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A posture and load sampling approach to determining low-back pain risk in occupational settings

W.P. Neumann[a,*], R.P. Wells[a], R.W. Norman[a], J. Frank[b,c], H. Shannon[b,d], M.S. Kerr[b,c], the OUBPS Working Group[e]

[a] *Department of Kinesiology, University of Waterloo, Waterloo, Ont., Canada N2L 3G1*
[b] *Institute for Work and Health, Toronto, Canada*
[c] *Department of Public Health Sciences,University of Toronto, Canada*
[d] *Department of Clinical Epidemiology and Biostatistics, McMaster University, Hamilton, Ont., Canada*
[e] *Ontario Universities Back Pain Study, Ont., Canada*

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Abstract

A posture and load sampling approach to measure physical exposures was implemented within a case-control study of low-back pain reporting. The purpose of this paper was to determine how well this method was able to identify known low-back pain risk factors. Subjects, including both cyclic production and non-cyclic support workers, were studied while working in an automotive assembly facility. The study included 104 (with 20 proxies) cases, workers who reported low-back pain at work, and 129 randomly selected controls. Results indicate significant associations between low-back pain reporting and peak spinal loads (OR = 2.0 for compression), shift-average spinal loading (OR = 1.7 for compression), percent of time with loads in the hand (OR = 1.5), maximum flexion angle (OR = 2.2), and percent of time spent forward flexed beyond 45°(OR = 1.3). Posture and hand load variables, considered to be intermediate exposure variables, were handled separately in multivariable regression analyses from variables of peak and average spine force which directly estimate tissue loading. The work and posture sampling approach is particularly useful for heterogeneous work situations where traditional task analysis is difficult and can provide information on work and tissue load parameters which have been directly associated with risk of reporting low-back pain.

Relevance to industry

This paper demonstrates the effectiveness of an observational method in quantifying workplace exposures to physical risk factors for low-back pain. The method works for both cyclic and non-cyclic work. Quantified risk assessment provides key information for decision makers trying to control injury rates in industrial systems.

Keywords: Exposure assessment; Work sampling; Low-back pain; Posture; Load; Occupational biomechanics; Epidemiology

1. Introduction

A wide variety of variables have been studied in an effort to understand the risk factors associated

*Corresponding author.
E-mail address: pneumann@ts.mah.se (W.P. Neumann).

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with low-back pain (Garg, 1989; Bongers et al., 1993; Hagberg et al., 1995). A recent review by the National Institute for Occupational Safety and Health (NIOSH) (Bernard, 1997) has acknowledged that there is evidence for awkward postures (pp. 6–26), there is evidence for heavy physical work (pp. 6–12), and there is strong evidence for lifting and forceful movements (pp. 6–20) as risk factors for low-back pain (LBP). Recently, Norman et al. (1998) have shown that, among the physical loading factors considered, variables tended to cluster in four independent categories: peak spinal loads, accumulated spinal loads, forces in the hands, and trunk kinematic (postural) variables. Variables contributed independently to the risk estimates between categories while within each category variables were highly inter-correlated and thus found to be mutually exclusive in multivariable regression analyses. While the risk factors identified by Norman et al. (1998) are more clearly defined and precisely measurable than the category of "heavy physical work" used by necessity in the NIOSH review, both approaches are consistent with the underlying hypothesis that an injury occurs when the body's tissues are subjected to more load than they can withstand. Since tissue tolerance cannot be measured in vivo (Van Tulder et al., 1997), injury prevention efforts must rely on the ability to measure workplace exposure to physical loading to assess possible risk. This raises the question: how can we effectively measure physical exposures in the workplace?

The purpose of this paper is to determine how well an observational work and posture sampling technique was able to identify known low-back pain risk factors. Data presented in this paper come from part of an epidemiological study of low-back pain reporting. The Ontario Universities Back Pain Study (OUBPS) was a case-control study, employing an incidence density sampling strategy, run over two years in a large automotive assembly facility. The study included detailed measurements of biomechanical, psychophysical, and psychosocial variables and has shown all three of these to be strongly and independently associated with risk of reporting low-back pain at work (Kerr et al., in press), a finding that has been separately supported by other researchers (Wickström and Pentti, 1998; Smedley et al., 1995). The biomechanical measurement battery included self-report questionnaires, detailed observer checklists, digital video analysis, detailed biomechanical modelling, electromyography, and a posture and load sampling technique. The test battery was designed to facilitate inter-method comparisons by measuring known risk factors in consistent units of measurement (Wells et al., 1997; Neumann et al., 1999). The assessment of the performance of each of the methods used in this study is a necessary step for evaluating the relative performance of each tool's ability to assess workplace exposure. The posture and load sampling method, which was developed to quantify the postures, hand loads, and spinal loading during both cyclic and non-cyclic work (Wells et al., 1995), will be examined within the context of this larger epidemiological study. Specifically, this posture and load sampling assessment method will be examined for its ability to identify risk associated with known low-back pain risk factors.

