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Abstract

Background: The etiologic role of biomechanical factors for low back injury (LBI) needs to be confirmed in prospective studies that control for psychosocial factors. Methods: Complete baseline information on 1,233 vehicle operators was gathered during medical examinations and by questionnaire. First LBI during 7.5 years of follow-up was ascertained from insurance records. Hazard ratios and etiologic fractions were analyzed with Cox regression models stratified by injury severity and controlling for age, sex, height, weight, ethnicity, and biomechanical and psychosocial job factors. Severe LBI was defined as medically diagnosed postlaminectomy syndrome, spinal stenosis, herniated lumbar disc, sciatica, or spinal instability. Results: An exponential dose-response relationship was found between weekly driving hours and incidence of first LBI. Indicators of physical workload were more strongly associated with more severe low back injuries compared to less severe injuries. Rates of severe LBI increased 39% for every 10-hr increase in weekly driving (hazard ratio 1.39, 95% confidence interval 1.15-1.68). Higher risks of severe LBI were also found among operators performing heavy physical labor on cable cars (hazard ratio 2.76, 95% confidence intervals 1.24-614) or reporting more ergonomic problems at baseline HR for upper quartile 1.65 (95% confidence interval 1.08-2.50). Estimates of etiologic fractions suggest that reduction of ergonomic problems to the low level currently experienced by 25% of drivers would result in a 19% reduction of severe LBI among all drivers. A change from full- (more than 30 hr) to part-time driving (20-30 hr) could reduce the number of severe LBI by 59%, although this gain would be reduced to 28% at the company level if injuries expected among additional employees, hired to maintain full service are included. Conclusions: Duration of professional driving and ergonomic problems are independent and

preventable risk factors for LBI even after adjustment for psychosocial factors.

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Physical Workload, Ergonomic Problems, and Incidence of Low Back Injury: A 7.5-Year Prospective Study of San Francisco Transit Operators

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Background *The etiologic role of biomechanical factors for low back injury (LBI) needs to be confirmed in prospective studies that control for psychosocial factors.*

Methods *Complete baseline information on 1,233 vehicle operators was gathered during medical examinations and by questionnaire. First LBI during 7.5 years of follow-up was ascertained from insurance records. Hazard ratios and etiologic fractions were analyzed with Cox regression models stratified by injury severity and controlling for age, sex, height, weight, ethnicity, and biomechanical and psychosocial job factors. Severe LBI was defined as medically diagnosed postlaminectomy syndrome, spinal stenosis, herniated lumbar disc, sciatica, or spinal instability.*

Results *An exponential dose–response relationship was found between weekly driving hours and incidence of first LBI. Indicators of physical workload were more strongly associated with more severe low back injuries compared to less severe injuries. Rates of severe LBI increased 39% for every 10-hr increase in weekly driving (hazard ratio 1.39, 95% confidence interval 1.15–1.68). Higher risks of severe LBI were also found among operators performing heavy physical labor on cable cars (hazard ratio 2.76, 95% confidence intervals 1.24–6.14) or reporting more ergonomic problems at baseline (HR for upper quartile 1.65 (95% confidence interval 1.08–2.50). Estimates of etiologic fractions suggest that reduction of ergonomic problems to the low level currently experienced by 25% of drivers would result in a 19% reduction of severe LBI among all drivers. A change from full- (more than 30 hr) to part-time driving (20–30 hr) could reduce the number of severe LBI by 59%, although this gain would be partially offset by an increase in the number of exposed employees.*

Conclusions *Duration of professional driving and ergonomic problems are independent and preventable risk factors for LBI even after adjustment for psychosocial factors.* Am. J. Ind. Med. 00:1–16, 2004. *© 2004 Wiley-Liss, Inc.*

KEY WORDS: attributable risk; back pain; bus-driver; cohort study; motor vehicle driving; epidemiology; occupational injury; prevention; workers' compensation; working hours

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INTRODUCTION

Work-related back injuries represent about 20% of all workers' compensation claims and are responsible for 33% of all workers' compensation costs in the United States [Andersson et al., 1991]. The costs of work-related back injuries in the US totaled $49 billion in 1992 [Leigh et al., 1997]. The prevention of low back injuries and associated disability has become a major challenge for employers, insurance carriers, and occupational health specialists. However, the development of effective intervention strategies has been hampered by limited information on occupational risk factors that are amenable to change [Krause et al., 2001].

Several physical and psychosocial job factors have been associated with occupational back pain in the scientific literature. Biomechanical factors include physical demands such as heavy manual labor, frequent lifting, pulling or pushing, trunk flexion or rotation, prolonged sitting or standing, whole body vibration, and driving motor vehicles [Pope et al., 1991; Bernard, 1997; Krause et al., 1998a; National Research Council, 2001]. Physical workload and self-reported ergonomic problems have been associated with back and neck pain in a cross-sectional study of bus drivers [Krause et al., 1997a]. Observer-based measures of high peak lumbar cumulative compression of lumbar discs and high peak hand force were both associated with LBI reports in a case-control study of assembly-line workers in an automobile plant even after adjustment for psychosocial risk factors [Kerr et al., 2001]. Psychosocial job factors including high levels of psychological job demands, job stressors, job dissatisfaction, and low supervisory support were associated with spinal disorders in several studies [Hoogendoorn et al., 2000b], but few studies have adjusted adequately for physical workload [Krause et al., 1997b, 1998a; Thorbjornsson et al., 1998, 2000; Kerr et al., 2001; Torp et al., 2001]. Although the accumulated evidence for the etiological role of biomechanical risk factors in LBI has been rated by several academic researchers and scientific advisory groups as sufficient enough to propose ergonomic interventions, critics maintain that more evidence that adjusts for psychosocial job factors in high quality prospective studies is needed for making convincing causal inferences [Frank et al., 1996; Hoogendoorn et al., 2000a].

To date only a few studies have prospectively investigated biomechanical risk factors while simultaneously adjusting for psychosocial job factors and other possible confounders in multivariate analyses. The results from these studies are inconsistent. In 1991, a prospective study of employees of the Boeing aircraft company found no association between physical job demands and reporting of low back pain; on the other hand, psychosocial factors such as job dissatisfaction and poor supervisor ratings in the previous 6 months were predictive of back injury reporting [Bigos et al., 1991, 1992]. The Boeing study has been criticized for its failure to assess physical workload on an individual basis, and because there was relatively little variation in workload levels between groups of employees. This would increase the possibility of false negative findings for biomechanical risk factors and of positive findings for psychosocial factors [Frank et al., 1995; Bernard, 1997]. In 1998, a prospective study of public transit operators in San Francisco, with individual measurement of both physical and psychosocial factors, confirmed the findings of the Boeing study regarding supervisor support and job dissatisfaction. This study also provided evidence for the etiological role of psychological job demands and job stressors [Krause et al., 1998b]. In contrast to the Boeing study, however, the San Francisco study showed that cumulative and current physical workload measured in years and hours of professional driving, respectively, predicted work-related spinal injury independent of individual and psychosocial factors. Although both the Boeing and San Francisco studies were industry-based, outcome definitions were not fully comparable because the San Francisco study combined back and neck injuries.

The goal of the present study is to investigate the etiologic role of biomechanical job factors for work-related low back injuries while controlling for demographic and psychosocial job factors in a more recent cohort of transit operators in San Francisco. The present study was designed to examine these associations prospectively for low back injuries with adjustment for psychosocial job factors. In addition, the study examines risk factors and etiologic fractions separately for two severity classes of low back pain defined by medical diagnostic criteria.

