Biomechanical and Psychosocial Risk Factors for Low Back Pain at Work

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ABSTRACT

Objectives. This study determined whether the physical and psychosocial demands of work are associated with low back pain.

Methods. A case–control approach was used. Case subjects (n=137) reported a new episode of low back pain to their employer, a large automobile manufacturing complex. Control subjects were randomly selected from the study base as cases accrued (n=179) or were matched to cases by exact job (n=65). Individual, clinical, and psychosocial variables were assessed by interview. Physical demands were assessed with direct workplace measurements of subjects at their usual jobs. The analysis used multiple logistic regression adjusted for individual characteristics.

Results. Self-reported risk factors included a physically demanding job, a poor workplace social environment, inconsistency between job and education level, better job satisfaction, and better coworker support. Low job control showed a borderline association. Physical-measure risk factors included peak lumbar shear force, peak load handled, and cumulative lumbar disc compression. Low body mass index and prior low back pain compensation claims were the only significant individual characteristics.

Conclusions. This study identified specific physical and psychosocial demands of work as independent risk factors for low back pain. (*Am J Public Health.* 2001;91:1069–1075)

Low back pain remains the predominant occupational health problem in most industrialized countries, accounting for about 20% to 30% of all worker's compensation claims and up to 50% of all direct compensation costs.[1–4] The absence of any definitive diagnostic procedure, combined with the substantial functional impairment and costs that often accompany the condition, has produced a climate of uncertainty regarding not only the presence of pain itself but also its attribution to the work environment.[5–7] A number of recently published papers draw contradictory conclusions regarding the importance to low back pain of work in general, and the physical demands of work in particular.[8–11] Previous studies of low back pain have been criticized as being too narrowly focused on only 1 or perhaps 2 of the categories of individual, physical (biomechanical), and psychosocial aspects of the problem.[12] Moreover, direct workplace measures of biomechanical variables in individual study subjects have rarely been used.

The main aim of this study was therefore to determine which of the work-related biomechanical and psychosocial factors measured were associated with an increased risk of reporting low back pain, after control for differences in individual worker characteristics, such as prior low back pain history.

Methods

Study Setting and Subjects

Participants were recruited from a study base of approximately 10 000 unionized employees of a modern automobile production complex that manufactures passenger cars and light trucks. All hourly-paid workers (i.e., assembly and nonassembly workers) were eligible to participate.

Case subjects were defined as workers reporting a new episode of low back pain to one of the on-site occupational nursing stations. Case subjects were not required to file a worker's compensation claim or to be absent from work. Subjects were ineligible if they had reported a similar low back pain incident in the last 90 days. A total of 324 worker reports of low back pain were recorded at the clinics over the study time frame, with 56 subjects (17%) refusing to participate and 83 (26%) ineligible or not contacted. Of the remaining 185 subjects, 48 did not complete the study, leaving 137 enrolled as cases. When adjusted for ineligibility, the case participation rate was estimated to be 61%.

The main control group consisted of workers randomly selected (unmatched) from the same study base as the case subjects. A total of 460 eligible workers were contacted, of whom 207 (45%) agreed to participate. When late dropouts are accounted for, a total

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of 179 workers (39%) formed the main control group. A second control group was also recruited, with controls matched to cases by the actual job performed (not job title). In addition to providing insight into whether the presence of back pain may have biased questionnaire responses, this matched control group provided proxy biomechanical data for case subjects for whom no job assessment was possible (n=20). Of the 108 eligible matched control subjects contacted, 65 (60%) agreed to participate.

Data Collection

Data were collected with an in-home, interview-assisted questionnaire and a detailed worksite assessment of the physical demands of each worker's normal job. Subjects were not paid for their participation, either directly or through time off work for the interviews.

Physical demands assessments. The study used a hierarchy of complementary methods for the physical demands assessments, including a self-report questionnaire of physical loading at work; a detailed observer checklist that included a job-task breakdown and a separate loading analysis for each job component; a work sampling technique in which posture, hand position, hand force direction, and amplitude were randomly sampled over an extended period; a digital video analysis system that provided detailed kinematic trunk posture data; and a direct muscle monitoring approach using a 4-channel portable electromyography system monitoring erector spinae musculature bilaterally at T9 and L3 levels. A 15-segment, 2-dimensional, quasi-dynamic biomechanical model was used to generate spinal loading estimates from joint coordinate and hand load input data collected in the field.[13] Measures were designed to result in directly comparable units of exposure, whenever possible.[14]