2. Methods

2.1. Risk-relationship study

The study was run in a large automobile assembly facility with a study base of over 10,000 hourly paid workers. Incident cases were identified as they reported to the plant nursing station with low-back pain. Cases were not required to have any lost time due to their LBP. Controls were selected randomly from the hourly paid employee roster. Both cases and controls were screened to have had no LBP reports in the previous 90 days. When a case was not available for a physical loading assessment, a worker doing the same work tasks as the unavailable case was recruited and their physical loading data were used as a "proxy" to the missing case (cf. Punnett et al., 1991). The use of proxy data for workplace physical loading variables assisted with maintaining overall study power in situations where injured workers did not return to their previous job tasks. In total 129 controls and 104 cases (including 20 "proxies") were studied using a detailed battery of physical loading measures while the participant performed their regular work. Participants included both online production workers whose jobs had regular cycle times as well as support and maintenance workers whose jobs might have no regular cycle. This paper will report only on the results from the work and posture sampling exposure measurement method.

2.2. Posture and load sampling method

For each observation an observer recorded the trunk posture (13 categories), horizontal hand position (close, medium or far), hand force amplitude (6 categories), and hand force direction (4 directions) using categorical scales provided. These categories were simultaneously recorded with single mark on the paper work sheet which is presented in the appendix. The analyst was required to observe the worker and then select the set of posture and load categories which, in the observer's judgement, best represented the spinal loading of the worker in that instant. Operators, all of whom had university education in Kinesiology, were trained both in laboratory and field settings in the use of the checklist until their performance was judged to be satisfactory by a senior research term member. Observations were made every 10–20 s with a randomized interval, which was indicated using a pre-recorded audiotape, until over 250 observations were made. If a worker did several different kinds of work during a shift then separate work sampling forms would be completed for each type of work and a time-weighted combination of these sheets would be generated to provide exposure distribution estimates for the complete shift.

2.3. Biomechanical post-processing

For each observation cell in the work sampling matrix (posture, hand distance, load amplitude, direction of force) a biomechanical analysis was run, based on male and female median Canadian population heights and weights (Canadian Standardized Test of Fitness Operations Manual, 1986), to determine the lumbar compression, moment, and joint shear values at the L4/L5 level associated with each posture and load combination. The biomechanical model of the lumbar spine used was a quasi-dynamic, two-dimensional linked segment model with 15 segments. Technical details of the model are described in Norman et al. (1998). Automated "look-up" tables were created using the spinal load associated with each posture and load category. This allowed the spinal load estimate of moment, compression, and shear force corresponding to each sample to be tabulated along with the postural and hand load information.

The work sampling data were then processed to provide summaries of the posture, external load, and spinal loading exposures for the worker. Posture ranges from the sampling form were collapsed into ranges selected to be directly comparable to those used in a previous research study in a similar environment (Punnett et al., 1991). External load information was also summarized as a percentage of time in which forces greater than 1 kg were present. The distribution of spinal loading estimates were examined by creating an amplitude probability distribution function (APDF, per Jonsson, 1982) based on all the samples taken. Lumbar spinal loading levels at the lower (0, 1, 10 percentile), median (50 percentile), and peak (90, 99, 100 percentile) were extracted for statistical analysis. These seemingly duplicate variables were included to allow examination of which data processing methods proved most sensitive to group differences. The percent of time spent in posterior shear, with flexor moments, and the percent time spent with compression levels above the NIOSH action and maximum permissible limits (NIOSH, 1981) of 3433 and 6376 N of spinal compression were also recorded. The complete list of exposure variables examined from the work sampling method is presented in Table 1.

