexed at 45°. The estimated compression values were linearly related to the postural angle, yielding a calibration equation that was then applied to all postural data points to continuously estimate compression. This provided an estimate of spinal compression based on trunk posture for comparison to compression estimated via EMG.

Using the phasic signals in the EMG and the movements in the Virtual Corset data at the beginning and end of the shift, the data were synchronized in the time domain and saved to a common file. In this process, the EMG data was parsed and interpolated down to the sampling frequency of the Virtual Corset (7.6 Hz).

2.2.2 Summary measures

The time-synchronized EMG and Virtual Corset data were analyzed in parallel by selecting the working portions of the data (i.e., excluding breaks) and generating summary statistics for those portions. For EMG and Virtual Corset variables (muscle activity, torso angles and derived spinal compression), an amplitude probability distribution function (APDF) was generated for both EMG and Virtual Corset variables (raw and derived) [3-5]. For the EMG, the APDF 0.10, or 10th percentile was used as a measure of static load, or the load above which 90% of the exposures occur. The APDF 0.50, or median, was used as a measure of central tendency; while the APDF 0.90 represented the peak load or the load below which 90% of the exposures occur. For the inclinometer, the 50th percentile in flexion/extension and lateral flexion represented the median posture, and the 10th and the 90th percentile the postural extremes in each direction. The proportion of time spent above the NIOSH action limit [1] of 3400 N spinal compression and twice the action limit of 6800 N spinal compression was also calculated as an indication of exposure intensities or higher risk.

Characterizing peak values using higher-order (10th or 12th power) operations has been used to describe the relative importance of vibration versus shocks in whole body vibration dose [6]. We used a similar approach, RMD (root mean 10th power), to summarize the shift's exposure while retaining the influence of the peaks. Similar to the RMS (root mean square), the RMD involves taking the 10th power of all values, averaging the 10th power values, then taking the 10th root of this average.

Although peak load is an important risk factor for back pain, cumulative loads have predictive power independent of peak load [7]. Cumulative compression [N·s] was calculated as the mean estimated spinal compression multiplied by the duration of the workshift (total shift cumulative load). To allow for comparisons across workers, cumulative compressions were also normalized to a standard 8-hour equivalent dose using a time-weighted average.

The standardized rate of change metric (RCMS) has been used as a measure of exposure intensity in studies of electromagnetic radiation [8]. Because the waveform of EMG signals and continuous posture data share many attributes with electromagnetic signals, this measure was used to characterize the variability of the signal. The RCMS is the lineal length of the signal divided by the signal standard deviation.

Differences between groups are described qualitatively because the sample size in this sub-study precludes inferential analyses.

3. Results

3.1 Participant characteristics

Eight male workers were analyzed, four from the transportation industry and four from the wood products industry. The wood products jobs included lumber milling, woodturning, and wood product manufacturing, all with a substantial manual materials handling (MMH) component. The transportation jobs involved relatively little MMH, but all involved at least some driving. Physical characteristics of the subject group are provided in Table 1.

Table 1
EMG exposure summary statistics for transportation and wood products industries

	Transportation mean (s)	Wood Products mean (s)
Age	35.25 (9.0)	34.3 (8.8)
Height (cm)	175.8 (5.7)	177.8 (3.3)
Mass (kg)	80.8 (11.9)	85.8 (17.5)
BMI	27.2 (4.8)	27.0 (4.21)

3.2 Comparing exposures across industries

Torso flexion/extension static, median, and peak values were consistently higher among workers in the wood products industry, indicating more time was spent in flexion in that group (Table 2). The negative value for 'static' posture among workers in the transportation industry indicates that they had more than 10% of the work shift in extension, perhaps in a slightly reclined seat in a vehicle. The angular velocities for both sagittal and frontal planes are higher in wood products than in transportation, which is consistent with the higher level of trunk motion activity in this group. Wood product workers had twice the range of motion (90^{th} – 10^{th} percentile). Velocities in the sagittal and lateral planes were similar indicating movements typically were in both planes (not monoaxial).

Similarly, static, median, and peak EMG-estimated spinal compression values were all higher for wood products industry than the transportation industry, indicating consistently higher exposures (Table 3). The RCMS for EMG-estimated spinal compression was nearly twice as high in workers in the wood products industry as workers in the transportation industry, suggesting a higher signal variability. However, the proportion of time spent above EMG-estimated compression rates of 3400 N (not shown in table) was higher in wood products industry than in the transportation industry (10.8% vs 0.3%); similar results were found for the proportion of time spent above 6800 N (wood products= 1.5% vs transportation = 0.01%).

Table2
Inclinometer-measured trunk posture for transportation and wood product industries

	Transportation mean (s)	Wood Products mean (s)
Flexion/extension 'static' posture angle (degrees)	-2.0 (5.5)	5.1 (4.3)
Flexion/extension 'median' posture angle (degrees)	9.2 (2.7)	15.9 (6.0)
Flexion/extension 'peak' posture angle (degrees)	26.1 (5.3)	44.0 (17.6)
Flexion/extension angular velocity,) (degrees/sec)	13.0 (4.3)	22.5 (10.4)
Lateral flexion angular velocity, (degrees/sec)	15.2 (4.9)	25.6 (9.5)
Flexion/extension RCMS	0.30 (0.1)	0.30 (0.09)
Flexion/extension RMD(degrees)	72.1 (19)	80.3 (9.0)

3.2 Comparing inclinometer and EMG

Both EMG and Virtual Corset (VC) exposure measures distinguished between industrial groups. Static, median, and peak levels of estimated compression were consistently higher in wood products than in transportation for both methods. Estimates of cumulative spinal compression were about twice as high in the wood products industry as in transportation. The correlation between EMG- and VC-estimated median spinal compression was 0.99 in the wood products group and 0.75 in the transportation group (0.89 for pooled data). Inclinometer-predicted compression values were marginally higher than the corresponding EMG-estimated values.