To limit type I (α) error, the analysis presented here used a reduced set of biomechanical variables, based on expert consensus before the study. The variables examined included the following: 2-dimensional quasi-dynamic biomechanical model estimates of peak and cumulative moment of force about the L4/L5 spinal juncture, lumbar disc compression, and shear forces in the lumbar spine; direct measures of the peak force handled; computerized videotape analysis of back posture using displacement and percentage of time exposed; and body motion variables assessing trunk flexion and extension velocity and frequency of trunk movements. A complete description of the biomechanical model and assessment procedures used has been published elsewhere.[15]

Interview-assisted questionnaire. The 4 main subscales from the core version of the Job Content Instrument[16]—job control, psychological job demands, supervisor support, and coworker support—formed the basis for our questionnaire. We used the original Job Content Instrument items for these scales, with revised Swedish quantitative response options ranging from "often" to "never" rather than the original options of "strongly agree" to "strongly disagree."[17] Two other scales based on items related to the Job Content Instrument were formed: self-identity through work and a workplace social environment scale. Perceptions of job satisfaction,[18,19] education relative to others doing the same job, worker empowerment,[20] and personal locus of control[21] were also assessed. Psychophysical demands were assessed twice: by combining 2 items from the Job Content Instrument—"My job requires a lot of effort" and "My job requires rapid and continuous physical activity"—and by the Borg scale.[22] Additional data collected during the interview included health-related quality of life from the Medical Outcomes Study 36-item short form (SF-36) and back pain–specific functional measures from the Roland and Morris disability scale.[23,24] A simple physical examination was also administered. Complete methodologic details can be found elsewhere.[25]

Analytic Methods

Mean group values were compared by either Student t tests for unmatched data or paired t tests for matched sets. Binary and categorical data were compared by χ^2 tests. Multiple logistic regression with a backward deletion approach[26] was used to determine odds ratios and their 95% confidence intervals. Variables were not removed if they changed estimated coefficients for any of the significant model terms by more than 10%.[27] Terms for the potential confounders age, body mass index, marital status, smoking, having preschool children, and prior history of low back pain compensation claims were added to all models. Analysis of agreement between the paired cases and job-matched controls was done with Stratford's modification of Shrout and Fleiss's intraclass correlation method.[28,29]

All computerized analyses were performed with SAS, Version 6.12.[30,31] For continuous variables, odds ratios are based on the interquartile range (i.e., the 75th percentile to the 25th percentile) from the random control distribution.[32] Of the 137 cases recruited, 105 (77%) had biomechanical data, either from assessment of their own job (n=85) or from assessment of a job-matched proxy (n=20). For the random controls, 130 of 179 (73%) had biomechanical data. There were few or no missing questionnaire data.

Results

Individual Worker Characteristics

There were few statistically significant differences between cases and controls (Table 1). As expected, the extent of low back pain was markedly different, with mean values of the Roland and Morris disability scores for the cases and controls falling within values expected for low back pain patients and for the general population, respectively. Cases were also more likely than controls to have had a prior compensation claim for low back pain. Cases also had markedly lower SF-36 physical scores but showed little difference on the mental health scores. More detailed information about the subject population can be found elsewhere.[25]

Risk Factor Analysis

When we examined the variables individually, we found that all measured biomechanical variables, except a measure of low (static) loading, showed significantly higher exposure levels for cases than controls. Such consistency was not observed for comparisons of the individual self-reported psychosocial factors. Some factors, such as higher levels of psychological work demands, were associated with increased low back pain risk, as expected, while other factors showed associations in unexpected directions. For example, cases had higher ratings than controls for job self-identity and slightly better coworker support and job satisfaction scores. Finally, several factors, including job control, showed no statistical association with low back pain in the bivariate analysis.

Multivariate logistic regression analysis (Table 2) revealed several biomechanical and psychosocial factors that were significantly related to reporting low back pain at the study site. The measured biomechanical risk factors identified were peak shear force, peak hand force, and the compressive forces accumulated in the lumbar discs over a full shift. The self-reported risk factors identified included worker perceptions of the following: a physically demanding job, a poor workplace social environment, and a higher education level relative to others holding similar jobs. It is interesting to note that although no bivariate relationship was seen for job control, there was a sizeable, albeit not quite statistically significant, relationship observed after adjustment for the other study variables, in particular the measured physical demands of work. Similarly, the multivariate regression coefficients for job satisfaction and coworker support became statistically significant ($P<.05$); workers who were more, not less, satisfied and those who had better, not worse, coworker support were some-

TABLE 1—Population Characteristics In Study of Risk Factors for Low Back Pain (LBP) at Work