MATERIALS AND METHODS

Study Design and Population

This is a 7.5-year prospective cohort study of 1,974 transit vehicle operators employed by the San Francisco Municipal Railway (Muni) who completed physical examination and extensive medical history forms required for commercial driver's license renewal between August 1993 and September 1995. Subjects were excluded because a review of data showed that they were supervisors or other non-active transit operators (73) and the social security number was missing (60) and their medical examination files could not be linked to an injury dataset. This left a total eligible study population of 1,841 transit operators. Of these, 1,503 (81.6%) responded to an additional (optional) occupational questionnaire immediately after their medical examinations. Due to missing data on one or more of the variables used in the multivariate analyses, 222 drivers were excluded. An additional 48 respondents were excluded because they operated vehicles for less than 20 hr per week, indicating supervisory roles or assignment to modified duty due to existing health problems including back problems. The final sample included 1,233 study participants.

Data Sources and Collection

Data were obtained from five different sources: A baseline health survey and medical examination of all Muni drivers between August 30th, 1993 and September 29th, 1995 administered during the mandatory biannual medical relicensing examination, that provided information on demographic (age, sex, ethnicity) and anthropometric (height and weight) variables, total years of professional driving, type of vehicle operated, and ergonomic problems. A voluntary baseline occupational questionnaire administered after completion of the medical examination and after the decision on the driver's license renewal had been made, providing information on weekly driving hours and psychosocial job factors. Company employment records for all drivers, providing information on separation dates between March 1st, 1986 and April 28th, 2001. The workers' compensation insurer's database, containing information on work-related injuries by Muni drivers until February 13th, 2001. A medical bill review file containing all physician diagnoses made throughout the history of each workers' compensation claim based on the 9th revision of the International Classification of Disease (ICD-9).

Definition and Measurement of the Outcome

The outcome of the study was the first incidence of a compensated LBI during 7.5-years of follow up. The observation time for each subject started with the day of the baseline health survey and medical examination and was censored at the day of the first LBI, the day of separation from active duty as a transit operator, or February 13th, 2001, the day of workers' compensation data reading, which ever came first.

Low back injuries were ascertained by linking the eligible transit operators by their social security number to the workers' compensation file that included all claims from Muni employees in the follow up period from August 30th, 1993 to February 13th, 2001. The claims of these drivers were then linked by the claim number to the medical bill review file to obtain the ICD-9 codes of the claim.

LBI cases were defined by matching the following administrative and diagnostic criteria: A date of injury after the baseline medical examination, and an ICD-9 code indicating a non-traumatic injury relating to the lumbar or sacral region of the spine, according to a list of codes compiled by Cherkin et al. [1992]. This list contains codes indicative of both "possible" and "definite" spinal injuries in the low back area. While the former include unspecified sites of the spine and ambiguously defined sites (e.g., "lumbar or thoracic"), the latter codes pertain explicitly and exclusively to the lumbar or sacral region. Only cases with a "definite" diagnostic ICD-9 code on any physician bill record during the course of the claim were included. A physician was defined as a medical doctor, an osteopathic physician, or a chiropractic doctor. ICD-9 codes were used instead of ANSI injury codes as it has been shown that the latter may result in misclassification in identifying low back injuries [Oleinick et al., 1996].

Cases were excluded if, in the life of the claim, any ICD-9 code indicated a vertebral fracture, neoplasm, infection, or inflammatory disease, or if the "nature of accident" or "nature of injury" code indicated a burn, open wound, or fracture. In other words, low back injuries were excluded if they were caused by an acute trauma visibly disrupting the structural integrity of skin or bones.

Severity of LBI was defined by the most severe definite low back diagnosis recorded in the history of the claim. Cases with ICD-9 codes indicating postlaminectomy syndrome, spinal stenosis, herniated lumbar disc, sciatica, or spinal instability were classified as "more severe" compared to cases with ICD-9 codes indicating degenerative changes of the lumbar spine or non-specific low back pain, which were classified as "less severe." A list of ICD-9 codes rank-ordered by severity is provided in the Appendix. About 69% of study participants belonged to the "non-specific low back pain" group, which is roughly comparable to the 75% prevalence rate of non-specific LBI found in an unselected sample of California Low Back Pain Claimants during the years 1994–1996 [Krause et al., 1999].

Definition and Measurement of Predictor Variables and Covariates

The core biomechanical risk factors under study were physical workload and ergonomic problems. In transit vehicle operators, physical workload and the resultant cumulative biomechanical forces acting on the lumbar spine are largely determined by vehicle type and workstation design, which in turn determine type and amount of whole body vibration [Johanning et al., 1991], predominant working posture, amount of sitting and standing, movements of the trunk while driving, and forces exerted while operating steering wheels, levers, and foot pedals [Nachemson and Elfstrom, 1970].

Vehicle type was ascertained by company relicensing examination records. Participants in this study operated four different vehicle types: diesel buses, electric trolley buses, light rail trains, and the historic cable cars of San Francisco. Operators, therefore, were exposed to different types and levels of physical demands. For example, bus and light rail drivers perform their job predominantly in a sitting position, with slightly more frequent trunk flexion and rotation in order to operate the steering wheel and mechanical door openers of buses. The foot brake force of diesel and trolley bus drivers in an empty bus on a downhill slope was measured as up to 70 and 99 pounds, respectively. Industrial ergonomic design criteria for repeated force application at measured pedal angles of about 40° are 49 pounds for men, and 33 pounds for women [Alvin, 1993, p. 68]. Similar activities (operating a clutch or foot brake) have been shown to increase intradiscal pressure [Nachemson and Elfstrom, 1970]. Cable cars are operated in a predominantly standing position and require very heavy physical labor with frequent trunk bending, pushing and pulling of mechanical levers, and moving the whole vehicle on a turntable. For example, the gripman of the cable car operates a mechanical handbrake several hundred times a day to slow down the vehicle. The pulling force needed to move the levers of the brake averaged 304 pounds (SD 33 pounds) in a series of measurements with different gripmen (personal communication with ergonomist Ira Janowitz). Hand force has been identified as a biomechanical risk indicator for low back injuries [Kerr et al., 2001].

The duration of exposure to these physical factors was assessed by two additional variables. Years of professional driving, obtained from the medical examination dataset, was used as a proxy measure of past (cumulative) physical workload. Based on findings from a previous study [Krause et al., 1998b], years of professional driving were categorized into groups of less than 5 years, 6–15 years (reference group), and more than 15 years of professional driving. Weekly hours of professional driving during the last 12 months, assessed by the occupational questionnaire, was used as a proxy measure for current physical workload. For the analyses, driving hours were categorized into groups of 20–30 hr (regular part-time driver), 31–50 hr (regular full time driver, reference group), and more than 50 hr of weekly driving (drivers with substantially increased driving hours due to overtime driving). The three variables (vehicle type, driving years, and weekly hours of driving) together comprise an objective measure of physical workload in this population.

Ergonomic problems were assessed at baseline by an eight-part question developed from an ergonomic evaluation of the vehicle fleet conducted by an ergonomist in an earlier study [Thompson, 1991a; Krause et al., 1997a]. The question was: ''Think of the type of vehicle you usually drive: how much of a problem is each of the following: (a) adjusting the seat, (b) back support, (c) vibration, rocking, or bouncing of seat, (d) steering, (e) reaching across the wheel, (f) position of the cash box and transfer cutter, (g) adjusting mirrors, (h) heat, cold, or draft.'' The response categories were: (1) no problem, (2) small problem, (3) some problem, and (4) a big problem. The scores were summed to produce a single score, categorized in quartiles.