Table 3
EMG- and inclinometer-estimated spinal compression in transportation and wood product industries

	Transportation mean (s)		Wood Products mean (s)	
	EMG	**VC**	**EMG**	**VC**
'Static' compression (N)	425.3 (62.4)	510.7 (170.7)	667.4 (265.1)	872.6 (601.2)
'Median' compression (N)	731.7 (359.1)	760.3 (671.9)	1452.7 (786. 1)	1468.0 (1118.6)
'Peak' compression (N)	1581.2 (3189.1)	1305.5 (1405.8)	3347.0 (2062.8)	3388.6 (3218.1)
Total work-shift Cumulative compression (MN.s)	28.7 (31.5)	27.2 (21.9)	57.6 (26.8)	67.23 (49.0)
8-hr corrected Cumulative compression (MN.s)	26.1 (32.1)	25.0 (22.7)	53.8 (24.5)	61.6 (39.3)
RCMS	0.62 (0.17)	0.30 (0.077)	0.64 (0.09)	0.29 (0.09)
RMD (N)	10609 (12948)	3897 (2627)	14021 (18328)	5700 (3623)

4. Discussion

EMG-estimated compression levels, cumulative compression, trunk flexion levels, trunk flexion velocity and lateral flexion velocity were higher in wood products than in transportation. This is consistent with our knowledge and observations of more manual materials handling and less sedentary driving tasks among workers in wood products compared to transportation; the characterization of exposure patterns is made richer by the inclusion of a variety of summary statistics. It should be noted that although data is stratified by industry, these do not represent homogenous exposure groups; there is substantial exposure variability within each industry. The cumulative compression values are slightly higher than those found by Norman et al in automotive assembly [7] and Village et al in health care workers [3]. Total work-shift cumulative compression is slightly higher than 8-hr corrected cumulative compression since three of the workers had shifts greater than 8 hours. Long shifts (9, 10, and 12 hours) are relatively common in heavy industry and should be considered when calculating daily exposures. The proportion of time spent above 3400N and 6800N of spinal compression is particularly telling, as order-of-magnitude differences suggest an increase in peak loading in wood products when compared to transportation. It is anticipated that a palette of summary statistics (similar to that used here) will provide insight when analyzing groups with more subtle differences in exposure.

The higher values in the RCMS and RMD for EMG-estimated compression compared to RCMS and RMD likely reflect the higher frequency of oscillation in muscle activity compared to trunk posture. A higher frequency signal has more peaks per unit time, resulting in more lineal length to contribute to RCMS and more peaks to contribute to RMD. Despite the very different measures recorded by the Virtual Corset (postural angle) and the EMG (muscle voltage), calibrating each measure using standard positions and lifts against WATBAK-estimated compression gives remarkably similar estimates of compression over the workshift. Median spinal compressions estimated using data from the two instruments had a correlation of 0.89 (data from both industries combined). According to Shultz et al [9] "…even a rough estimate of the loads generated by an activity will usually suffice for the solution of practical problems." Given the variances in compression between the work groups, the inclinometer could be a low-cost alternative to EMG measures for use in industry, and allow for description of workplace exposures in terms of a 'common metric' as described by Wells [2]. Further work using larger sample sizes will allow statistical testing to determine whether similar conclusions about variances in compression are reached when using the inclinometer and the EMG data. Although estimation of spinal compression from posture data excludes external loading from the estimate, some jobs contain mostly postural stress with relatively little manual materials handling. In these cases, the inclinometer may be an adequate estimate of exposure. Future analysis will investigate the job- and task-based determinants of suitability of this method. The next steps for this project will involve applying signal characterization methods to the entire EMG/inclinometer exposure databank and identifying and describing exposure differences between all five industries.

Estimating spinal loads using biomechanical models has its limitations. The biomechanical model used was 'quasi-dynamic' and sagittal, although workplace tasks are generally dynamic and frequently asymmetrical. Although static modelling underestimates the load of dynamic tasks by 19-200% [1], it is unclear if estimates based on a static calibration would over or underestimate dynamic loads, given that the EMG activity is also higher under dynamic conditions. The EMG calibration also assumes a linear relationship between muscle activity and muscle force, which is largely supported by the literature. What is more controversial is that EMG also uses muscle force from a single muscle group to estimate spinal compression. Constraining the y-intercept to be the unloaded standing compression assumes that the compression does not go below this level, which is reasonable when lying-down postures or spinal traction are not expected.

This study developed automated direct measurement techniques to collect information on low back exposures over a full work shift and automated analysis techniques to determine daily exposure patterns of peak and cumulative joint loading. Overall, the summary statistics distinguish between exposures in these two industries and characterize exposure variability and central tendency. The data suggest the possibility of using inclinometer data to estimate spinal compression.

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