Continuous Variables	Case (n = 137), Mean (SD)	Control (n = 179), Mean (SD)	*P* (*t* Test)
Age, y	41.1 (8.5)	41.5 (8.2)	.63
Height, cm	177.2 (7.1)	176.2 (7.0)	.23
Weight, kg	83.6 (14.2)	83.4 (13.3)	.87
Body mass index	26.6 (3.9)	26.8 (3.9)	.60
Back pain disability (Roland and Morris scale)	11.7 (7.0)	2.5 (5.0)	.001*
SF-36 physical health index	34.5 (9.9)	49.2 (8.6)	.0001*
SF-36 mental health index	52.2 (9.1)	54.0 (8.6)	.06
Categorical Variables	**Case (n = 137), n (%)**	**Control (n = 179), n (%)**	***P* (χ^2)**
Male sex	126 (92)	166 (93)	.80
Current smoker	62 (45)	75 (42)	.55
Main wage earner	112 (82)	141 (79)	.51
Preschool children at home	29 (21)	34 (19)	.63
Married	104 (77)	151 (85)	.06
Prior compensation claim for LBP	70 (51)	57 (32)	.001*
Alcohol consumption (drinks) in past year			.70
None	16 (12)	17 (9)	
Occasionally	30 (22)	41 (23)	
1–2 per month	22 (16)	26 (15)	
1–2 per week	43 (31)	69 (39)	
1 per day	19 (14)	21 (12)	
>1 per day	7 (5)	5 (3)	
Highest completed education level			.71
<High school	42 (31)	51 (29)	
High school	63 (46)	79 (44)	
>High school	32 (23)	48 (27)	
Type of occupation in auto complex			.74
Production operator (assembler)	69 (50)	88 (49)	
Support worker	33 (24)	41 (23)	
Maintenance worker	15 (11)	16 (9)	
Utility worker	20 (15)	34 (19)	

Note. SF-36 = Medical Outcomes Study 36-item short form.
**P* value of statistical test assessing group difference < .05.

what more likely to report low back pain. Our final model emphasizes the complex interrelationship between the biomechanical and psychosocial work environments.[27]

The statistical properties of the final regression model examined were as follows: (1) the Hosmer–Lemeshow[32] goodness-of-fit χ^2_8 was 8.73 (P=0.37); (2) the area under the receiver operating characteristic curve[33] was 0.84; and (3) Nagelkerke's adjusted R^2 estimating the amount of variance explained by the model[34] was 0.43. Respectively, the 3 tests show that use of the logistic model was appropriate, that the study's final statistical model correctly identifies most cases and controls, and that it also accounts for a large portion of the observed differences between cases and controls.

To determine the relative explanatory power of the different types of risk factors, we compared the regression parameters for logistic regression models restricted to terms from each of the key study domains—individual, psychosocial, psychophysical, and biomechanical. To ensure comparability, we restricted these models to the group of subjects with data on all terms examined in the final model (cases = 97, controls = 124). The criteria used were the –2 log likelihood (–2LL) χ^2 for covariates only and the adjusted R^2 statistic (Table 3). The results of these comparisons indicate that, as a group, the directly measured biomechanical variables in the final model accounted for more of the explained variance than the terms in each of the other restricted models. If self-reported physical demands is combined with the terms for the measured biomechanical factors into an overall physical demands model, the adjusted R^2 statistic increases substantially (from 0.183 to 0.314), as do the –2LL values (from 32.47 to 59.09). The differences in the regression statistics between the models in Table 3, particularly the difference in the –2LL between the models with and without the physical demands terms, clearly indicate the large contribution that these variables are making to the final model and therefore to the reporting of low back pain.

Agreement Between Data From Cases and Job Matches

It is possible that low back pain could affect perceptions about work or the way that work is performed, a possible source of bias that could influence the results from the risk factor analysis. No significant differences were found between matched sets of people in the same jobs with and without low back pain for any of the directly measured variables. The average intraclass correlation coefficient was 0.6, indicating good overall agreement, which was to be expected given that the matching criteria focused on the physical demands of the job.[29,35]

Observed agreement was much weaker for the psychosocial variables (Table 4), with none exceeding even the average level observed for the physical demands measures. In fact, a gradient was seen, with those variables most directly linked to work, such as job control and psychophysical exertion, showing the best agreement, and those variables more related to personal characteristics, such as mastery and social relations, having the least agreement. While it is evident that pairwise agreement was limited, the average difference between responses for cases and matches was also marginal; for only 3—the Borg scale, empowerment, and psychological job demands—was there evidence to suggest that cases provided systematically different responses than controls. Notably, none of these 3 variables remained in the study's final statistical model, suggesting that our main findings are not strongly affected by bias from the injury process.