Anthropometric variables (height and weight) were recorded at the medical examination. Height and weight were categorized according to their distribution in three groups: the lower 10%, the upper 10%, and the group that included the remaining 80% of the distribution (the reference group). Standard sociodemographic variables (age, sex, race/ethnicity) were collected both at the medical examination and on the occupational questionnaire.

Psychosocial job factors were measured with scales derived from the Job Content Questionnaire (JCQ) developed by Karasek et al. [1998]. The four scales used in this study were the psychological demands scale (five items, for example: ''My job requires working very fast''), decision latitude scale (nine items, for example: ''I have a lot of say about what happens on my job''), supervisor support scale (four items, for example: ''Superintendents/dispatchers pay attention to what I am saying'') and coworker support scale (four items, for example: ''People I work with are helpful in getting the job done''). Response categories for all items were (1) strongly agree, (2) agree, (3) disagree, and (4) strongly disagree. Items were summed separately to create the four scales.

Data Analysis

All analyses were conducted with the statistical software program STATA 8.2 for Windows. Differences between responders and non-responders were calculated based on *t*-tests for independent samples and Pearson's chi square-tests.

Cox proportional hazard regression analysis was used to model the effect of each predictor variable on the rate of first LBI during 7.5-years of follow-up. Subjects contributed time at risk until the first incidence of LBI, separation as an active driver or end of follow up, whichever came first.

Multivariate analyses were performed to identify the independent effects of each predictor variable successively adjusted for different sets of variables in three models. Variables were selected based on theoretical grounds and on results from previous prospective and cross-sectional studies of urban transit operators [Krause et al., 1997a, 1998a]. In the first model, physical workload, ergonomic problems, and anthropometric variables were each analyzed separately, with adjustment for age, sex, and race/ethnicity. In the second model, all of these variables were included together in the same model. In the third (full) model, physical workload, ergonomic problems, and anthropometric and demographic variables were included in the same model additionally adjusted for four psychosocial job factors (psychological demands, decision latitude, supervisor support, co-worker support). Analyses were also stratified for the full model by severity of injury: Drivers with less severe injuries and more severe injuries were separately compared to drivers with no injuries.

To assess the percentage of injuries that could be prevented if the specific risk factors were removed, the etiologic fraction among the exposed (also called attributable risk percent) and the etiologic fraction among the study population (also called population attributable risk percent) were calculated. These analyses were restricted to hours of weekly driving and ergonomic problems, because these exposures are modifiable. The etiologic fraction among the exposed (EF_e) was calculated as (HR−1)/HR, where HR is the fully adjusted hazard ratio for those exposed in each exposure category in comparison with the reference group. The etiologic fraction among the whole study population (EF_p) was calculated as $EF_e \times CF$, where CF is the fraction of all cases for each exposure category [Miettinen, 1974]. To calculate forecasted cost savings, the population etiologic fraction of injuries was multiplied by the mean total direct workers' compensation cost determined separately for less and more severe injuries.

RESULTS

Frequencies of Injuries

Among the 1,841 eligible drivers, a total of 3,688 workers' compensation claims were observed during the 7.5-year follow up period. Mean time of observation was 1,744 days (4.8 years) with a range of 2–2,724 days (7.5 years). ICD-9 codes were missing for 497 of the claims (13.5%), leaving a total number of 3,191 claims. Of these claims, 910 (28.5%) had at least one ICD-9 code that was indicative of a definite LBI diagnosis. The medical bills reviewed contained up to four ICD-9 codes per bill and up to 46 different ICD-9 codes per LBI case. Based on these additional codes, 127 injuries were excluded, because at least one ICD-9 code indicated the presence of neoplasm (n = 10), diffuse disease of connective tissue (n = 1), athropathy associated with other underlying endocrine and metabolic disorders (n = 1), osteomyelitis (n = 2), fractures (n = 45), dislocations (n = 44), open wounds (n = 6), crushing injury (n = 1), burns (n = 7), spinal cord, plexus, and nerve root injuries (n = 9), and pregnancies (n = 1). In addition, five injuries were excluded because the workers' compensation claim file indicated that the type of injury was abrasion (n = 1) or skin lesion (n = 1) or was caused by contact to electricity (n = 1), temperature (n = 1), or fire (n = 1).

Of the 778 low back injuries that remained after applying all exclusion criteria, 501 injuries occurred among the 1,233 study participants (8.33 injuries per 100 subjects per year of observation), 108 injuries occurred among the 270 subjects who responded to the occupational questionnaire but who were excluded because of missing values or driving less than 20 hr per week (8.45 injuries per 100 subjects per year), and 169 injuries occurred in the 338 subjects who did not respond to the occupational questionnaire (11.19 injuries per 100 subjects per year).

Table I shows the injuries for the 1,233 study participants by order of occurrence. Of the 501 low back injuries, 331 were first low back injuries, which is the outcome in the following analyses. The mean time between the baseline examination and the first reported LBI was 905 days (2.5 years), with a range of 2–2,518 days (6.9 years) and a median of 822 days (2.3 years).

Comparison of Study Participants and Non-Responders

Table II compares the 1,233 subjects who constitute the study sample for the analyses in this paper to the 338 subjects who did not fill out the occupational questionnaire. There were no statistically significant differences between the two groups with regard to age, sex, height, weight, years of professional driving, vehicle type, and ergonomic problem score (all $P \geq 0.10$). The ethnic/racial distribution, however, was different ($P < 0.001$), with more African Americans and fewer Asian/Pacific Islanders and Hispanics among the non-responders. Non-responders also had a higher incidence of LBI during the follow up than study participants (34 vs. 27%, $P = 0.01$). There was, however, no difference in the type of injury or the severity ranking of the injury ($P = 0.60$ and $P = 0.19$, respectively).

The results above remained virtually unchanged when all 1,503 responders, including the 270 responders with some missing data or driving less than 20 hr, were compared to the 338 non-responders. Comparisons of weekly driving hours and psychosocial job factors could not be calculated, because these variables were assessed by questionnaire.

Multivariate Predictors of Incidence of Low Back Injury

Table III shows adjusted LBI hazard ratios and 95% confidence intervals for physical workload (years and weekly hours of driving, vehicle type), ergonomic problems, and

TABLE I. Frequency of Low Back Injuries and Order of Occurrence Among 1,233 Study Participants

	First injury	Second injury	Third injury	Fourth injury	Fifth injury	Sixth injury	Seventh injury	Eighth injury	All injuries
Low back injury	331	115	37	12	3	1	1	1	501

San Francisco Transit Operator Cohort 1993–2001.

