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Observational Stress Factors and Musculoskeletal Disorders in Urban Transit Operators

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Associations and pathways between observed (rather than self-reported) job stressors and musculoskeletal disorders in 66 transit operators were investigated to determine specific stressors and vulnerable body regions affected, while adjusting for physical workload. *Job stressors*, defined as barriers to progress with work, comprised 7 categories and the sum of stressors. Outcomes included back and neck pain, low back pain, neck pain, pain of the upper extremities and the lower extremities, and any combination of these. Stressors were significantly associated with the combined musculoskeletal disorders category (odds ratio [OR] = 1.55), back and neck pain (OR = 1.41), low back pain (OR = 1.46), and pain in the lower extremities (OR = 1.44) after controlling for confounders. Five barrier categories had at least 1 significant association with outcomes. Results provide specific intervention targets by avoiding common method variance bias.

Background and Theoretical Framework

Transit operators are known for high prevalence of job stress and musculoskeletal disorders (Evans, 1994; Kompier & DiMarino, 1995; Krause, Ragland, Greiner, Holman, & Fisher, 1997) and high rates of disablement due to musculoskeletal disorders, especially back pain (Kompier et al., 1990).

The literature suggests that work characteristics may have an effect on musculoskeletal pain through two types of mechanisms. One, biomechanical mechanisms indicate that increased physical workload leads to increased tissue loading, tissue failure, and pain (National Research Council, 2001). Two, psychophysiological mechanisms indicate that work stress leads to lowered pain thresholds (Theorell, Nordemar, & Michelsen, 1993) or increased muscle tension (Theorell, Harms-Ringdahl, Ahlberg-Hulten, & Westin, 1991; Ursin, Endresen, & Ursin, 1988; Waersted, Bjorklund, & Westgaard, 1991). Whereas the environmental factors that initiate biomechanical pathways are well researched, the factors that trigger psychophysiological pathways are less understood. Furthermore, it is not known which specific psychosocial job stressors are associated with musculoskeletal disorder and which body regions are most vulnerable. It is possible that stressors act anatomically specifically on the musculoskeletal system. A study of engineering workers suggested that the activation of stress-related and physical workload–related mechanisms might be anatomically specific (Randall, Griffiths, & Cox, 2002). Biomechanical mechanisms were evident for the reporting of pain in the lower body regions, and both biomechanical and psychophysiological mechanisms were operative in the report of pain in the upper body region. Finally, detailed information on specific job stressors and specific musculoskeletal disorders is important for the development of specific intervention strategies.

Both physical and psychosocial job factors have been associated with back and neck pain (Bernard, 1997; Kerr et al., 2001; Krause, Ragland, Fisher, & Syme, 1998). Whereas ergonomic factors have been consistently associated with musculoskeletal disorders (Bernard, 1997; Burdorf & Sorock, 1997; Hoogendoorn, van Poppel, Koes, & Bouter, 1999; National Research Council, 2001), the respective lit-

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erature on psychosocial factors remains inconsistent, mainly because of the failure to rule out confounding by physical risk factors (Ariens, van Mechelen, Bongers, Bouter, & van der Wal, 2001; Bernard, 1997; Bongers, de Winter, Kompier, & Hildebrandt, 1993; Davis & Heaney, 2000; Hoogendoorn, van Poppel, Bongers, Koes, & Bouter, 2000). In addition, common method variance, denial of stress, and negative affectivity may distort associations between self-reported job stress and self-reported musculoskeletal disorders. Therefore, a number of scholars have suggested using objective stressor measures in occupational stress research (Greiner & Krause, 2000; Kasl, 1993; Kristensen, 1996). Stressor measures assessed independently of worker perception might be particularly important in research with back pain as outcome because that pain experience is likely to affect perception and reporting of stress. Whereas biomechanical load can be measured independently of worker perception by observational ergonomic methods (National Research Council, 2001), observational instruments for the measurement of psychosocial job stressors have not yet been used in research on musculoskeletal disorders.