Discussion

Previous studies of low back pain have been criticized as being too narrowly focused on only 1 or perhaps 2 of the categories of individual, physical (biomechanical), and psychosocial risk factors.[12,36] The data collection protocol for this study was specifically designed to be comprehensive, using a variety of methods to collect individual, clinical, biomechanical, and psychosocial data.

Interpreting the Biomechanical Results

Our finding that peak hand loading is associated with low back pain is consistent with findings from other published studies; direct comparisons between the studies are difficult, however, because the exposure ranges used to determine risk estimates vary considerably.[37] Peak lumbar shear force proved to be a robust risk factor, as did cumulative lumbar disc compression. There is substantial lab-

TABLE 2—Results From the Final Study Regression Model of Risk Factors for Low Back Pain (LBP) at Work (97 Cases, 124 Controls)

	OR	95% CI	Interquartile Range Used for OR Estimate
Individual characteristics			
Age, y	1.0	0.54, 1.74	12 years
Smoking (cigarettes, yes/no)	1.3	0.64, 2.60	N/A[a]
Marital status (married, yes/no)	1.3	0.53, 3.32	N/A[a]
Preschool children at home (yes/no)	0.9	0.33, 2.46	N/A[a]
Body mass index	2.0*	1.20, 3.58	4.8 units (cases lower)
Prior compensation claim for LBP (yes/no)	2.2*	1.07, 4.43	N/A[a]
Workplace—psychosocial			
Lower workplace social environment score	2.6*	1.30, 5.42	3 units (cases lower)
Higher education relative to others in similar jobs	2.2*	1.05, 4.92	N/A[a]
Lower job control	2.0	0.93, 4.28	32 units (cases lower)
Higher job satisfaction	1.7*	1.15, 2.48	1 unit (cases higher)
Higher coworker support	1.6*	1.07, 2.32	2 units (cases higher)
Workplace—psychophysical: higher perceived exertion at work	3.0*	1.79, 5.36	2 units (cases higher)
Workplace—biomechanical			
Higher peak lumbar shear	1.7*	1.02, 2.86	190 N (cases higher)
Higher cumulative lumbar disc compression	2.0*	1.22, 3.59	4.6×10^6 N·s/shift (cases higher)
Higher peak hand force	1.9*	1.21, 3.10	17 kg (cases higher)

Note. OR = odds ratio; CI = confidence interval; N/A = not applicable. The ORs for the continuous variables are expressed in relation to the spread of the interquartile range from the random controls. "Units" in last column refers to subscale scores for self-reported variables.
[a]Dichotomous.
*$P < .05$.

TABLE 3—Relative Contributions of Different Risk Factor Domains to Low Back Pain at Work (97 Cases, 124 Controls)

Model	-2LL χ^2 for Covariates	*P* (*df*)	Adjusted R^2
Individual characteristics: body mass index, prior compensation claim for LBP	7.92	.019 (2)	0.047
Workplace—psychosocial: workplace social environment, education relative to others, job control, job satisfaction, coworker support	19.89	.0013 (5)	0.115
Workplace—psychophysical: perceived exertion at work	20.39	.001 (1)	0.118
Workplace—biomechanical: lumbar shear, cumulative lumbar disc compression, hand force	32.47	.0001 (3)	0.183
Workplace—physical demands: perceived exertion at work plus lumbar shear, cumulative lumbar disc compression, hand force	59.09	.0001 (4)	0.314
Full model (as shown in Table 2)	85.93	.0001 (15)	0.432

Note. -2LL = -2 log likelihood. The variables included in each model are the same as those in Table 2. All models include the same subjects to ensure comparability between models. -2LL estimates are from comparisons with null models.

oratory evidence demonstrating the adverse effects of these variables in vitro, although there is very little epidemiologic evidence to support these laboratory findings.[38] Shear forces in the anterio-posterial direction act transversely across the lumbar spine to resist the tendency of the top parts of the torso to slide forward relative to the lower parts. Resistance is provided by facet joints, by discs, and, if the lordotic curve is not completely lost, by spine extensor muscles.[39,40] Elevated spinal shear can result from a forward-inclined torso, particularly with loads in the hands, or from pulling actions in an upright posture. While the clinical relevance of shear forces remains unclear, they may be resisted primarily by the facet joints of the vertebrae, which are known to have abundant pain receptors.[38] Shear forces could also initiate new inflammation or aggravate existing problems in the facet joint region, including the annular fibers of the discs.[15] Our finding that peak hand load and spinal shear are risk factors for low back pain is in general agreement with the recent critical review of the work-relatedness of musculoskeletal factors prepared by the US National Institute for Occupational Safety and Health (NIOSH).[41] As a final note on peak shear force, other analyses of our data have shown that peak compression can be substituted for shear with little loss of model explanatory power, reflecting the high correlation between these 2 factors ($r = 0.83$).[15]