TABLE II. Characteristics of Study Sample Compared With Non-Responders

Variable	Study participants[a] (n = 1,233) Mean or n	(SD or %)	Non-responders (n = 338) Mean or n	(SD or %)	t or χ^2	P
Age (years)	46.7	(7.8)	47.2	(7.2)	0.92	0.36
Sex						
Men	1,055	(85.6%)	280	(82.8%)		
Women	178	(14.4%)	58	(17.2%)	1.54	0.21
Race/ethnicity						
African American	671	(54.4%)	217	(66.6%)		
Asian/Pacific Islander	239	(19.4%)	35	(10.7%)		
Hispanic	157	(12.7%)	22	(6.8%)		
Caucasian	148	(12.0%)	41	(12.6%)		
Other	18	(1.5%)	11	(3.4%)	30.84	<0.001
Height (cm)	173.2	(8.7)	173.7	(8.9)	0.94	0.35
Weight (kg)	87.4	(18.7)	88.9	(20.0)	1.30	0.20
Years of professional driving	13.3	(8.1)	14.1	(7.4)	1.48	0.14
Vehicle type						
Diesel bus	555	(45.0%)	142	(51.3%)		
Trolley bus	421	(34.1%)	78	(28.2%)		
Light rail	160	(13.0%)	30	(10.8%)		
Cable car	97	(7.9%)	27	(9.8%)	6.17	0.10
Ergonomic problem score	15.8	(5.9)	15.3	(6.4)	1.48	0.14
Subjects with a low back injury during the follow-up period	331	(26.8%)	114	(33.7%)	6.19	0.01
Type of first low back injury in follow-up period[b]						
Postlaminectomy syndrome	1	(0.3%)	1	(0.9%)		
Spinal stenosis	9	(2.7%)	2	(1.8%)		
Herniated disc with myelopathy	8	(2.4%)	2	(1.8%)		
Herniated disc without myelopathy	61	(18.4%)	15	(13.2%)		
Sciatica	23	(7.0%)	7	(6.1%)		
Possible instability	1	(0.3%)	1	(0.9%)		
Probably degenerative changes	12	(3.6%)	8	(7.0%)		
Non-specific backache	216	(65.3%)	78	(68.4%)	5.49	0.60
Severity of first low back injury in follow-up period[c]						
Less severe	228	(68.9%)	86	(75.4%)		
More severe	103	(31.1%)	28	(24.6%)	1.75	0.19

[a]Responders with complete information on all variables under study. Responders with missing values (n = 222) and driving less than 20 hr per week (n = 48) are excluded from this table; however, they showed a similar distribution in all variables listed.
[b]Ranked by severity from highest to lowest.
[c]Severity was classified by ICD-9 codes as listed in the Appendix.

anthropometric and demographic variables. The first model adjusts each variable for age, sex, and race/ethnicity, the second model adjusts for all variables in the table, and the third (full) model additionally adjusts for four psychosocial job factors (psychological demands, decision latitude, supervisor support, coworker support).

Compared to driving 6 to 15 years, professional driving for 5 years or less was associated with a significant increase in the hazard rate of LBI (HR = 1.36, 95% CI = 1.01–1.83, $P = 0.045$) in the fully adjusted model (Model 3 in Table III).

Compared to part-time driving (20–30 hr per week), full-time driving (31–50 hr per week) was associated with an increase in the hazard rate of LBI by 51% (HR = 1.51, 95% CI 0.96–2.36, $P = 0.071$), and driving overtime (more than 50 hr per week) was associated with an increase in the hazard rate by 117% (HR = 2.17, 95% CI = 1.28–3.68, $P = 0.004$). Compared to all full- and overtime drivers combined (31 hr or

TABLE III. Adjusted Low Back Injury Hazard Ratios[a] for Physical Workload, Ergonomic Problems, and Anthropometric and Demographic Factors

		Model 1		Model 2		Model 3	
Variable	**n**	**Hazard ratio**	**95% confidence interval**	**Hazard ratio**	**95% confidence interval**	**Hazard ratio**	**95% confidence interval**
Years of professional driving							
5 or less	262	1.15	0.86–1.54	1.36	1.01–1.83	1.36	1.01–1.83
6–15	566	1.00	Reference	1.00	Reference	1.00	Reference
>15	405	0.90	0.67–1.22	0.86	0.63–1.18	0.86	0.63–1.18
Total driving hours per week							
20–30 (part-time)	107	1.00	Reference	1.00	Reference	1.00	Reference
31–50 (full-time)	990	1.53	1.00–2.33	1.54	0.98–2.39	1.51	0.96–2.36
>50 (overtime)	136	2.05	1.24–3.37	2.24	1.33–3.76	2.17	1.28–3.68
Vehicle type							
Diesel bus	555	1.00	Reference	1.00	Reference	1.00	Reference
Trolley bus	421	1.03	0.81–1.31	0.95	0.74–1.21	0.96	0.75–1.23
Light rail	160	0.75	0.48–1.14	0.80	0.52–1.24	0.79	0.51–1.23
Cable car	97	1.58	1.05–2.37	1.93	1.25–2.98	1.82	1.17–2.84
Ergonomic problems							
1st quartile (low)	298	1.00	Reference	1.00	Reference	1.00	Reference
2nd quartile	267	1.20	0.84–1.70	1.28	0.90–1.82	1.26	0.88–1.80
3rd quartile	322	1.35	0.97–1.86	1.52	1.08–2.13	1.48	1.05–2.09
4th quartile (high)	346	1.42	1.03–1.95	1.58	1.13–2.20	1.54	1.09–2.17
Height							
Small (<162 cm)	115	0.86	0.58–1.28	0.86	0.57–1.28	0.84	0.56–1.26
Reference (162–183 cm)	984	1.00	Reference	1.00	Reference	1.00	Reference
Tall (>183 cm)	134	1.29	0.92–1.80	1.26	0.90–1.77	1.26	0.90–1.77
Weight							
Light (<67 kg)	129	0.82	0.55–1.24	0.88	0.59–1.33	0.91	0.60–1.38
Reference (67–112 kg)	979	1.00	Reference	1.00	Reference	1.00	Reference
Heavy (>112 kg)	125	1.00	0.71–1.41	0.92	0.65–1.31	0.92	0.64–1.30
Age (years)							
<40	234	1.24	0.95–1.61	1.15	0.86–1.54	1.16	0.86–1.55
40–50	610	1.00	Reference	1.00	Reference	1.00	Reference
>50	389	0.62	0.47–0.82	0.72	0.53–0.97	0.72	0.53–0.97
Sex							
Men	1055	1.00	Reference	1.00	Reference	1.00	Reference
Women	178	1.39	1.05–1.83	1.52	1.10–2.11	1.52	1.10–2.11
Race/ethnicity							
African American	671	1.00	Reference	1.00	Reference	1.00	Reference
Asian/Pacific islander	239	0.49	0.35–0.70	0.54	0.38–0.78	0.55	0.38–0.79
Hispanic	157	0.93	0.68–1.28	0.98	0.70–1.37	0.97	0.70–1.36
Caucasian	148	0.87	0.61–1.26	0.81	0.55–1.21	0.82	0.55–1.21
Other	18	0.45	0.14–1.39	0.43	0.14–1.35	0.43	0.14–1.37

San Francisco Transit Operator Cohort 1993–2001, n = 1,233.
[a]Based on multivariate Cox proportional regression analyses: Model 1: Each variable adjusted for age, sex, race/ethnicity. Model 2: Each variable adjusted for all other variables in the table. Model 3: Model 2 + adjustment for four psychosocial job factors (psychological demands, decision latitude, supervisor support, coworker support).

more, not shown in table), part-time drivers had a 56% lower hazard rate (HR = 0.64, 95% CI = 0.41–1.00, $P = 0.050$). When driving hours were entered as a continuous variable in the full model, a statistically significant exponential dose–response relationship was found between weekly driving hours and the hazard of LBI: for every 10 hr of weekly driving, the LBI rate increased by 12% (HR = 1.12, 95% CI = 1.00–1.25, $P = 0.047$, not shown in table).