2.4. Tool reliability

Inter-observer reliability of the tool was assessed (Edmondstone et al., 1996). Four experienced observers each analysed 10 jobs on video tape with sampling cues recorded directly on the video tapes. Of the 10 jobs used, seven were

Table 1
Exposure variables from the posture and load sampling method examined for LBP risk relationship for cases and controls using a t-test

	Case			Random controls			t-test p-value
	N	Mean	Std Dev	N	Mean	Std Dev	
Compression: minimum (N)	104	391	109	129	406	115	0.3143
Compression: 1%ile (N)	104	446	104	129	441	117	0.6933
Compression: 10%ile (N)	104	545	104	129	540	95	0.6755
Median compression: 50%ile (N)	104	736	171	129	698	142	0.0674
Peak compression: 90%ile (N)	104	1498	524	129	1287	420	0.0010[a]
Peak compression: 99%ile (N)	104	2500	836	129	2153	706	0.0007[a]
Peak compression: 100%ile (N)	104	3293	1275	129	2686	1007	0.0001[a]
% Time in flexor moment postures	104	3.3	6.1	129	3.5	7.0	0.8542
Peak flexor moment: 100%ile (N m)	75	38	34	89	35	28	0.6056
Peak flexor moment: 99%ile (N m)	49	31	34	61	25	24	0.2869
Peak flexor moment: 90%ile (N m)	10	37	42	13	12	8	0.0982
Median (extensor) moment: 50%ile (N m)	104	20	10	129	18	7	0.0574
Peak extensor moment: 90%ile (N m)	104	64	32	129	52	26	0.0019[a]
Peak extensor moment: 99%ile (N m)	104	129	51	129	108	45	0.0012[a]
Peak extensor moment: 100%ile (N m)	104	178	77	129	141	61	0.0001[a]
% Time in posterior shear postures	104	53.0	19.5	129	51.9	19.7	0.6734
Peak posterior shear: 100%ile (N)	104	114	73	129	91	61	0.0084[a]
Peak posterior shear: 99%ile (N)	104	76	59	129	57	38	0.0049[a]
Peak posterior shear: 90%ile (N)	101	27	25	125	22	20	0.0626[a]
Median (anterior) shear: 50%ile (N)	42	12	13	52	10	10	0.5730
Peak anterior shear: 90%ile (N)	103	58	49	127	45	43	0.0379[a]
Peak anterior shear: 99%ile (N)	104	145	81	129	127	54	0.0518
Peak anterior shear: 100%ile (N)	104	192	135	129	165	92	0.0889
% time over AL (3433 N compression)	104	0.5	1.0	129	0.2	0.6	0.0120[a]
% time over MPL (6376 N compression)	104	0.0	0.0	129	0.0	0.0	—
Average load: compression (N)	104	900	205	129	826	159	0.0031[a]
Average load: extensor moment (N m)	104	29	12	129	25	9	0.0032[a]
Average load: flexor moment (N m)	104	0.9	2.8	129	0.7	1.3	0.3691
Average load: anterior shear (N)	104	19	15	129	15	11	0.0458[a]
Average load: posterior shear (N)	104	9.1	6.7	129	6.9	5.2	0.0052[a]
Maximum forward flexion (deg)	104	69.8	25.8	129	60.6	27.2	0.0090[a]
Neutral: 0–15° (% time)	104	79.5	14.7	129	82.5	12.8	0.1037
Mild flexion: 15–45° (% time)	104	11.7	10.0	129	9.1	9.1	0.0415[a]
Severe flexion: 45 + deg. (% time)	104	4.0	5.2	129	2.6	4.2	0.0206[a]
Twist or lateral bend > 20° (% time)	104	4.5	5.9	129	5.5	6.9	0.2887
Twist > 20° (% time)	104	2.3	4.4	129	1.8	3.4	0.3935
Lateral bend (% time)	104	2.3	3.0	129	3.6	6.0	0.0255[a]
Extension < 0° (% time)	104	0.8	2.4	129	0.7	2.3	0.7016
Maximum hand force (kg)	104	18.4	8.6	129	15.0	9.0	0.0042[a]
Load bearing > 0 kg (% time)	104	26.0	21.8	129	20.0	16.7	0.0210[a]

[a] Indicates significant ($p < 0.05$) differences between cases and controls.

production work with regular cycles ranging from 1 to 4 min, while three were non-production work without any regular cycle of activity. This approximated the distribution of jobs observed in the epidemiological investigation. Comparison of this sub-set of jobs to the main database indicated that the exposure amplitudes from the reliability test set tended to be slightly higher but were within 1.5 standard deviations of the main database. This suggests that the jobs used to assess the tool's reliability formed a realistic sample of jobs used to determine risk relationships. Intra-class correlation coefficients were used to indicate the similarity of results from different observers. Measurement of the percent of time in moderately flexed postures and twisted or laterally bent postures showed substantial inter-observer reliability (ICC = 0.69 and 0.66, respectively). The percent of time spent in neutral or severely flexed postures as well as both the peak and average spinal compression levels showed excellent reliability with ICCs ranging from 0.82 to 0.92.