Although there is considerable biomechanical evidence linking disc compression with vertebral damage,[38–40,42] we found only 1 epidemiologic study that used disc compression estimates from individual subjects with and without low back pain.[43] In that study, no significant effect for disc compression was observed, although compression estimates were available for relatively few subjects. The authors did, however, report a strong association for nonneutral trunk postures. The reverse was true for our study, possibly because we developed our final model using terms for the compression and shear estimates as well as the posture variables. Since increased spinal forces are a consequence of nonneutral postures, this probably left little explanatory power for the posture variables in the model, hence their elimination.[42] The mean peak compression estimate of 3402 N and 2744 N observed for cases and controls, respectively, indicate significant exposure to disc compression in our study, given that 3400 N is the NIOSH "action limit."[44] Finally, whereas our study did

TABLE 4—Intraclass Correlation Coefficients (ICCs) and Mean Differences in Scores Comparing Case Subjects and Job-Matched Controls for Self-Reported (Psychosocial) Variables, Ranked by ICC Values

	ICC[a]	95% CI	Mean Pairwise Difference (%)[b]	*P* (Paired *t* Test)	n[c]
Job control	0.59	0.53, 0.64	4.3 (8.0)	.04*	64
Physical exertion (JCI)	0.43	0.36, 0.49	0.2 (3.3)	.27	65
Borg scale	0.42	0.34, 0.48	1.0 (11.8)	<.01*	65
Empowerment	0.40	0.32, 0.47	−0.9 (−7.2)	.02*	65
Psychological job demands	0.37	0.29, 0.44	3.0 (9.8)	<.01*	65
Supervisor support	0.21	0.13, 0.29	−0.2 (−2.0)	.66	63
Job self-identify	0.19	0.10, 0.27	0.9 (8.1)	.04*	64
Job dissatisfaction	0.18	0.10, 0.26	−0.1 (−2.8)	.58	65
Mastery	0.09	0.01, 0.18	0.3 (1.5)	.5	65
Workplace social environment	0.08	0.00, 0.16	−0.2 (−1.4)	.56	65
Coworker support	0.01	0.00, 0.07	−0.2 (−1.7)	.56	61

Note. CI = confidence interval; JCI = Job Content Instrument.[16]
[a]Variables are placed in order of decreasing ICC value from top to bottom.
[b]Negative sign for mean difference between case and control pairs indicates that case subjects had lower scores than controls. Percentage is mean difference calculated by dividing mean difference shown by the value of job-matched control mean.
[c]Number of matched pairs in each analysis.
*$P < .05$ (systematic group differences).

find significant effects for some biomechanical force estimates, it should be noted that our 2-dimensional biomechanical model is limited in its precision compared with the 3- and 4-dimensional models now available; thus, our risk estimates may be low.

Interpreting the Psychophysical Results

It is important to note that although the Borg scale rating of psychophysical demands did not remain in the final model, the self-reported physical exertion scale did, even with the measured physical demands included in the model. The perceived exertion scale not only had the largest odds ratio estimate (3.0), it also had the largest impact on the amount of variance explained by the model. On the basis of these results, it is possible that worker perceptions about the physical demands of work may be tapping into important but unmeasured factors, such as aerobic demands, tissue tolerance, physical capacity, or individual work style. As discussed earlier, cases reported slightly higher scores on the Borg scale than job-matched controls, but this possible bias was not seen for the physical exertion scale that remained in the final model (Table 4). This reporting difference between the 2 scales may be accounted for by the fact that the Borg scale makes specific reference to the demands of work on the body, whereas the Job Content Instrument exertion scale does not; thus, the Borg scale is more susceptible to reporting bias. The fact that self-reported demands was an independent factor over and above measured demands of work suggests that the direct measures we used may not have captured all of the variance associated with the overall physical demands of work. The direct measures were, for the most part, specific to the low back. A more generic measure of physical demands, like the exertion scale, might have been able to account for some of this unexplained variance, and thus might have been retained in the study's final model.