Compared to bus driving, operating street-cars (light rail) was associated with a slightly reduced hazard (HR 0.79, 95% CI = 0.51–1.23, $P = 0.30$), and operating cable cars was associated with a statistically significant increased injury rate (HR = 1.82, 95% CI = 1.17–2.84, $P = 0.008$). The ergonomic problem score showed a strong relationship with low back injuries. Compared to subjects who scored in the first quartile of the scale (low ergonomic problems), subjects in the second to fourth quartiles had hazard ratios of 1.26 ($P = 0.20$), 1.48 ($P = 0.02$), and 1.54 ($P = 0.01$), respectively. When entered as a continuous variable in the full model, every 10-point increment on the ergonomic problem scale (mean 15.83, SD 5.91, range 8–32) was associated with a 21% increase in LBI rates (HR = 1.21, 95% CI = 1.00–1.47, $P = 0.053$, not shown in table).

There was a significantly higher hazard rate for women (HR = 1.52, $P = 0.01$) and a decreased rate for subjects older than 50 years (HR = 0.72, $P = 0.03$). Age entered as a continuous variable showed a statistically significant inverse relationship: for every 10-year increase in age, injury risk decreased by 25% (HR = 0.80 95% CI = 0.66–0.97, $P = 0.02$, not shown in table). Compared to African Americans, which was by far the largest ethnic/racial group, Asian and Pacific Islanders had a significantly decreased hazard rate (HR = 0.55, $P = 0.001$).

Analysis Stratified by Severity

When the data analysis was stratified by severity of injury (less severe vs. more severe), different risk patterns emerged (Table IV). Professional driving of five years or less was predictive of less severe injuries (HR = 1.55, $P = 0.02$) but not of more severe injuries (HR = 1.05, $P = 0.88$).

Full-time weekly driving of 31–50 hr was associated with a 39% increase in less severe injuries ($P = 0.19$), and a 134% increase in more severe injuries (HR = 2.34, $P = 0.12$). Overtime driving (more than 50 hr per week) was associated with a 62% increase in less severe injuries (HR = 1.62, $P = 0.14$) and a 460% increase in more severe injuries (HR = 5.60, $P = 0.003$). Compared to part-time drivers (20–30 hr), full time and overtime drivers combined (31 hr or more) had a 41% increased hazard rate for less severe injuries (HR = 1.41, $P = 0.17$) and a 159% increased hazard rate for more severe injuries (HR = 2.59, $P = 0.08$, not shown in table). When analyzed as a continuous variable, an increase of 10 hr in weekly driving was not associated with less severe injuries (HR = 1.04, 95% CI = 0.91–1.20, $P = 0.55$), but significantly predicted more severe injuries (HR = 1.39, 95% CI = 1.15–1.68, $P = 0.001$, not shown in table).

Cable car operators had a higher hazard rate for both less severe (HR = 1.64, $P = 0.07$) and more severe injuries (HR = 2.76, $P = 0.01$) compared to diesel bus drivers. The hazard ratios for a high ergonomic problem score (3rd and 4th quartile) were similar for less and for more severe injuries, ranging from 1.49 to 1.65. These associations were statistically significant only for less severe injuries ($P = 0.05$ and $P = 0.02$ for 3rd and 4th quartile, respectively), because of the small number of cases with more severe injuries ($P = 0.11$ and $P = 0.19$, respectively). Entered as a continuous variable, 10 units of the ergonomic problem scale were associated with similar effect sizes for both less severe (HR = 1.20, 95% CI 0.95–1.52, $P = 0.12$) and more severe low back injuries (HR = 1.33, 95% CI 0.94–1.88, $P = 0.11$, not shown in table).

Women were at higher risk for both less severe (HR 1.38, $P = 0.12$) and more severe injuries (HR 2.02, $P = 0.01$).

Forecasted Reduction in Low Back Injuries by Reduction in Weekly Driving Hours and Ergonomic Problems

Table V shows, by injury severity, the etiologic fractions for duration of weekly driving hours and ergonomic problems, for the exposed group and for the whole study population. Among operators who drove more than 50 hr per week, 38% of the 26 less severe and 82% of the 23 more severe injuries were attributable to their longer work hours compared to part-time drivers, who drove between 20 and 30 hr per week (etiologic fraction among exposed). Among operators who drove more than 30 hr (full- and overtime drivers combined), 29% of the 207 less severe and 61% of the 99 more severe back injuries were attributable to the larger number of driving hours. Taking into account the distribution of part- and full-time work in the company, assigning all full- and over-time drivers to current average levels of part-time driving would prevent a forecasted 26% of less severe and 59% of more severe low back injuries among current drivers in the company (etiologic fraction among study population or population attributable risk).

These forecasts do not take into account injuries among new drivers who would need to be hired in order to maintain full transport service at reduced weekly hours. Preliminary analyses (calculations not shown) indicate that about 1,034 new part-time drivers would have to be added if all 1,233 study participants only worked part-time. The net effect of risk reduction and workforce expansion would be an increase (by 71 cases) of less severe low back and a decrease (by 29 cases) of more severe injuries. Mean total workers' compensation costs of the injuries in this study were $10,435 for less severe and $36,227 for more severe injuries. The forecasted net effect of assigning a part-time work schedule to all transit operators in this cohort and accounting for costs due to additional injuries among the expanded workforce of part-time drivers is a reduction of $309,725 in total direct workers' compensation costs over a 7.5 year period.

If ergonomic problems were reduced to the lower level currently experienced by a quarter of operators, the forecasted reduction of injuries would be 64 (28%) for less severe and

TABLE IV. Adjusted[a] Low Back Injury Hazard Ratios[b] for Physical Workload, Ergonomic Problems, Anthropometric and Demographic Factors

		Less severe injuries Cases: 228 Non-Cases: 902			More severe injuries Cases: 103 Non-Cases: 902	
Variable	**n**	**Hazard Ratio**	**95% Confidence Interval**	**n**	**Hazard Ratio**	**95% Confidence Interval**
Years of professional driving						
5 or less	241	1.55	1.08–2.21	192	1.05	0.59–1.87
6–15	509	1.00	Reference	466	1.00	Reference
>15	380	0.91	0.62–1.34	347	0.69	0.40–1.20
Total driving hours per week						
20–30 (part-time)	103	1.00	Reference	86	1.00	Reference
31–50 (full-time)	914	1.39	0.85–2.30	809	2.34	0.80–6.78
>50 (overtime)	113	1.62	0.86–3.04	110	5.60	1.79–17.51
Vehicle type						
Diesel bus	512	1.00	Reference	446	1.00	Reference
Trolley bus	381	0.92	0.68–1.24	341	1.08	0.69–1.67
Light rail	151	0.68	0.40–1.17	143	1.13	0.52–2.46
Cable car	86	1.64	0.96-2.78	75	2.76	1.24–6.14
Ergonomic problems						
1st Quartile (low)	277	1.00	Reference	258	1.00	Reference
2nd Quartile	252	1.41	0.92–2.15	217	0.92	0.47–1.80
3rd Quartile	290	1.51	0.99–2.30	259	1.63	0.90–2.96
4th Quartile (high)	311	1.65	1.08–2.50	271	1.49	0.81–2.74
Height						
Small (<162 cm)	106	0.88	0.54–1.43	92	0.69	0.33–1.47
Reference (162–183 cm)	902	1.00	Reference	812	1.00	Reference
Tall (>183 cm)	122	1.35	0.91–2.02	101	1.07	0.56–2.05
Weight						
Light (<67 kg)	123	0.96	0.60–1.54	107	0.72	0.30–1.71
Reference (67–111 kg)	891	1.00	Reference	802	1.00	Reference
Heavy (>111 kg)	116	1.03	0.68–1.56	96	0.69	0.34–1.40
Age (years)						
<40	212	1.22	0.86–1.73	172	1.04	0.60–1.83
40-50	552	1.00	Reference	488	1.00	Reference
>50	366	0.69	0.47–1.00	345	0.71	0.42–1.20
Sex						
Men	975	1.00	Reference	873	1.00	Reference
Women	155	1.38	0.92–2.06	132	2.02	1.15–3.55
Race/ethnicity						
African American	607	1.00	Reference	532	1.00	Reference
Asian/Pacific Islander	234	0.65	0.43–0.98	203	0.23	0.09–0.58
Hispanic	134	0.80	0.51–1.25	131	1.40	0.83–2.37
Caucasian	138	0.86	0.54–1.37	123	0.68	0.33–1.40
Other	17	0.40	0.10–1.64	16	0.42	0.06–3.12

Stratified by Severity of Injury San Francisco Transit Operator Cohort 1993–2001, n = 1,233. Severity was classified by ICD-9 codes as listed in the Appendix.