2.5. Statistical analysis

All variables were initially examined with a Student's *t*-test for significant differences between cases and controls. Initial analysis revealed one subject with results over five standard deviations from the group mean, closer examination revealed possible procedural errors and that subject's data were subsequently excluded. Variables which showed significant differences with case status were analysed for the strength of association using bivariable logistic regression to calculate the odds ratio. Exposures with negative values (e.g. posterior shear) were converted to positive values for the logistic regression calculations. Odds ratio amplitudes were calculated using exposure differences equal to the inter-quartile spread (IQS) of the randomly selected jobs. This normalization facilitated relative comparison of the odds ratio amplitudes between continuous variables that had different units of measurement (Norman et al., 1998).

Logistic regression modelling procedures, using backward selection, were used to investigate the multivariable relationship to LBP risk. Variables were submitted to the modelling procedure "as is" without any transformation procedures. To avoid over-restricting the models, all variables that met a significance of contribution better than $p = 0.10$, rather than 0.05, were retained. Odds ratios for each of the variables left in the multivariable model and the combined risk for exposure to all of the variables in the final model were calculated. Initial modelling revealed some instability in the model due to correlations among the variables submitted to the multivariable analysis. A theoretical model of the injury pathway was used to stratify variables into separate hierarchical levels (per Victora et al., 1997). The model illustrates how tissue can be damaged when the loads applied to tissue exceed their tolerance level. The theoretical model (Fig. 1) suggests that spinal tissue loading is a result of the postures adopted and hand forces (loads) exerted while performing work actions. Since the biomechanical model (WATBAK) calculated spinal loading estimates using posture and hand load as inputs, some correlation between these variables would result. When data from other measures used in this study were examined for example, Peak hand force was moderately correlated with peak spine compression, moment and shear loads at $r \sim 0.58$–0.66 (from Norman et al., 1998). Similarly, the percent of time spent flexed $> 45°$ tended to correlate with 90 percentile compression, moment and shear forces $r \sim 0.57$–0.80. Correlations among exposure variables would restrict the number of variables which retain significance in a multivariable model. While this would result in a minimum risk factor set, it tended to eliminate specific risk factors which could be acted upon to improve work design in a particular industrial situation. This problem was avoided by analysing the work action

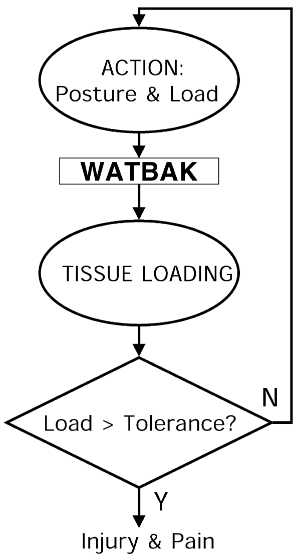

Fig. 1. Theoretical injury model used to stratify exposure variables in the multivariable analysis. Tissue loading parameters were calculated from posture and hand force inputs using the WATBAK biomechanical model. These two types of exposure variables were analysed separately in multivariable analysis.

variables (posture and hand load) separately from the spinal load estimate variables in two separate multivariable logistic regression procedures. This approach was similar to structural equations modelling in strategy (Witte et al., 1994) but was better suited to the relatively small sample sizes and complex inter-relationships found in occupational biomechanical exposure databases such as the one used in this study.

3. Results

Table 1 summarizes the results of the Student's "*t*" test. Peak spinal loading estimates, shift-average spinal loading estimates, trunk kinematics, and hand load variables showed significant differences between cases and controls. Exposure variables which did not show significant differences between the groups studied included median spinal load, low-level compression (as indicated by the APDF's 10 percentile), trunk flexor moments, postures near neutral, and the percent time spent twisted. Some of these variables had very low exposures in both groups and may not have been relevant in this work situation. Generally, the single highest instant of loading, the 100th percentile from the APDF, showed stronger group differences than did the 99th or 90th percentiles. In order to reduce duplication of variables, the absolute peak loading variables (100th percentile) for each individual were used exclusively for all further analyses. The bivariable odds ratios for variables which showed significant differences on the *t*-test are presented in Table 2. These were calculated using an exposure difference equal to the inter-quartile spread of the random controls.