In this study of urban transit operators, observational rather than self-report methods were used to measure psychosocial job stressors and to investigate their associations with musculoskeletal disorder while adjusting for physical workload. Action regulation theory (Hacker, 1985, 1994; Volpert, 1982) provided the theoretical framework to conceptualize job stressors in the work environment. The theory allows for assessment of both, with job stressors mainly acting through biomechanical pathways and stressors mainly acting through psychophysical pathways, within one theoretical model. Task characteristics are differentiated in relation to their action regulation function into motor and information-processing operations. Motor operations include movements such as operating controls, typing, bodily posture adjustments, locomotion, carrying, lifting, and so forth Information-processing operations include perception of information relevant for carrying out the task, structuring information, forwarding or communicating information to others, and so forth. In general, job barriers are conceptualized as job situations in which the worker cannot meet job demands as expected because of poor job design and insufficient worker control. Job demands cannot be dealt with efficiently because they are not matched by appropriate external resources. The analysis of job stressors is done first by identifying specific work task demands for each job and second by evaluating whether the worker has been provided with sufficient means and resources (e.g., information, time, decision latitude) to perform the required job tasks.

We hypothesized that the prevalence of musculoskeletal disorders increases with stressor levels. The objectives of this study were to (a) determine whether observational stressors are associated with prevalence of musculoskeletal disorders in general, (b) determine whether any associations between job stressors and musculoskeletal disorders differ by body region, (c) compare the importance of stress factors that are hypothesized to mainly initiate biomechanical mechanisms with those that mainly trigger psychophysiological mechanisms, (d) control for physical workload in multivariate analysis to determine the independent effects of job stressors, and (e) identify specific job stressors associated with musculoskeletal disorder in urban transit work.

Method

Study Population

Eligible for the study were 1,974 transit operators employed by San Francisco Municipal Railways (MUNI) who completed medical examinations and extensive medical history forms during the mandatory biannual medical examinations for their driver's license renewal between August 30, 1993, and September 29, 1995. This group included virtually the entire population of transit operators for MUNI, which is one of the largest transit systems in the United States, as measured by ridership.

Sample

The sampling was done in two stages. First, 27 transit lines were chosen from a total of 90 lines operated by the company on the basis of interviews with management, union representatives, and drivers to include all vehicle types—rail, bus, and cable car—and a variety of task requirements and stressors. After the lines were selected, a convenience sample of 81 different transit runs was chosen; these were operated by 71 different operators who were contacted by the shop steward (for details of the sampling strategy, see Greiner, Ragland, Krause, Syme, & Fisher, 1997). Five operators had to be excluded because of missing or incomplete data on musculoskeletal outcomes, resulting in a sample of 66. The sample was predominantly male (79%), and participants had a mean age of 47.2 years, had worked on average 15.1 years as a professional driver, and drove an average of 47.7 hr weekly. The sample represented the total MUNI population reasonably well with regard to gender, age, vehicle type operated, and musculoskeletal disorders. However, participants had a significantly longer history of professional driving (mean 15.1 vs. 13.3 years) and significantly longer weekly driving hours (47.7 vs. 42.6 hr) than the full population.

Measurement of Observational Job Stressors

Observational job analyses were conducted during regular working hours by seven trained job analysts. The job analysts followed a structured protocol that guided the observation and interview, and they documented all information in standardized answer forms. The method yielded good interrater reliability as reported previously (Greiner et al., 1997). The kappa statistic was 0.67 for the agreement of the presence or absence of identical job barriers as rated by two analysts independently observing two workers on the same transit line. The first step in a job analysis was to differentiate and describe the individual motor and informational task elements necessary to carry out the job. Examples of task elements include perceiving driving- and vehicle-related information, perceiving and processing customer-related information, providing passenger service, vehicles driving, operating controls, handling equipment (e.g., money collecting box, turntables for cable car drivers), and locomotion (Greiner, Krause, Ragland, & Fisher, 1998).