[a]All variables adjusted for each variable shown in the table and for psychosocial job factors (psychological demands, decision latitude, supervisor support, coworker support; same covariates as in Model 3 of Table III).

[b]Based on Cox proportional hazard model.

TABLE V. Percentage of Injuries Attributable to Amount of Weekly Driving Hours and Ergonomic Problems Among the Exposed and Among the Total Study Population (n = 1,233), by Injury Severity

	Less severe injures				More severe injuries			
Variable	Number of 1st low back injury	Fully adjusted hazard ratio[a]	Etiologic fraction among exposed[b]	Etiologic fraction among study population[c]	Number of 1st low back injury	Fully adjusted hazard ratio[a]	Etiologic fraction among exposed[b]	Etiologic fraction among study population[c]
Weekly driving hours								
20–30 (part-time)	21	1.00	Reference	Reference	4	1.00	Reference	Reference
31–50 (full-time)	181	1.39	28%	22%	76	2.34	57%	42%
> 50 (overtime)	26	1.62	38%	4%	23	5.60	82%	18%
> 30 (full- or overtime)	207	1.41	29%	26%	99	2.59	61%	59%
Ergonomic problems								
1st Quartile (low)	40	1.00	Reference	Reference	21	1.00	Reference	Reference
2nd Quartile (medium-low)	50	1.41	29%	7%	15	0.92	—	—
3rd Quartile (medium-high)	63	1.51	34%	9%	32	1.63	39%	12%
4th Quartile (high)	75	1.65	39%	13%	35	1.49	32%	12%
Medium low to high (combination of the second to fourth exposure group)	188	1.51	34%	28%	82	1.32	24%	19%

[a]Adjusted for physical workload (years of professional driving, driving hours per week, vehicle type), ergonomic problems, demographic variables (age, sex, race/ethnicity), anthropometric variables (height, weight), and psychosocial job factors (psychological demands, decision latitude, supervisor support, coworker support).
[b]Percentage of injuries in the specific exposure group attributable to the exposure.
[c]Percentage of injuries in the whole study population attributable to the exposure (n = 1,130 for drivers with no or less severe injury, n = 1,005 for drivers with no or more severe injury).

20 (19%) for more severe injuries (based on population attributable risk). The forecasted savings of total workers' compensation costs associated with such a reduction would total $1,392,380 for 1,233 operators over a 7.5 year period.

The estimates of cost savings are limited to first injuries in the observation period. Additional savings can be forecasted regarding repeat injuries which were not studied here.

DISCUSSION

Summary of Findings

The purpose of this study was to examine the impact of physical workload and ergonomic problems on the incidence of low back injuries. All physical workload and ergonomic variables were adjusted for psychosocial job factors, demographic and anthropometric factors, and each other. The main results can be summarized as follows: Transit operators who had been professional drivers for 5 years or less had a 36% increased risk for all low back injuries. A stratified analysis showed that the increased risk for this group was mostly due to an increase in less severe injuries. There was an exponential dose–response relationship between hours of weekly driving and injury risk. Each 10-hr increase in weekly driving was associated with a 12% increased injury risk, 4% for less severe, and 39% for more severe low back injuries, respectively. Compared to part-time drivers (driving 20–30 hr per week), the majority of full-time drivers (31–50 hr per week) had a 51% increased injury risk. Transit operators who drove more than 50 hr per week had a 117% increased risk for all low back injuries, and a 460% increased risk for more severe injuries. Assigning all full-time (more than 30 hr) drivers to part-time driving (20–30 hr) would reduce the number of severe low back injuries among the study population by 59%. Cable car operators, who perform heavy physical labor, had a 64 and 176% increased risk for less and more severe injuries, respectively. Drivers who scored high on the ergonomic problem scale had a significantly higher risk for LBI, with a 21% increased injury risk for every 10-point increase on the ergonomic problem scale. Reducing ergonomic problems to the low level currently experienced by 25% of employees would result in a 28% reduction of all less severe and a 19% reduction of all more severe low back injuries. Younger drivers and women had a significantly increased injury risk independent of height, weight, and physical and psychosocial job factors. Injury risk decreased by 25% for every 10 years of age.

Strengths and Limitations

The prospective design is a major strength of this study and allows for a causal interpretation of the findings

[Rothman, 1986]. The use of Cox regression models ensured that risk estimates took the length of the injury-free periods between baseline examination and first injury into account. Adjusting for potential confounders, including worker characteristics and psychosocial job factors, overcomes a major limitation of earlier studies [Bongers et al., 1993; Krause et al., 1997a].

The outcome measure in this study was based on administrative medical bill review records containing all ICD9 diagnosis codes assigned by physicians throughout the life of a claim. This method of assessing outcome has several advantages. First, it reduces the misclassification observed in studies using workers' compensation ANSI codes or body part injured [Oleinick et al., 1996]. Second, all medical diagnoses in the entire history of a claim were reviewed, thereby taking into account diagnostic findings not available at the time of the first injury report. For example, confirmation and further specification of initial diagnoses through radiographic imaging techniques typically occurs only during subsequent doctor visits and after some trial therapy. Third, common method bias, i.e., the tendency to find spurious associations in studies measuring both predictors and outcome by self-report, is avoided [Spector, 1987; Williams et al., 1989]. Fourth, results were stratified by severity of injury, revealing a severity-specific risk factor pattern. Compared to less severe injuries, more severe injuries showed a weaker association with age or seniority, but were more strongly associated with increased work hours, heavy physical work on cable cars, and female gender. While the public health significance of mild low back pain may be disputed, severe low back injuries with prolonged disability have been recognized as a major societal burden. Seven percent of severe low back injuries are responsible for about 75% of all costs associated with work-related back pain [Hashemi et al., 1998].

The absence of individual observer-based measurements of whole-body vibration or biomechanical modeling of spinal loads may be considered a weakness in a study of ergonomic risk factors. This is a typical limitation of large-scale epidemiological studies due to the costs associated with individual standardized measurements. This limitation is minimized by the fact that physical demands do not vary appreciably between transit operators who operate the same vehicle type, a factor which was accounted for in this study. The usefulness of additional information obtained from direct measurements of whole body vibration or spinal load in the context of this study would, therefore, be questionable. Furthermore, at this company, drivers are typically assigned a different vehicle every day (although of the same vehicle type), so that a one-time observation of a specific vehicle would not substantially improve accuracy of the assessment of biomechanical risk factors associated with vehicle type. Vehicle type, in combination with duration of driving measured in years and weekly hours, constitute the main determinants of physical workload in this population, and both were included in our analyses. LBI in transit operators needs to be conceptualized as a combination of chronic cumulative biomechanical stressors, such as repeated upper body twisting movements or whole body vibration, which lead to fatigue of the spine, and repetitive or singular biomechanical stressors such as contusions, abrupt movements, and sudden increases in mechanical loads, which act on the fatigued spinal structures and precipitate the onset of pain with or without temporary or permanent structural damage. Accordingly, cumulative past (long-term) and current (short-term) exposure to biomechanical forces need to be taken into account, which was achieved by measuring past years and current hours of driving. Although information on physical workload was easy to obtain from drivers, company records of vehicle type and driving history were used instead in order to reduce recall error, and to increase the objectivity of the measurement, i.e., independence from worker or expert appraisal. Additional objective information on body height and weight and self-reported information from the ergonomic questionnaire were used to further account for individual variation in ergonomic misfit.