The first multivariable model, which examined posture and hand loads variables, identified the maximum flexion level, percent of time exerting hand forces, and the percent of time twisted as risk factors (Table 3). Odds ratios for these factors ranged from 1.3 to 2.2 for the exposure differences used. The posture and load multivariable model also included the percent of time spent in either twisted and/or laterally bent postures as a protective factor with an odds ratio of 0.5 indicating less exposure among cases than controls. The protective effect appeared to be driven by the percentage of time spent in lateral bent postures which showed significant differences in the *t*-test results (Table 1). The average levels of exposure to lateral bending were low in the workforce studied at 2.3% and 3.6% of time for cases and controls, respectively.

The second multivariable model, which examined spinal tissue loading variables, identified peak moment, average anterior and posterior shear

Table 2
Bivariable odds ratios (OR) and 95% confidence intervals (95% CI) for significant risk factors variables were calculated using an exposure difference (Unit) equivalent to the inter-quartile spread of the randomly selected subjects

Variable	−2 Log *l* Chi-Square	Unit	OR	95% CI
% Time over 3433 N compression	7.72	0.3	1.2	1.0–1.4
% Time over 200 N m moment	8.85	0.0	1.0	1.0–1.0
Average load: compression (N)	8.92	250	1.7	1.2–2.5
Average load: moment (N m)	8.33	13	1.6	1.2–2.3
Average load: posterior shear (N)	9.16	7	1.7	1.2–2.4
Peak load: compression (N)	17.00	1433	2.0	1.4–2.9
Peak load: moment (N m)	17.63	68	1.8	1.3–2.4
Peak load: posterior shear (N)	8.12	82	1.6	1.2–2.3
Peak load: (1%ile) anterior shear (N)	4.66	94	1.5	1.0–2.4
Peak load: max. wt. (kg)	8.71	12	1.7	1.2–2.5
% Time severe flexion (45 + deg)	5.54	4.4	1.3	1.1–1.8
% Lateral bend	4.79	3.7	0.8	0.6–1.0
% Time loaded (load > 0 kg)	4.52	28	1.5	1.0–2.2
Maximum forward flexion (deg)	6.93	60	2.2	1.2–4.1

Table 3
Results of the multivariable logistic regression modelling using backwards elimination selection for (1) work performance variables and (2) Spinal loading variables. Odds ratios (OR) were calculated using exposure differences equal to the inter-quartile spread from the random control subjects. The posture and load variables model performance characteristics were: R-square = 0.11, Concordance = 64.9%, -2 Log l Chi-Square = 20.21. The Spinal loading variables model performance characteristics were: R-square = 0.15, Concordance = 68.7%, -2 Log l Chi-Square = 27.8

	Exposure Diff.	OR	95% CI
Multivariable model 1: posture and load variables			
% Twist or lateral bend	6.5	0.5	0.3–0.9
% Twist	1.7	1.3	1.0–1.5
% Time loaded	25.6	1.7	1.2–2.4
Max. forward flexion (deg)	60	2.2	1.2–4.1
Multivariable model 2: spinal loading variables			
Peak moment (N m)	70.9	1.5	1.2–2.1
Ave. anterior shear (N)	10.4	1.3	1.1–1.7
Ave. posterior shear (N)	6.2	1.6	1.2–2.3

forces as independent LBP risk factors from this sub-set of variables (Table 3). Odds ratios for these variables ranged from 1.3 to 1.6 when calculated using an exposure difference equal to the random controls' inter-quartile spread.

4. Discussion

The work sampling technique has confirmed, in bivariable analysis, the importance of peak spine load, cumulative spine load (as represented by the shift-long average), hand forces, and posture as risk factors for low-back pain. Peak spine load as measured in the compressive, extensor moment, and both posterior and anterior shear modes showed significant and substantial odds ratios. These are, at the group level, similar in amplitude to those reported in Norman et al. (1998) using data from different methods. These results are also compatible with the findings of Marras et al. (1993, 1995) who identified peak load moment as the single strongest predictor in their data set. Although not directly comparable, these findings also complement the findings of earlier studies which the NIOSH review (Bernard, 1997) called "lifting and forceful movements"; work situations which can arguably be said to result in large forces in the spine. Similarly, the significant odds ratios for maximum hand load, as measured by the posture and load sampling tool, are compatible with the findings of the previously mentioned research.