Job stressors were conceptualized as barriers to these task elements. *Barriers* were defined as events or conditions that impede or interrupt the task progression without efficient worker control over these obstacles. They are due to either poor organizational, technical, or environmental design, and they place extra demands on the worker without adequate resources so that extra effort is needed to overcome these barriers. Each barrier was described in detail by the analyst and classified in one of the theoretical barrier categories. Obstacles were rated as true barriers only if the worker lacked sufficient resources to control the obstacle. Obstacles that could be controlled or had no or only minor impact on the working activity were not considered barriers. The observed amount of extra work in minutes performed per 4-hr shift to overcome the barrier served as the quantitative measure. Extra work included additional work steps or intensified effort. Whereas additional work steps could be directly observed and their duration precisely registered by the analyst, intensified effort (e.g., applying higher force to operate a stiff pedal, intensified concentration, or split attention) was often not directly measurable. In such cases, a default value of 7 min per 4-hr shift was computed if the barrier was present at least once a day; if the barrier occurred less frequently, a corresponding fraction of 7 min was imputed. Minor barriers, requiring less than 2 min of extra work per 4-hr shift and/or occurring less than once a week, were excluded. To facilitate the interpretation of the results in the logistic regression models, one unit of extra work was set to 10 minutes.

Job barriers were classified into seven groups according to the specific tasks they were obstructing. The following exposure measures were used:

1. *Sight barriers*: obstacles that impede vision of the traffic situation or passenger-related information due to poor mirrors, overcrowding of the vehicle, poor vehicle design, or "blind corners" in the traffic environment. Typically, extra work included driving slowly, frequently adjusting mirrors, and bending over to better view the situation.

2. *Vehicle movement barriers*: obstacles that impede moving or maneuvering the vehicle, such as physical obstacles in the street, double-parked vehicles, blocked stops, poorly designed stops, and narrow and sharp turns. Extra work consisted usually of increased maneuvering effort, circumventing obstacles, or waiting (e.g., to clear blocked stops).

3. *Timeliness barriers:* obstacles to starting the run on time, including blocked garage exits; absence of an available vehicle at the beginning of the run; and picking up passengers after their scheduled vehicle has been canceled, which requires the operator to pick up more passengers than normal and to deal with passengers disgruntled about delayed transportation.

4. *Passenger service barriers*: obstacles to passenger loading and unloading, such as malfunctioning doors, kneelers, and wheelchair ramps; blocked passenger access at a stop due to environmental design; broken microphones, stop-request signals, and destination signs aiding passenger information. Extra work included manual operation of the doors, waiting for passengers to enter the vehicle, and dealing with disgruntled passengers who missed their stop due to a nonfunctional stop-request signal.

5. *Attention barriers:* obstacles to focused attention on driving include unruly behavior of passengers, which requires split attention of the operator (especially when such passengers are in the back of the vehicle) and/or disciplinary action.

6. *Operating-controls barriers:* These include hand controls that are hard to reach, stiff foot pedals, delayed acceleration, and unreliable brakes and switches, usually leading to the application of more force.

7. *Movement-and-handling barriers*: obstacles that obstructed movement, locomotion, maintenance of bodily posture, or handling of equipment. Examples include physical obstacles that impede driver access to the vehicle, passengers standing very close to the driver and impeding driver movement, and equipment that is awkward to handle. Extra work usually included maintenance of awkward positions and application of more force.

In addition to these measures of individual barriers, the sum of extra work in minutes was measured across all seven categories.

To explore the role of potential biomechanical and psychophysiological pathways, we pooled movementand-handling barriers and barriers for operating controls into the variable "mainly physical barriers" and timeliness barriers, barriers to providing passenger service, and attention barriers into the variable "mainly psychological barriers." For sight barriers and vehicle movement barriers the mechanisms were assumed to be operative, and these stressors were combined into a third variable as "physical and psychological barriers."