The individual assessment of ergonomic problems by self-report instead of by observation has its advantages and disadvantages. The ergonomic items in the occupational questionnaire were based on an on-site evaluation of the vehicle fleet by an ergonomist, which strengthens the validity of the ergonomic scale used in this study [Thompson, 1991b; Krause et al., 1997a]. Moreover, the drivers are the best source of information for rating the extent and severity of any ergonomic problems at the individual level. On the other hand, an ergonomic observation has the advantage of evaluating in more detail any ergonomic misfit.

To account for any major systematic ergonomic misfit of the physical dimensions of the workstation and the physical size of the individual driver, two anthropometric dimensions, body height and weight, were included in the multivariate model. Based on the report of the ergonomist and an earlier cross-sectional study, we hypothesized that both very small and very tall drivers would be subject to an ergonomic misfit with the standard vehicle equipment [Thompson, 1991b; Krause et al., 1997a]. However, in the fully adjusted model of this prospective study, these anthropometric factors accounted for little additional risk, supporting the notion that the indirect measures of physical workload and ergonomic factors utilized in this study captured much of the relevant exposure.

Like most prospective studies, the predictor variables were measured only once, at the beginning of the study, thereby preventing any analytical adjustments for changes in the predictor variables that may have occurred during the follow-up period. However, the drivers in this public transportation company rarely switch from one vehicle type to another, and the vehicle fleet remained largely unchanged throughout the follow-up. Other factors such as hours of weekly driving or specific ergonomic problems may have changed during follow-up. A possible consequence of not adjusting for changing values of predictors is non-differential misclassification, which usually biases the results towards the null hypothesis [Rothman and Greenland, 1998]. Therefore, the hazard ratios for physical workload and ergonomic problems reported in this study potentially represent an underestimation of the true effect sizes.

Discussion of Findings, Comparison With Previous Studies, and Implications for Prevention

The findings of this study contribute to an understanding of the occupational epidemiology of LBI and musculoskeletal disorders in general, and have implications for the prevention of LBI among the high risk group of professional drivers and public transit operators in particular. The findings suggest that physical job demands and ergonomic problems associated with the operation of motor vehicles are strong predictors of LBI, especially more severe injury characterized by objective morphological changes, even after adjustment for possibly confounding psychosocial job factors.

This study confirms findings from a cross-sectional and prospective cohort study conducted within the same company 5–10 years earlier, both showing strong associations between biomechanical factors and spinal disorders [Krause et al., 1997a, 1998a]. The findings are also consistent with several recent prospective studies conducted in different study populations [Krause et al., 1998a; Thorbjornsson et al., 2000; Torp et al., 2001], a larger body of earlier high quality cross-sectional and case-control studies reviewed in 1997 [Bernard, 1997], and a recent case-control study [Kerr et al., 2001]. Inconsistent findings were reported from two prospective studies, but they lacked adequate individual measurements of physical workload [Bigos et al., 1991; Hoogendoorn et al., 2000a].

Years of professional driving

The increased injury risk for drivers with five or fewer years of professional driving could be due to several causes. Drivers with health problems may leave this very demanding occupation after only a few years of service [Backman and Jarvinen, 1983], resulting in a selection bias known as the healthy worker effect [Eisen et al., 1995]. More senior drivers may tend to have a higher acceptance of less severe low back pain and, therefore, underreport work-related low back injuries. The latter interpretation would be in accordance with our findings that the higher risk among less senior drivers was limited to less severe injuries.

Weekly driving hours

The strong association between weekly driving hours and LBI, especially for more severe injuries, replicates findings from previous cross-sectional and prospective studies in the same company [Krause et al., 1997a, 1998a] and confirms previous evidence for a causal role of motor vehicle driving in work-related spinal disorders [Kelsey and Hardy, 1975; Netterstrøm and Juel, 1989; Johanning, 1991; Bovenzi and Zadini, 1992; Pietri et al., 1992; Jensen et al., 1996; Gluck and Oleinick, 1998]. It shows that the prolonged weekly exposure to driving takes its toll. As other studies have shown, the high risk of this occupation is not restricted to low back injuries, but also includes cardiovascular and gastrointestinal disease [Winkleby et al., 1988; Albright et al., 1992; Belkic et al., 1994; Evans, 1994; Tüchsen and Endahl, 1999]. A review of research on health problems among bus drivers stated that ‘‘it is usually not possible for transit operators to work full-time in their profession throughout their occupational career’’ [Tränkle and Bailer, 1996].

Potential for prevention

With respect to prevention, our findings suggest that reducing weekly driving hours could substantially lower the risk of LBI among drivers. Assigning all full time drivers to part-time driving of 20 to 30 hr per week would eliminate 26% of all less severe and 59% of all more severe low back injuries. Limiting weekly driving hours to a maximum of 50 hr would still prevent 4% of less severe and 18% of more severe injuries. Reduced driving hours can be achieved without reduction in pay by offering job rotation between driving and non-driving assignments (e.g., supervisory, maintenance, and administrative jobs). Alternatively, creation of more part-time jobs and reduction of overtime through hiring of more employees would reduce exposure, but this approach is problematic if these measures result in reduced income for drivers. Further, although reduced work hours could reduce the risk of back injuries among professional drivers, such gains would be partially offset by a larger number of employees exposed to the remaining risks of driving leading to a wider distribution of a decreased injury risk among more employees without substantially reducing the number of injuries at the company level if overall services were maintained. The net effect of reduced work hours across current employees and additional hires will be greater if the risk function accelerates with more driving hours. Although our finding of an exponential dose response curve suggests that such risk acceleration is present, its exact size is difficult to determine. Nevertheless, recent reviews of intervention studies in public transportation companies in Europe have shown that work organizational changes, including reduction in weekly driving hours, can lead to a significant decrease in sickness absence, increases in productivity, and subsequently, in cost savings for the company [Kompier et al., 2000; Aust, 2001]. In most interventions, customary income levels had been preserved during these changes, which is arguably an essential feature for the overall success of such interventions.

The significant impact of ergonomic problems on LBI in this study confirms earlier cross-sectional findings that reported a strong association between ergonomic problems and self-reported back and neck pain [Krause et al., 1997a]. Apart from the situation with cable cars, all the ergonomic problems assessed in this study are modifiable in the bus and light rail fleets. The existence of a monotonic positive association between ergonomic problems and LBI implies that even modest modifications could result in a significant decrease in injury frequency. For example, ergonomic improvements that reduce the ergonomic problems to the lower level currently experienced by one quarter of drivers would eliminate 28% of less severe and 19% of more severe injuries. Moreover, ergonomic interventions may also reduce work disability for drivers who suffer from prolonged back pain. A recent randomized control trial involving 32 companies has shown that an ergonomic intervention was about twice as effective in reducing long-term disability after LBI than a state-of-the-art medical and behavioral treatment program [Loisel et al., 1997, 2001].

