Modeling determinants of working exposures and exposure variability

Catherine Trask\textsuperscript{a}, Mieke Koehoorn\textsuperscript{a}, Judy Village\textsuperscript{a}, Kay Teschke\textsuperscript{a}, Peter W. Johnson\textsuperscript{b}

\textsuperscript{a} School of Occupational and Environmental Hygiene, University of British Columbia, 2206 East Mall, Vancouver BC V6T 1Z3
\textsuperscript{b} Department of Environmental and Occupational Health Sciences, University of Washington Box 357234, Seattle, Washington USA 98195

Abstract

Work-related back injuries represent 25\% of workplace injuries in British Columbia, and more than a quarter of all back strain claims are from employees in five high-risk industries: forestry, wood and paper products, construction, transportation, and warehousing. Epidemiological studies require data on physical exposures to risk factors from large numbers of individuals in order to observe exposure-response relationships and for the results to be representative and generalizable. Unfortunately, there is a tradeoff between precision and expense, with the most precise measurement methods being too expensive to use in large epidemiological studies. The overall goal of this study is to identify a suite of measurements that afford both precision and cost efficiency for large scale work-site studies of numerous physical exposures across diverse settings and occupations. This paper describes: a) the development of a conceptual model that guided the selection of key risk factors (e.g., trunk flexion) associated with back injuries and the specific exposure measurement techniques that could be used to assess risk factors (e.g. inclinometer measuring posture in degrees); b) worker recruitment strategy and participation rates by industry; and c) exposure assessment methodologies by type of exposure measurement and industry. We also describe our proposed analytical plan for comparing exposure measurement methods (direct measurements, worker observations, and self-report methods); and the construction of statistical models to evaluate the exposure methods and develop an ‘exposure tool kit’ for use in future epidemiological studies.

Keywords: work related musculoskeletal disorders, methods development, epidemiology, determinants of exposure, low back disorders

1. Introduction

Musculoskeletal disorders are a major source of workplace disability in developed countries, accounting for a considerable economic burden of illness. As an example, in 2001 in the Canadian province of British Columbia \cite{1}, there were 17,420 accepted workers’ compensation claims for back strains, representing 25.5\% of all accepted short- and long-term disability claims. There has been remarkably little variation in this proportion over the last 10 years. In the 5-year period from 1997
to 2001, back injuries accounted for 23.3% of the 3,370,562 work days lost and cost the provincial workers’ compensation system 20% of the total $3,220,900,882 wage replacement expenditures. More than 25% of all back strain claims were from employees in five high-risk industries: forestry, wood and paper products, construction, transportation, and warehousing.

This paper outlines the first phase in a program of research that will examine the etiology of back injuries in the five at-risk heavy industries and to test interventions to reduce these injuries (Figure 1). In Phase I (the subject of this paper), we are evaluating ways to recruit workers at a variety of worksites, improve exposure assessment of back injury risk factors, and identify and model the work environment factors which contribute to increased and decreased exposure levels. Based on the findings from Phase I, Phase 2 will investigate the relative importance of the many postulated risk factors and their interactions in the etiology and progression of acute and chronic back injuries in heavy industry. This data and data from Phase 1 will be used to design control measures. Phase 3 will be a randomized workplace trial of the effectiveness of the control measures.

Phase 1 addresses a persistent problem in back injury epidemiology, the difficulty of assessing exposures for large scale epidemiological studies. Epidemiological studies require exposure data on large numbers of individuals in order to observe exposure-response relationships and for the results to be representative and generalizable. Unfortunately, there is a tradeoff between precision and expense, with the most precise measurement methods being too expensive to use in large studies. Previous epidemiological studies investigating risks for occupational injuries have been criticized for gross measurement of physical demands (reliance on job title or self-reports) at the expense of sample size, or for small sample sizes to allow detailed physical demand measures [2]. Likewise, brief direct measurement sampling can be unrepresentative [3] since it neglects to address the temporal variations in exposure throughout the work day [4, 5]. The goal of this study is to identify the suite of measurements that will allow the most efficient and accurate collection of exposure data for epidemiological studies and predictive exposure modeling, and to develop an “exposure assessment tool kit” to facilitate future research.

2. Methods

2.1 Development of conceptual model and methods

Initially a literature review was conducted to identify the risk factors which have been consistently found to be related to work-related back pain and back disorders. Based on this review, we constructed a conceptual model (Figure 2) of risk factors where there was strong or consistent evidence for an association with back injuries. These factors were categorized as occupational physical exposures (working postures; repeated lifting and heavy lifting; whole body vibration); psychosocial factors (e.g., job satisfaction, control, support); and personal factors (age and length of job tenure; body condition and morphology including weight, height, physical condition, body type; smoking; and previous injury). For the purposes of our study, we focused on the measurement of the physical exposures.
We conducted a literature review to identify risk factors which have been consistently found to be related to back disorders. These risk factors (see Figure 2) formed the framework for the decision making process about which risk factors to measure in an epidemiological study: work postures, materials handling, and whole body vibration. These factors were further evaluated for feasible measurement methods in heavy industries. Different measurement methods were designed, tested, and piloted on a convenience sample of 7 university utility operations employees with multiple exposures, with iterative refinement after each sampling trial. A final “battery” of methods that was feasible for full-shift (8 hours) on-site use and flexible enough to measure risk factors in a wide variety of work environments (e.g. grain elevator, helicopter, log boom, etc.) was adopted.