Ascertainment of Prevalent Musculoskeletal Disorders

Medical history forms obtained during each driver's biannual medical relicensing examination were used to determine the 12-month prevalence of musculoskeletal disorders. These disorders were analyzed in six groups: any pain in upper and/or lower back, neck, upper extremities, lower extremities and/or the legs (musculoskeletal disorder); lower back pain; back (upper, lower) and/or neck pain; neck pain; pain of the upper extremities, including shoulder, upper arm, elbow, forearm, wrist, or hand; and pain of the lower extremities, including legs, knees, or feet.

These groups were not mutually exclusive. Musculoskeletal disorder included all of the other five groups and served as a general measure of any musculoskeletal pain. The category of back and neck pain included several spinal regions and was created to facilitate comparisons with findings from earlier studies of the same population using self-report data on job stressors that could not differentiate between neck and lower or upper back pain (Krause et al., 1997; Krause, Ragland, et al., 1998).

Measurement of Control Variables

Analyses were adjusted for gender, age, lifetime years of professional driving, weekly driving hours during the past 12 months, and vehicle type operated most during the past 12 months. Years of professional driving, weekly driving hours, and vehicle type served as proxy measures of physical workload. Among transit operators, physical workload leading to biomechanical loads on the spine is largely determined by the amount of (a) whole-body vibration, (b) static work posture, (c) trunk bending or twisting, and (d) other movements while driving, such as operating hand controls and working foot pedals. The amount of professional driving (including driving a truck, cab, delivery van, or other motor vehicles), measured in lifetime years and weekly driving hours, was an accurate proxy for the exposure to all four factors. The number of years of professional driving at MUNI and at previous jobs was an indicator of cumulative past physical workload. The number of regular weekly driving hours (including overtime) in the current job over a 12-month period was an indicator for current physical workload. A third indicator of physical workload in terms of ergonomic/biomechanical load associated with driving was the vehicle type, as ascertained by company records of relicensing examinations. Participants operated four different vehicle types: diesel bus, electric trolley buses, light-rail train, and the historic cable cars of San Francisco. Vehicle types were grouped into rail-boundand street-bound vehicles to reduce the number of variables in the logistic regression model. The odds ratios (ORs) derived from univariate analyses of each vehicle type were similar for light rail and cable car drivers on the one hand, and for diesel and trolley bus drivers on the other hand.

Data Analyses

First, the average duration of extra work was determined for each barrier type and for the barrier summary measure. Second, the distribution of each musculoskeletal disorder, broken down by sociodemographic variables and physical workload variables, was examined and statistically tested by chi-square test or, if appropriate, the trend test for ordered data.

Third, logistic regression models were analyzed for the six groups of musculoskeletal outcomes. Due to the specific hypotheses, all statistical tests were carried out as one-tailed tests. The stressor and control variables were entered simultaneously into logistic regression models to estimate the independent effects of each risk factor. The results were expressed as adjusted ORs with one-tailed 95% confidence limits and one-tailed significance tests for the ORs. Model fit was determined by the Hosmer and Lemeshow goodness-of-fit test, which divides subjects into deciles based on predicted probabilities and then computes a chi-square statistic from observed and expected frequencies. This test is preferable to the Pearson chi-square test when the number of covariance patterns approaches the sample size, which was the case for all of our logistic regression models. If the test is statistically significant, the null hypothesis of no difference between the observed and predicted values is rejected, implying that the model fit is not acceptable. All analyses were conducted with the STATA program (Version 6; StataCorp, 1997).

Results

Frequency of Job Barriers

Table 1 shows that participants had an average of 31.5 min of extra work per 4-hr shift, with a maximum of 122 min. Among the individual barrier categories, vehicle movement barriers were responsible for the highest amount of extra work (7.1 min per 4-hr shift), followed by barriers to providing passenger service (5.1 min) and sight barriers (4.9 min).

Prevalence of Musculoskeletal Disorders

Figure 1 shows the 12-month prevalence for six groups of musculoskeletal disorders. A total of 49.2% of operators reported having a musculoskeletal disorder within the past 12 months. Of the specific disorders, back and neck pain was most prevalent (40%), driven mostly by back disorders given that only 18.5% of operators reported neck pain alone. For the other disorders, 32.3% reported lower back pain, 30.8% reported problems of the lower extremities, and 27.3% reported problems of the upper extremities.