The higher risk of injury found among cable car operators is similar to findings observed in a previous study in the same population [Krause et al., 1998a] and supports the independent role of physical factors in the etiology of low back injuries. This new study also shows that the risk of severe LBI associated with cable cars is especially high compared to other vehicle types. Similarly elevated risks were observed for both motormen and conductors of cable car crews in stratified analyses (not shown in tables). While motormen bend frequently and push and pull mechanical levers, all cable car crew members stand most of the day, and they have to manually turn the cable car around at the end of the line, requiring heavy pushing and pulling. Unfortunately, the legally protected historic features of cable cars limit the options for ergonomic prevention in this subgroup of operators. In addition to carefully investigating every possibility for changes in workplace conditions for cable car operators, job rotation and reduced work hours remain the main options for prevention in this subgroup of operators.

CONCLUSION

This study overcomes several methodological limitations of previous research and provides strong evidence for a causal role of physical workplace factors in the incidence of occupational low back injuries. Physical workload, duration of driving, and ergonomic workplace conditions were significant predictors of LBI among the urban transit operators in this study, even after taking individual and psychosocial risk factors into account. Most of these work conditions are amenable to change and, therefore, indicate a substantial potential for prevention at the workplace. The actualization of this potential could prevent low back injuries and associated work disability in this high risk occupation, and reduce the substantial human and economic costs associated with LBI.

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Appendix: Definition of Severity of Low Back Injury by ICD-9 Codes

The following table lists the diagnostic codes used in this study to determine possible and definite low back injury (LBI) cases, injury severity (1 = highest, 9 = lowest severity rank), and injury severity group rankings based on ICD-9-CM codes contained in the International Classification of Diseases, 9th revision, Clinical Modification, 5th Edition, 1997. The clinical categories are based on the work of Cherkin et al. [1992]. The severity ranking is based on clinical judgment by the first author (Krause) and has been used in previous epidemiological studies of occupational low back pain [Dasinger et al., 1999, 2000, 2001; Krause et al., 1999, 2001], showing good predictive validity in terms of a strong association with duration of work disability [Dasinger et al., 2000].

Diagnoses definitely or possibly associated with lowback problems, severity rank, and group

Clinical category	ICD-9 Code(s)	Diagnosis	Severity rank[a]	Severity Group[b,c]
Herniated disc	722.1	Displacement of thoracic or lumbar disc without myelopathy	4	2
	722.10	Displacement of lumbar disc without myelopathy	4	2
	722.2	Displacement of unspecified disc without myelopathy	4	2
	722.7	Disc disorder with myelopathy, site unspecified	3	1
	722.73	Lumbar disc disorder with myelopathy	3	1
Probably degenerative changes	*721.3*	Lumbosacral sypondylosis without myelopathy	7	3
	721.5-6	Unique or unusual forms of spondylosis	7	3
	721.8-9	Unique or unusual forms of spondylosis	7	3
	722.52	Degeneration of lumbar or lumbosacral disc	7	3
	722.6	Degeneration of disc, site unspecified	7	3
	722.90	Other and unspecified disc disorder, site unspecified	7	3
	722.93	Other and unspecified lumbar disc disorder	7	3
	720.10	spinal enthesiopathy	7	3
Spinal stenosis	*721.42*	Spondylogenic compression of lumbar spinal cord	2	1
	721.91	Spondylogenic compression of spinal cord unspecified	2	1
	724.00	Spinal stenosis, unspecified site (not cervical)	2	1
	724.09	Spinal stenosis, other	2	1
	724.02	Lumbar stenosis	2	1
Radiating back pain	*724.3*	Sciatica	5	2
Possible instability	*724.6*	Disorders of sacrum (including lumbosacral joint instability)	6	2
	738.4	Acquired spondylolisthesis	6	2
	756.11	Spondylolysis, lumbosacral region	6	2
	756.12	Spondylolisthesis	6	2

(*Continued*)

(*Continued*)

Diagnoses definitely or possibly associated with lowback problems, severity rank, and group

Clinical category	ICD-9 Code(s)	Diagnosis	Severity rank[a]	Severity Group[b,c]
Nonspecific backache	307.89	Psychogenic backache	8	3
	724.2	Lumbago	8	3
	724.5	Backache, unspecified	8	3
	846.0-9	Sprains and strains, sacroiliac	8	3
	847.1	Sprains and strains, dorsal (spine)	8	3
	847.2	Sprains and strains, lumbar	8	3
	847.3	Sprains and strains, sacral	8	3
	847.9	Sprains and strains, unspecified region	8	3
Sequelae of previous back surgery	722.80	Postlaminectomy syndrome, unspecified region	1	1
	722.83	Postlaminectomy syndrome, lumbar	1	1
	737.12	Kyphosis postlaminectomy	2	1
	737.21	Lordosis postlaminectomy	2	1
	996.4	Mechanical complication of internal orthopedic device, implant and graft	1	1
Miscellaneous	722.30	Schmorl's nodes, unspecified region	9	3
	722.32	Lumbar Schmorl's nodes	9	3
	724.4	Thoracic or lumbosacral neuritis or radiculitis, unspecified	5	2
	724.8	Other symptoms referable to back	9	3
	724.9	Other unspecified back disorders	9	3
	737.10	Kyphose aquired (postural)	9	3
	737.20	Lordosis aquired (postural)	9	3
	737.30	Idiopathic scoliosis	9	3
	737.40	Curvature of spine, unspecified	9	3
	737.41	Kyphosis	9	3
	737.42	Lordosis	9	3
	737.43	Scoliosis	9	3
	737.8	Other curvatures of spine	9	3
	737.9	Unspecified curvature of spine	9	3
	738.5	Other acquired deformity of back or spine	9	3
	739.3	Nonallopathic lesions, lumbar region	8	3
	739.4	Nonallopathic lesions, sacral region	8	3
	741.3	Spina bifida, lumbar region	9	3
	756.10	Anomaly of spine, unspecified	9	3
	756.13	Various congenital anomalies	9	3
	756.14	Various congenital anomalies	9	3
	756.15	Various congenital anomalies	9	3
	756.16	Various congenital anomalies	9	3
	756.17	Various congenital anomalies	9	3
	756.19	Various congenital anomalies	9	3

Codes in *bold italic* type are classified as "definitely low back," and other codes refer to "possibly low back" based on the definition proposed by Cherkin et al. [1992].

[a]Severity is clinically ranked on an ordinal scale from most severe (1) to least severe (9) by Krause: 1 = "Postlaminectomy syndrome"; 2 = "Spinal stenosis"; 3 = "Herniated disc with myelopathy"; 4 = "Herniated disk without myelopathy"; 5 = "Sciatica"; 6 = "Possible instability"; 7 = "Probably degenerative changes"; 8 = "Nonspecific backache"; 9 = "Miscellaneous".

[b]Severity ranks are grouped as high severity (1), middle severity (2), and low severity (3) by Krause: 1 = "Postlaminectomy syndrome, spinal stenosis, or herniated disc with myelopathy" (1–3); 2 = "Possible instability, sciatica, herniated lumbar disc without myelopathy" (4–6); 3 = "Nonspecific backache, degenerative changes, and miscellaneous" (7–9).

[c]Because of small numbers in the higher severity categories, multivariate analyses in this investigation collapsed the high and middle severity group into one category labeled "more severe;" the low severity group was labeled "less severe."