Interpreting the Psychosocial Results

Although a significant association was observed for the Job Content Instrument psychological demands scale when it was examined alone, the significance of the association disappeared once the self-rated physical demands of work were controlled for in the multivariate analysis. This result, and other findings not shown here (including those from correlation and factor analyses), suggest that this scale behaved as a measure more of physical than of psychological demands of work in this setting. Further research on its utility as a measure of psychological job demands appears warranted, at least in settings with a physically active workforce. Factor loading patterns from a principal components analysis did, however, support the use of the separate scales for job control, coworker support, supervisor support, empowerment, physical demands, job dissatisfaction, and the workplace social environment.

Our workplace social environment scale combined 4 questions: Was it a pleasant work environment? Was it free from conflicts? Were workers subject to harassment? Was someone available for helping out with job problems? The strength of the association observed for this scale appears to underline the importance of providing employees with a positive work environment. However, given that this scale was newly developed for our study, further corroboration of its relationship with low back pain is needed. Our finding that case subjects were more satisfied with work than were controls is in direct contradiction to findings from the Boeing study, a frequently cited cohort study of predictors for low back pain among airplane assembly workers, where job dissatisfaction was the only work-related predictor of low back pain. These contradictory results may indicate the instability of this variable's effects in different study settings.[18] For both studies, the proportion of subjects dissatisfied with work was low (about 15%). Since the unexpected results for job satisfaction, and coworker support, were evident in both the bivariate (unadjusted) and multivariate (adjusted) analyses, overfitting of the final statistical model is unlikely. Finally, our observed association between low back pain and a feeling of being overeducated relative to workers in similar jobs may provide support for status inconsistency as a health risk factor.[45]

Study Limitations

While the number of statistically significant terms in our final regression model suggests that inadequate statistical power was not a problem in our study, our results nonetheless remain potentially susceptible to the biases possible in case–control studies. Of particular concern were recall bias, since we collected data from workers who had recently had an episode of low back pain, and selection bias, since this was an observational study. Recall bias was limited by use of objective measures where possible, especially for the physical demands of the job. For self-report data, our study was designed to permit an examination of the agreement between responses of cases and job-matched controls; as previously mentioned, this analysis indicated that our results were not strongly influenced by potential recall bias. The high level of agreement on the measured physical demands between the cases and their job-matched controls in this study also does not suggest a strong effect of injury on work "style." Further, for the effect for the physical demands of work reported in our study to have been overstated, one would have to assume that cases had done their jobs in a more adverse biomechanical way after their injury than before; the results observed for the measured biomechanical variables would have to be consistently heavier for cases than controls. This appears to be a counterintuitive, if not improbable, notion. Moreover, there were no significant differences between cases and job-matched controls for any of the biomechanical variables studied.[35]

As with any observational study, the potential for selection bias also needs to be considered. We used several strategies to help prevent this bias. Rather than sample at 1 point in time and obtain a mixture of prevalent and incident cases, we collected newly reported cases of low back pain using existing occupational health services. We also used incidence density sampling of controls and selected all subjects from within a well-defined study base. Medical confidentiality prevented us from recruiting subjects directly from the nursing stations; therefore, log sheets and frequent discussions with the nurses were used to monitor subject recruitment, again with no evidence of systematic bias reported. In addition, a comparison of participating and nonparticipating worker's compensation claims showed no differences in claim duration, age, or experience. Finally, our subject participation rate is comparable to that in other workplace studies, which, by their nature, must operate within an environment that is intolerant of interference with production. For example, in the Boeing study, 75% of the workers initially agreed to participate, with 52% of those agreeing (or 39% of those originally approached) returning the study questionnaire.[46]

The Work-Relatedness of Low Back Pain

The data from our study affirm the existence of diverse work-related risk factors for low back pain. While the case–control nature of our study may limit its ability to establish etiologic pathways, our results appear to clearly substantiate the multifactorial nature of the condition. The odds ratios reported are substantial for the biomechanical, psychophysical, and psychosocial risk factors identified, even after a number of individual characteristics believed to influence low back pain are adjusted for. Our study does not support the notion that the reporting of low back pain is solely, or primarily, related to either biomechanical or psychosocial factors.

Our results are clearly not in agreement with those from the cohort study of Boeing aircraft assembly workers, which did not find an association for workplace physical demands but did report an association with job satisfaction.[18,46] That study found no effect for physical demands measures, such as disc compression, possibly because it used group-level estimates of exposure rather than data for individual workers, a strategy likely to increase measurement error and thereby reduce study power.[12,47] In contrast, our study identified specific risk factors when using data from the workplace biomechanical (physical demands) assessments of individual subjects. We did not, however, find any association between low back pain and job title when we used a 4-level, site-specific job classification system. Had such a crude classification system been used to represent the physical demands of the jobs in our study, we would not have observed any relationship between the physical demands of work and low back pain.