Sociodemographic Characteristics, Physical Work Load, and Musculoskeletal Disorders

The 12-month prevalence of musculoskeletal disorders, broken down by sociodemographic characteristics and physical workload, is displayed in Table 2. Women had consistently higher rates than men for all

Table 1
Extra Work in Minutes per 4-Hr Shift Due to Job Barriers Observed Among 66 Public Transit Operators

Barrier category	*M*	*SD*	Range
Barrier summary	31.46	25.70	0–122
Vehicle movement	7.09	8.78	0–33
Providing passenger service	5.08	11.84	0–87
Focused attention on driving	3.12	7.22	0–38
Sight	4.86	6.47	0–26
Operating controls	4.39	6.22	0–28
Timeliness	3.19	8.68	0–66
Movement and handling	0.89	2.55	0–14

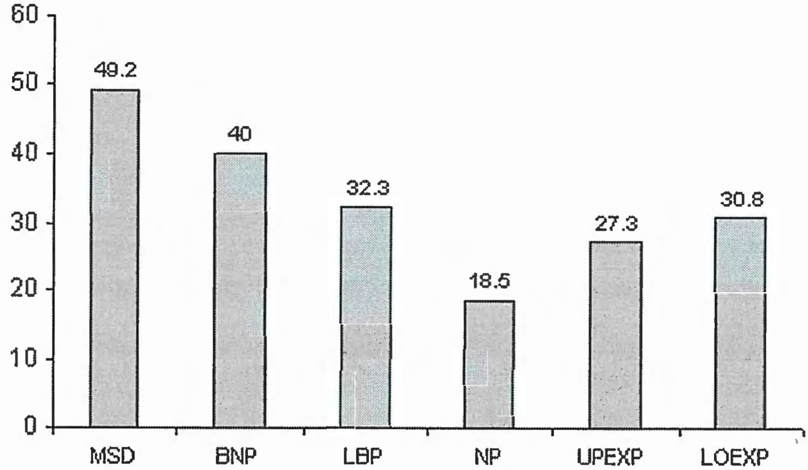

Figure 1. Self-reported 12-month prevalence (in percentages) of different musculoskeletal disorders in urban transit operators (n = 66). MSD = musculoskeletal disorders (general); BNP = back and neck pain; LBP = low back pain; NP = neck pain; UPEXP = pain in the upper extremities; LOEXP = pain in the lower extremities.

musculoskeletal outcomes, with statistically significant differences for back and neck pain, low back pain, and pain of the upper extremities. These results are in accordance with results found in other studies of this population (Krause, Ragland, et al., 1998, Krause et al., 1997; Krause, Rugulies, Ragland, & Syme, 2004). Prevalence of neck pain increased significantly within the 12-month period, and, except for pain of the lower extremities, the other musculoskeletal disorders increased consistently with years of professional driving. The prevalence of musculoskeletal disorders was also consistently higher in operators driving street-bound vehicles. These associations did not show statistical significance, most likely because of the small sample size. The results for age and weekly driving hours were less consistent.

Associations of Observational Job Barriers With Musculoskeletal Disorder Outcomes

Table 3 shows crude and adjusted ORs with one-tailed 95% confidence limits of the association between the summary barrier measure and all outcome variables. The adjusted ORs were controlled for age, gender, years of professional driving, weekly driving hours, and vehicle type. After adjustment, the strength of all associations increased, indicating some degree of negative confounding by sociodemographic and physical workload variables. The measure of 10 min of extra work per 4-hr shift because of observed barriers increased the adjusted likelihood of any musculoskeletal disorder in the past 12 months by 55% (adjusted OR = 1.55, p = .006), of back and neck pain by 41% (adjusted OR = 1.41, p = .015), of lower back pain by 46% (adjusted OR = 1.46, p = .010), and of lower extremities by 44% (adjusted OR = 1.44, p = .006). The OR for upper extremities was elevated by 24% (p = .060). There was no association with neck pain (adjusted OR = 0.96, p = .380). The model fit of the fully adjusted models as tested by the Hosmer–Lemeshow goodness-of-fit test was acceptable for all outcomes, ranging from p = .17 (lower back pain) to p = .85 (upper extremities). The pseudo-R^2 values of the fully adjusted models ranged between .14 (lower extremities, neck pain) and .22 (upper extremities).