2.2 Data collection

Statistical cross-comparison of methods depends on concurrent measurement of a work shift with several different measures. This study employed a combination of direct measurement, observation, and self-report methods to compile an exposure data bank for comparison of methods in heavy industry.

2.2.1 Whole body vibration

Whole body vibration (WBV) intensity, frequency, direction and duration were measured according to the guidelines of the 200X ISO 2631:1997 guidelines. A Larson Davis triaxial seatpan accelerometer and Larson Davis HVM100 Monitor (Larson Davis Laboratories, Provo, UT, USA) collected measurements at a rate of 14,400 Hz throughout periods of vehicle use during the workshift. During work breaks and at the end of the workshift, these data were downloaded to a laptop computer.

2.2.2 Posture measurements

Continuous posture measurements, in two dimensions relative to gravity, were made using a Virtual Corset (VC-323, Microstrain, Inc., Willeston, VT, USA). The Virtual Corset consists of two low-pass filtered accelerometers (inclinometers) packaged in a battery powered, pager-sized logger harnessed tightly to the trunk at the level of the T6 spinous process. Static and dynamic lateral flexion (frontal plane) and flexion-extension of the trunk (sagittal plane) movements were recorded relative to gravity at a rate of 7.5 Hz. Posture was measured throughout the shift and subsequently downloaded to a laptop computer.

2.2.3 EMG

Electromyography (EMG) was measured using a portable data collection system (ME3000 P4 and ME3000P8, Mega Electronics, Kupio, Finland). The raw EMG signals were filtered internally using an 8-500 Hz band pass filter and using a 100 ms moving window, the processed EMG signal was saved at 10 Hz. Disposable Ag-AgCl electrodes were placed over the erector spinae with an interelectrode distance of 20mm at approximately the level of L4/L5, with a ground electrode and preamplifier on the posterolateral aspect of the iliac crest. Workers were positioned in various postures with and without loads in order to calibrate and normalize the EMG signals. Data were downloaded from the EMG monitor onto laptop computers during work breaks.

2.2.2 Observations

Observations of physical exposures were made by trained observers once every minute triggered by a pre-set vibrating watch throughout the shift excluding work breaks, starting after the pre-shift instrumentation of the worker and ending just prior to de-instrumentation at the end of the shift. Data were recorded on paper using a coding system to indicate general task or activity, item or power tool in hands, items worn (such as a tool belt); trunk posture, general body posture (such as standing, walking, kneeling), presence of trunk support, lateral
bend or twist, type of manual materials handling (horizontal distance, weight and force estimate), and any additional pertinent comments. Where practicable and with worker permission, digital photographs were taken of unique worksites, tools, postures or handling methods.

When vehicles were used by workers, observations included vehicle type, terrain and slope, speed, driving style, and vehicle load. Vehicle information was also recorded, including type of vehicle, operating duration, gross vehicle weight, wheel characteristics, type of transmission, seat type and suspension type, back support, armrests, and location of cab in relation to the load. Where possible, photos were taken of the vehicle and where applicable, the seat area and tires.

2.2.3 Participant self-report

A post-shift interview was conducted with the worker to assess self-reported exposures of the work shift. Workers were asked to identify and give estimates of durations of their work postures from simplified drawings of representative postures, materials handling activities, and vibration activities. A short health history section summarized current and previous back pain and associated disability using selected instruments from the Nordic Questionnaire [6].

2.3 Subject recruitment and sampling strategy

The Workers’ Compensation Board identified a random sample of 50 employees in the Greater Vancouver area who had had an accepted workers’ compensation claim for back strain in 2001 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 their worksite. At each site, an additional 1 to 5 co-workers were also invited to participate. Wherever feasible, one follow-up measurement was made of each worker for a total of two full-shift measurements per individual.

2.4 Development of the exposure ‘toolkit’

The analysis to investigate the relationships between the various types of measurement methods (i.e. self-report, observation, and direct measure) is underway. We are evaluating the validity of self-report and observation measures against the direct measures. Validity will be assessed against the quantitative measures using sensitivity and specificity for categorical observation or self-report variables and the proportion of variance explained by a linear relationship for continuous variables. Multiple regression analyses will be used to determine whether combinations of the observation and/or self-report variables can be used to predict the direct measurements.