Conclusions

This study supports the concept of a multifactorial etiology for occupational low back pain. While we recognize that low back pain is common in both working and nonworking populations, our data strongly suggest a role for workplace factors in the etiology of low back pain reported at work. By using direct measurements of biomechanical demands rather than relying solely on the use of self-reported loads or group-level measures such as those based on job title, this study provides robust estimates of the relationships between these potentially modifiable demands and reporting of low back pain at work. Our risk estimates have also been adjusted for self-reported psychosocial risk factors and other potentially confounding variables. Finally, the results of our study show significant strengths of association for work-related psychosocial *and* biomechanical variables, suggesting that workplace efforts directed toward the primary prevention of low back pain will be most effective if they focus on both of these aspects of work. □

Contributors

M.S. Kerr was the principal author and participated in the design and execution of the study and the analysis of the data. R.P. Wells, H.S. Shannon, R.W.K. Norman, W.P. Neumann, and J.W. Frank participated in the design and execution of the study and the analysis of the data, as well as the writing of the report. C. Bombardier participated in the design and execution of the study and the analysis of the data.

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References

1. Spengler DM, Bigos SJ, Martin NA, Zeh J, Fisher L, Nachemson AL. Back injuries in industry: a retrospective study, I: overview and cost analysis. *Spine.* 1986;11:241–251.
2. Waddell G. A new clinical model for the treatment of low-back pain. *Spine.* 1987;12:632–644.
3. Clinical Standards Advisory Group. *Epidemiology Review: The Epidemiology and Cost of Back Pain.* London, England: Her Majesty's Stationery Office; 1994.
4. Statistics Canada. *Work Injuries 1992–1994.* Ottawa, Ontario: Minister of Industry; 1995: 72–208.
5. Van Tulder MW, Assendelft WJJ, Koes BW, Bouter LM. Spinal radiographic findings and nonspecific low back pain: a systematic review of observational studies. *Spine.* 1997;22: 427–434.
6. Frank JW, Pulcins IR, Kerr MS, Shannon HS, Stansfeld S. Occupational back pain—an unhelpful polemic. *Scand J Work Environ Health.* 1995;21:3–14.
7. Tarasuk V, Eakin JM. The problem of legitimacy in the experience of work-related back injury. *Qual Health Res.* 1995;5:204–221.
8. Hadler NM. Workers with disabling back pain. *N Engl J Med.* 1997;337:341–343.
9. Daltroy LH, Iversen MD, Larson MG, et al. A controlled trial of an educational program to prevent low back injuries. *N Engl J Med.* 1997;337: 322–328.
10. Smedley J, Egger P, Cooper C, Coggon D. Prospective cohort study of predictors of incident low back pain in nurses. *BMJ.* 1997;314: 1225–1228.
11. Cherkin DC, MacCormick FA, Berg AO. Managing low back pain—a comparison of the be-