Table 4 displays the adjusted ORs for estimating the effect of specific barrier categories on all outcomes. All analyses were adjusted for age, gender, years of professional driving, weekly driving hours, and vehicle type. Several effects were strong and statistically significant for musculoskeletal disorders, back and neck pain, lower back pain, and pain in the lower extremities. The associations with pain in the upper extremities, although strong for several barriers, did not reach statistical significance. Neck pain was significantly associated only with movement barriers, and no consistent pattern of association was

Table 2
Prevalence (Over 12 Months) of Musculoskeletal Disorders by Sociodemographic Characteristics and Indicators of Physical Workload in 66 Urban Transit Operators

Measure	*n*	MSD (%)	BNP (%)	LBP (%)	NP (%)	UPEXP (%)	LOEXP (%)
Gender							
Male	51	43.1	33.3	25.5	15.7	19.2	27.5
Female	14	71.4	64.3	57.1	28.6	57.1	42.9
p		.06	.04	.03	.27	.01	.27
Age							
<40	8	50.0	25.0	12.5	25.0	25.0	37.5
40–50	37	48.7	40.5	35.1	16.2	27.0	35.1
>50	20	50.0	45.0	35.0	20.0	28.6	20.0
p		.99	.62	.44	.83	.98	.45
Years as a professional driver							
<10	12	41.7	33.3	25.0	8.3	16.7	25.0
10–19	36	47.2	36.1	33.3	13.9	27.0	33.3
≥20	16	62.5	56.3	37.5	37.5	37.5	31.3
p		.26	.20	.50	.04	.22	.76
Weekly driving hours							
≤40	19	52.6	42.1	31.6	15.8	25.0	21.1
41–45	24	37.5	33.3	29.2	20.8	29.2	29.2
>45	22	59.1	45.5	36.4	18.2	27.3	40.9
p		.64	.69	.73	.86	.88	.17
Vehicle type							
Rail	14	42.9	28.6	21.4	14.3	21.4	28.6
Street	50	52.0	44.0	36.0	20.0	29.4	32.0
p		.55	.30	.31	.62	.55	.81

Note. The *p* values were derived by using the nonparametric trend test for ordered groups for professional driving years and weekly driving hours and by using the Pearson chi-square test for the other variables. MSD = musculoskeletal disorders (general); BNP = back and neck pain; LBP = low back pain; NP = neck pain; UPEXP = pain in the upper extremities; LOEXP = pain in the lower extremities.

seen for the other barriers. Five of seven barrier categories had at least one statistically significant positive association with a musculoskeletal disorder outcome measure. For example, every 10 min of extra work during a 4-hr shift due to sight barriers had a significantly elevated OR with musculoskeletal disorder and lower extremities and clearly elevated but statistically not significant ORs for back and neck pain, lower back pain, and pain of the upper extremities. Barriers for movement, maintenance of posture,

Table 3
Associations of Observational Job Barriers (Summary Measure) with 12-Month Prevalence of Musculoskeletal Disorders in 66 Urban Transit Operators

Outcome	Crude odds ratio	Confidence limit	Adjusted odds ratio	Confidence limit
Musculoskeletal disorders (general)	1.34*	1.09	1.55*	1.16
Back and neck pain	1.26*	1.05	1.41*	1.09
Low back bain	1.33*	1.09	1.46*	1.12
Neck pain	0.97	0.78	0.96	0.77
Pain, upper extremities	1.18	0.99	1.24	0.99
Pain, lower extremities	1.37*	1.12	1.44*	1.14

Note. Adjusted odds ratios control for age, gender, years of driving as a professional driver, vehicle type (street or rail), and weekly working hours. Confidence limits are one-tailed 95% lower confidence limits.
* $p < .05$, one-tailed.