The NIOSH (Bernard, 1997) review's findings of "heavy physical work" as an important class of physical risk factor variables can be seen as related either to peak or cumulative spinal loading as measured in this study. Cumulative loading of spinal tissues is directly comparable to the shift-long-averaged spinal load variables identified using this technique and has been previously shown to be associated with LBP (Norman et al., 1998; Kumar, 1990). It is worth noting that, for peak and average spine loading, all loading modes showed significant case-control differences with the exception of peak and average anterior shear which were marginally significant and trunk flexor moment which were uncommon in the work studied and not significant. Reaction shear is the force calculated using link segment mechanics, while joint shear is a net resultant force calculation which considers both the reaction shear and also tissue forces. The sampling approach reported in this paper used a joint shear calculation. This is different from other measurement approaches in this case-control study which calculated "reaction" shear (Neumann et al., 1999). The joint shear calculated in this method did not show risk relationships as strong as those observed by other methods used in this study which assessed spinal loading using a reaction shear calculation (Norman et al., 1998).

Interpretation of the trunk postural variables from this study is more complex. As may be expected, neutral, or postures of less than moderate flexion ($<45^\circ$ inclination) categories showed no association with low-back pain. Extreme levels of trunk flexion, beyond 75°, occurred infrequently in this population and did not show statistical associations with risk when considered as separate categories. However, the peak flexion level, defined as the most extreme flexion posture category observed, was a significant risk factor and is consistent with previous findings for this study site from an independant, digital video analysis-based measurement method (Norman et al., 1998). The percent of time spent in intermediate levels of flexion (45–75°) or combined categories of severe flexion (>45°) also showed substantial and significant associations with risk. These findings support the NIOSH review (Bernard, 1997) which cited 11 of 12 studies as having identified "awkward postures" as a risk factor for low-back pain. These findings are also compatible with the reports of Punnett et al. (1991), who identified percent of time flexed as a risk factor, and Marras et al. (1995) who identified a number of kinematic exposure variables which were strongly linked with low-back pain in industrial environments.

The percent of time spent in lateral bending postures showed an unexpected protective effect in bivariable analysis. The percent of time spent laterally bent was small (under 4% of time) for both groups. This small amount of bending is inconsistent with the large loads and extreme deviations associated with other postural variables (e.g. Peak flexion level) which would lead to overloading of local tissues. Marras et al. (1995), reporting exposure differences between low-, medium- and high-risk jobs, found that low-risk jobs had slightly higher maximum left bending than did medium- or high-risk jobs. In Marras' study the exposure in all groups was also very low and was marginally significant for medium risk and not significant compared to high-risk jobs. For this variable the linear risk association assumed by logistic regression models may be incorrect. It is biomechanically improbable that extreme amounts of lateral bending will prevent low-back injury.

The use of categorical data can present complications in multivariable analyses where variables might disappear as insignificant or re-appear as significant depending on the classification scheme used (Hagberg, 1992). Additionally, the presence or absence of covariates and even the selection method used may change the variables which enter a multivariable model. The models presented here suggest complex inter-correlations among variables which tend to preclude each other from entering a multivariable model. Other researchers have also reported this tendency for risk factors to exclude each other in multivariable analyses. Svensson and Andersson (1989), for example, found that the "forward bending" risk factor, significant in bivariable comparisons, was dropped in covariate analyses in favour of the psychological variable "fatigue at the end of the work day". Of the 11 studies which NIOSH (Bernard, 1997) suggests have identified awkward postures as a risk factor three studies found that these variables were supplanted by others in multivariable analyses. These findings provide interesting insight into the possible interrelationship of variables in the data set but tend to hide potentially useful paths of action in reducing exposures to risk factors. For example, by adjusting the work to reduce the amount of forward bending the workers may well be at reduced risk of injury and may additionally report less feelings of fatigue since repetitive or prolonged forward bending is fatiguing. Exposure variables which are shown to be significant risk factors in bivariable analysis, and which are excluded from multivariable models due to multicollinearity, should not be ignored as potentially useful indicators for guiding ergonomic intervention. In the analysis presented in this paper a theoretical causal pathway was used to stratify multivariable analyses. By analysing the workers' posture and hand load exposure variables separately from the spinal loading variables which result from the working situation, we have attempted to provide more possible pathways for workplace intervention at different levels of the injury process. We hypothesize that such a multi-pronged prevention approach will be more effective in preventing low-back pain.