liefs and behaviors of family physicians and chiropractors. *West J Med.* 1988;149:475–480.
12. Winkel J, Mathiassen SE. Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations. *Ergonomics.* 1994;37:979–988.
13. Neumann P. *Exposure Measurement Tools for Epidemiological Investigation of Occupational Low Back Pain: Within and Between Method Characteristics* [master's thesis]. Waterloo, Ontario: University of Waterloo; 1999.
14. Wells R, Norman R, Neumann P, Frank J, Shannon H, Kerr M. Assessment of physical work load in epidemiologic studies: common measurement metrics for exposure assessment. *Ergonomics.* 1997;40:51–61.
15. Norman R, Wells R, Neumann P, et al. A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. *Clin Biomech.* 1998;13:561–573.
16. Theorell T, Karasek RA. Current issues relating to psychosocial job strain and cardiovascular disease research. *J Occup Health Psychol.* 1996; 1:9–26.
17. Ahlberg-Hulten G, Theorell T, Sigala F. Social support, job strain and musculoskeletal pain among female health care personnel. *Scand J Work Environ Health.* 1995;21:435–439.
18. Bigos SJ, Battie MC, Spengler DM, et al. A prospective study of work perceptions and psychosocial factors affecting the report of back injury. *Spine.* 1991;16:1–6.
19. North FM, Syme SL, Feeney A, Shipley M, Marmot M. Psychosocial work environment and sickness absence among British civil servants: the Whitehall II Study. *Am J Public Health.* 1996;86:332–340.
20. Jencks C, Perman L, Rainwater L. What is a good job? A new measure of labor-market success. *Am J Sociol.* 1988;93:1322–1357.
21. Pearlin LI, Schooler C. The structure of coping. *J Health Soc Behav.* 1978;19:2–21.
22. Borg GAV. Psychophysical basis of perceived exertion. *Med Sci Sports Exerc.* 1982;14: 377–381.
23. Ware JE Jr, Snow KK, Kosinski M, Gandek B. *SF-36 Health Survey Manual and Interpretation Guide.* Boston, Mass: The Health Institute; 1993.
24. Roland M, Morris R. A study of the natural history of back pain. Part I: development of a reliable and sensitive measure of disability in low-back pain. *Spine.* 1983;8:141–144.
25. Kerr MS. *A Case–Control Study of Biomechanical and Psychosocial Risk Factors for Low-Back Pain Reported in an Occupational Setting* [doctoral thesis]. Toronto, Ontario: University of Toronto; 1998.
26. Greenland S. Modeling and variable selection in epidemiologic analysis. *Am J Public Health.* 1989;79:340–349.
27. Sun G, Shook T, Kay GL. Inappropriate use of bivariate analysis to screen risk factors for use in multivariate analysis. *J Clin Epidemiol.* 1996; 49:907–916.
28. Stratford PW. Confidence limits for your ICC. *Phys Ther.* 1989;69:237–238.
29. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychol Bull.* 1979;86:420–428.
30. *SAS/STAT User's Guide, Version 6.* Cary, NC: SAS Institute Inc; 1989.
31. *Logistic Regression Examples—Using the SAS System.* Cary: SAS Institute Inc; 1995.
32. Hosmer DW, Lemeshow S. *Applied Logistic Regression.* New York, NY: John Wiley & Sons Inc; 1989.
33. Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology.* 1982;143:29–36.
34. Nagelkerke NJD. A note on a general definition of the coefficient of determination. *Biometrika.* 1991;78:691–692.
35. Kerr MS, Shannon HS, Frank JW, et al. Levels of agreement for biomechanical and psychosocial exposures between cases and job-matched controls in a study of reported low-back pain [abstract]. In: *13th International Symposium on Epidemiology in Occupational Health.* Helsinki, Finland: Finnish Institute of Occupational Health; 1998:173.
36. Frank JW, Kerr MS, Brooker A, et al. Disability resulting from occupational low back pain. Part I: what do we know about primary prevention? A review of the scientific evidence on prevention before disability begins. *Spine.* 1996; 21:2908–2917.
37. Burdorf A, Rossignol M, Fathallah FA, Snook SH, Herrick RF. Challenges in assessing risk factors in epidemiologic studies on back disorders. *Am J Ind Med.* 1997;32:142–152.
38. Adams MA, Dolan P. Recent advances in lumbar spine mechanics and their clinical significance. *Clin Biomech.* 1995;10:3–19.
39. McGill SM, Norman RW. Partitioning of the L4-L5 dynamic moment into disc, ligamentous, and muscular components during lifting. 1986 Volvo Award in Biomechanics. *Spine.* 1986;11: 666–678.
40. Potvin JR, McGill SM, Norman RW. Trunk muscle and lumbar ligament contributions to dynamic lifts with varying degrees of trunk flexion. *Spine.* 1991;16:1099–1107.
41. Bernard B. *Musculoskeletal Disorders and Workplace Factors. A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back.* Baltimore, Md: US Dept of Health and Human Services, National Institute for Occupational Safety and Health; 1997.
42. Chaffin DB, Andersson GB. *Occupational Biomechanics.* Toronto, Ontario: John Wiley & Sons Inc; 1991.
43. Punnett L, Fine LJ, Keyserling WM, Herrin GD, Chaffin DB. Back disorders and nonneutral trunk postures of automobile assembly workers. *Scand J Work Environ Health.* 1991;17:337–346.
44. Waters TR, Putz-Anderson V, Garg A, Fine LJ. Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics.* 1993;36:749–746.
45. Siegrist J. Adverse health effects of high-effort/low-reward conditions. *J Occup Health Psychol.* 1996;1:27–41.
46. Bigos SJ, Battie MC, Spengler DM, et al. A longitudinal, prospective study of industrial back injury reporting. *Clin Orthop.* 1992;279:21–34.
47. Burdorf A. Exposure assessment of risk factors for disorders of the back in occupational epidemiology. *Scand J Work Environ Health.* 1992;18:1–9.