3. Results

3.1 Conceptual Model of Occupational Exposure and Low Back Injury

Based on consistent evidence in the literature, we identified specific task, equipment, and workplace characteristics associated with low back pain as illustrated in Figure 2. These were the focus for our direct measurement, direct observation and self-report data collection techniques.

3.2 Study participants

A total of 126 individual workers (53 workers with claims and 73 co-workers) from 49 separate worksites were measured. This resulted in 223 measurement days, with repeated measures on 77% of workers. Distribution of worker/co-worker recruitment and duplicate measures are presented by industry in Table 1.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Number of workers with back injury claims (% with follow-up measures)</th>
<th>Number of co-workers (% with follow-up measures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>14 (64.3)</td>
<td>10 (90.0)</td>
</tr>
<tr>
<td>Forestry</td>
<td>6 (66.7)</td>
<td>18 (77.8)</td>
</tr>
<tr>
<td>Transportation</td>
<td>11 (81.8)</td>
<td>19 (78.9)</td>
</tr>
<tr>
<td>Warehouse</td>
<td>13 (84.6)</td>
<td>10 (90.0)</td>
</tr>
<tr>
<td>Wood products</td>
<td>9 (66.7)</td>
<td>16 (68.8)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>53 (73.6)</td>
<td>73 (79.4)</td>
</tr>
</tbody>
</table>

3.3 Exposure database

As shown in Table 2, the data collection phase resulted in a substantial bank of concurrent
measurements for use in assessing the validity and reliability of the various measurement metrics. This database has additional utility as a data source for future investigations of relationships between exposure variables.

Table 2
Number of measurement days with vibration, posture, EMG, observation, and interview measurements by industry

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>F</th>
<th>T</th>
<th>W</th>
<th>WP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days with Vibration Data</td>
<td>2</td>
<td>26</td>
<td>27</td>
<td>29</td>
<td>12</td>
<td>96</td>
</tr>
<tr>
<td>Days with Posture Data</td>
<td>41</td>
<td>41</td>
<td>54</td>
<td>33</td>
<td>41</td>
<td>210</td>
</tr>
<tr>
<td>Days with EMG Data</td>
<td>37</td>
<td>35</td>
<td>42</td>
<td>27</td>
<td>33</td>
<td>174</td>
</tr>
<tr>
<td>Days with Observation Data</td>
<td>42</td>
<td>41</td>
<td>54</td>
<td>43</td>
<td>42</td>
<td>222</td>
</tr>
<tr>
<td>Days with Interview Data</td>
<td>39</td>
<td>42</td>
<td>52</td>
<td>43</td>
<td>42</td>
<td>218</td>
</tr>
</tbody>
</table>

*C = construction, F = forestry, T = transportation, W = warehousing, WP = wood products

3. Discussion

Recruitment showed some variation across industries, with forestry and wood products being more difficult for recruitment of eligible workers and gain access to a worksite. This may be related to a general decline in these industries within the province; an aging workforce was evidenced by the large number of contacted workers who had retired. Follow-up proved most difficult amongst the workers with claims in construction, forestry, and wood products. The temporary and transient nature of building projects combined with a predominance of self-employed sub-contracting workers made contacting workers challenging; mill shut downs and frequent layoffs complicated efforts to follow-up workers in forestry and wood products.

The coverage of measurements across industries reflects challenges applying some methods in some environments. Only 64% of workers used vehicles, decreasing the number of vibration measurements possible; in particular, there was little vibration exposure in construction. In hospitable conditions included freezing (-27°C) conditions which caused condensation in circuitry and stopped ink flow in pens; extreme dust found in saw mills and grain elevators clogged instruments and presented an explosion hazard; extreme heat and heavy workloads resulted in problems adhering electrodes to the skin; and coastal rains soaked all equipment at outdoor sites. Field measurement was, on the whole, very demanding on the direct measurement equipment, and on several occasions sampling was stopped to allow for repairs. Paper measures were less prone to environmental interference, but observers faced safety concerns on log booms, in confined spaces, or during tree falling; loud and vibrating environments made it difficult to attend to the sampling interval. During the interview, many workers expressed reluctance to estimate exposure and a desire to match the observer’s record.

It might be argued that there is an inherent circularity in using scientific literature to suggest potential causes of back injury for the purpose of later describing the relationship between the cause and back injury. However, scientific methods are by nature iterative, and there is still much to be learned about the physical risk factors for back injury. The methods presented here will eventually allow for more detailed measurement of exposures and investigation of back disorder etiology in the second phase of the research, including an expanded understanding of the dose-response relationships with physical exposure limits.

Future work will complete the comparison analysis and provide recommendations for efficient and effective combinations of measurement techniques by physical exposures. It is anticipated that with more efficient yet comprehensive assessment of risk factors for back injury, relationships between exposure and disease will be more easily observed leading to the development of effective prevention strategies.

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References