There are limitations to any epidemiological study. While steps were taken to blind the field study team to each worker's case-control status, complete blinding was not feasible. Although a baseline physical exam was conducted, this study used the behaviour of reporting pain to the plant nursing staff, only some of whom subsequently filed a compensation claim, as the main criterion for case status. Participation rates, a concern in occupational settings, were 61% among the cases and 39% among the control group. In the present study substantial efforts were made to assess the impact of post-injury reporting, use of proxy subjects for physical loading data, and job performance bias that might have biased the results reported here. No such serious biases were found to affect the final full multivariable model (Kerr et al., in press). Other potential limitations of this study include measurement errors during the 2–8 h field data collection sessions. While they remain potential sources for error, the overall impact of these factors would likely be an increase in random error which would affect both groups equally thereby reducing, rather than overestimating, the likelihood of observing differences between the cases and controls (Kerr, 1998). Although genetic factors were not directly examined in this study, no significant differences were observed on any of the individual factors such as gender, height, or weight (Kerr et al., in press). These findings do not preclude the possibility of genetic factors also contributing to the multifactorial etiology of occupationally related low-back pain, particularly with respect to the determinants of individual tissue tolerances. In spite of these limitations, consistent differences and significant odds ratios emerged across multiple measurement systems addressing workplace physical exposures (Norman et al., 1998). Differences in multivariable model results were observed in this single method analysis and other analyses conducted from the larger study (e.g. Norman et al., 1998; Kerr et al., in press). Differences in multivariable analysis can be expected when different sub-sets of variables are included in the analysis. The consistency of effect observed for biomechanical variables in the epidemiological databases (Neumann et al., 1999) confirms the importance of these factors as low-back pain risk factors.

The disadvantages of a posture and load sampling approach, as implemented in this study, include the loss of the time history of exposure samples during data collection. This could be overcome with sequential or time-linked recording of posture changes (Fransson-Hall et al., 1995). The data are also separated from specific work process and actions making it more difficult to identify possible intervention strategies. The observation process requires intense concentration during the period required to amass sufficient samples. This limits the number of workers who can practically be assessed to one or two per day. Due to the randomized sampling interval brief or infrequent, but high-intensity efforts may be missed (Richardson and Pope, 1982). The addition of a "peak load" category to the instrument could overcome this limitation without unduly affecting cumulative loading estimates.

On the other hand, the posture and load sampling method has several advantages in work-place exposure measurement. It can be applied to both repetitive cyclic work and to non-cyclic jobs. No elemental job breakdown is required to obtain exposure estimates. The tool does not require detailed ergonomics training beyond what is needed to observe the posture and load conditions. It is a non-invasive, simple measurement approach which can be applied without interference to the workers' regular duties. This method provides information on peak and average spinal loading, hand loads, and trunk postures which have been identified as key independent risk factors for low-back pain.

5. Conclusions

This paper has demonstrated the ability of an observational posture and load sampling method, with biomechanical post-processing, to quantify physical exposure in the workplace. The method has identified risk factors for reporting low-back pain of peak spinal loading, accumulated spinal loading, hand loads, and trunk postural factors. The technique used here can be readily applied to non-cyclic jobs which are difficult to analyse with task-based assessment methods. The results of the case-control study confirm these measurable work exposures as risk factors for low-back pain reporting. The paper illustrates the utility of using an injury pathway theory to conduct a multivariable analysis which can identify suitable pathways for possible intervention.

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Appendix A

This section includes a copy of the 2-page paper forms used by the field data collection team.

Flexion was defined as the absolute angle of the torso (the line between L3 and C7) with respect to the vertical in the sagittal plane. Twist was defined as the relative angle of the shoulders with respect to the pelvis and had to exceed 20°. Lateral bending was defined as the absolute angle of the torso (the line between L3 and C7) with respect to the vertical in the frontal plane and had to exceed 20°.

The distance of the hands from the shoulders, the sagittal plane, was recorded as being either close, medium, or far. "Close" was defined as hands against the body or hanging straight down, "Medium" as hands being about forearm's length away from the body, while "Far" was defined as having the hands at about arms length from the body (in the sagittal plane). Load amplitude was measured whenever possible using a portable force gage, or estimated by the observer.

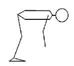
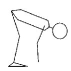
Observations were made every 10–20 s using a pre-recorded cue tone on a portable audio cassette player. The observation was based on the instant in which each tone ended. Longer intervals were used for more complex working situations and shorter average sample intervals were used for very simple working situations. In all cases the observers were required to select the categories which, in their judgement, best represented the biomechanical loading on the worker's lumbar spine.

Each observation was recorded on the form with a single tick mark. The biomechanical loading associated with each category was determined using the WATBAK biomechanical model. These loads were used to establish profiles of spinal compression, moment and shear based on the field recorded observations. More information about this software, which is part of the University of Waterloo's ERGOWATCH package, is available on the web at www.ergonomics.uwaterloo.ca. (See Fx1 and Fx2)

Posture and Load Sampling

Participant ID :__________ Task :____________________________ Date :____________

Height :______ Weight :________ Sex :_____ Samp.rate :_________ Observer :______

BACK	0 kg	-5 Kg		-11 kg		-18 kg		-23 kg		23+ kg	
1. 	C M F	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP
(-1 and beyond)		C M F PUSH OUT	C M F PULL TO	C M F PUSH OUT	C M F PULL TO	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL
2. 	C M F	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP
(0° - 15°)		C M F PUSH OUT	C M F PULL TO	C M F PUSH OUT	C M F PULL TO	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL
3. 	C M F	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP
(15° - 45°)		C M F PUSH OUT	C M F PULL TO	C M F PUSH OUT	C M F PULL TO	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL
4. 	C M F	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP
(45° - 75°)		C M F PUSH OUT	C M F PULL TO	C M F PUSH OUT	C M F PULL TO	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL
5. 	C M F	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP
(75° - 105°)		C M F PUSH OUT	C M F PULL TO	C M F PUSH OUT	C M F PULL TO	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL
6. 	C M F	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP
(105° - 120°)		C M F PUSH OUT	C M F PULL TO	C M F PUSH OUT	C M F PULL TO	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL
7. 	C M F	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F PUSH DOWN	C M F LIFT, PUSH UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP
LATERAL BEND (>20°)		C M F PUSH OUT	C M F PULL TO	C M F PUSH OUT	C M F PULL TO	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL
8. 	C M F	C M F PUSH DOWN	C M F LIFT, PUSHUP	C M F DOWN	C M F UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP	C M F DOWN	C M F UP
TWIST (>20°)		C M F PUSH OUT	C M F PULL TO	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL	C M F PUSH	C M F PULL

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BACK	-0 kg	-5 kg		-11 kg		-18 kg		-23 kg		23+ kg	
9. TWIST AND FLEX	C M F	C M F PUSH DOWN C M F PUSH OUT	C M F LIFT, PUSH UP C M F PULL TO	C M F PUSH DOWN C M F PUSH OUT	C M F LIFT, PUSH UP C M F PULL TO	C M F DOWN C M F PUSH	C M F UP C M F PULL	C M F DOWN C M F PUSH	C M F UP C M F PULL	C M F DOWN C M F PUSH	C M F UP C M F PULL
10. (-1 - -5)	C M F	C M F PUSH DOWN C M F PUSH OUT	C M F LIFT, PUSH UP C M F PULL TO	C M F PUSH DOWN C M F PUSH OUT	C M F LIFT, PUSH UP C M F PULL TO	C M F DOWN C M F PUSH	C M F UP C M F PULL	C M F DOWN C M F PUSH	C M F UP C M F PULL	C M F DOWN C M F PUSH	C M F UP C M F PULL
11. SIT (NEUTRAL) (0°- 15°)	C M F	C M F PUSH DOWN C M F PUSH OUT	C M F LIFT, PUSH UP C M F PULL TO	C M F PUSH DOWN C M F PUSH OUT	C M F LIFT, PUSH UP C M F PULL TO	C M F DOWN C M F PUSH	C M F UP C M F PULL	C M F DOWN C M F PUSH	C M F UP C M F PULL	C M F DOWN C M F PUSH	C M F UP C M F PULL
12. (15°- 45°)	C M F	C M F PUSH DOWN C M F PUSH OUT	C M F LIFT, PUSH UP C M F PULL TO	C M F PUSH DOWN C M F PUSH OUT	C M F LIFT, PUSH UP C M F PULL TO	C M F DOWN C M F PUSH	C M F UP C M F PULL	C M F DOWN C M F PUSH	C M F UP C M F PULL	C M F DOWN C M F PUSH	C M F UP C M F PULL
13. TWIST WHILE SEATED	C M F	C M F C M F	C M F C M F	C M F C M F	C M F C M F	C M F C M F	C M F C M F	C M F C M F	C M F C M F	C M F C M F	C M F C M F
OTHER	1. ____ ________ 2. ____ ________ 3. ____ ________ 4. ____ ________										
STAND UP											

VERSION 7.0

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