Table 4
Associations of Individual Observational Job Barriers With 12-Month Prevalence of Musculoskeletal Disorders in 66 Urban Transit Operators

Barrier category	MSD	BNP	LBP	NP	UPEXP	LOEXP
Sight						
OR	6.41*	2.11	1.62	1.08	1.72	3.79*
95% CL	(1.92)	(0.88)	(0.72)	(0.42)	(0.74)	(1.48)
Vehicle movement						
OR	2.38*	2.13*	2.50*	1.29	2.00	1.47
95% CL	(1.19)	(1.10)	(1.28)	(0.63)	(0.99)	(0.81)
Focused attention on driving						
OR	1.58	1.63	1.71	0.37	1.05	1.42
95% CL	(0.81)	(0.84)	(0.88)	(0.04)	(0.44)	(0.76)
Providing passenger service						
OR	0.80	0.89	0.93	0.46	0.94	1.03
95% CL	(0.48)	(0.56)	(0.59)	(0.13)	(0.54)	(0.71)
Timeliness						
OR	8.87*	6.17*	5.83*	0.52	2.24	2.69
95% CL	(1.77)	(1.51)	(1.50)	(0.15)	(0.69)	(0.85)
Movement and handling						
OR	62.14*	876.06*	105.96*	12.59*	5.23	6.70*
95% CL	(2.54)	(11.86)	(4.67)	(1.05)	(0.55)	(1.00)
Operating controls						
OR	2.25	2.18	2.58*	1.43	1.48	1.80
95% CL	(0.99)	(0.98)	(1.15)	(0.58)	(0.65)	(0.88)

Note. Barriers are measured in 10-min increments of extra work per 4 hr. Adjusted odds ratios (ORs) were controlled for age, gender, years of driving as a professional driver, vehicle type (rail or street), and weekly driving hours. Values in parentheses indicate one-tailed 95% lower confidence limits (CLs). MSD = musculoskeletal disorders (general); BNP = back and neck pain; LBP = low back pain; NP = neck pain; UPEXP = pain in the upper extremities; LOEXP = pain in the lower extremities.
$^{*}p < .05$, one-tailed.

equipment handling, and timeliness exhibited the strongest effect sizes. Operators on transit lines rated high on vehiclemovement barriers showed at least a twofold higher prevalence of musculoskeletal disorder, back and neck pain, lower back pain, and pain of the upper extremities, which were statistically significant, with the exception of the upper extremities measure. The ORs for barriers regarding focused attention on driving were elevated in four out of five disorders but not statistically significant. Barriers for providing passenger service had no clear associations with outcomes. All ORs for operating control barriers were clearly elevated, with some of them nearing statistical significance (musculoskeletal disorder: OR = 2.25, p = .053, back and neck pain: OR = 2.18, p = .055) and a significant OR of 2.58 for lower back pain. Only the "classical ergonomic" barriers, including obstacles to movement, maintenance of posture, and equipment handling, were significantly associated with neck pain. The goodness of fit of all fully adjusted models was acceptable, ranging between p = .08 (sight barriers and back and neck pain) and p = .99 (equipment barriers and upper extremities, and timeliness barriers and lower extremities, respectively).

Logistic regression models with barriers summarized by their potential main pathway were built similar to the previous models (see Table 5). Pooled barriers, which were hypothesized to act through a mainly biomechanical pathway, were significantly associated with musculoskeletal disorders (adjusted OR = 2.55, p = .018), back and neck pain (adjusted OR = 2.89, p = .011), lower back pain (adjusted OR = 2.96, p = .007), and lower extremities (adjusted OR = 1.83, p = .049). Pooled barriers hypothesized to act mainly through psychophysiological pathways were not significantly associated with any of the outcomes (adjusted ORs ranging 0.56–.1.26). Combined barriers hypothesized to act through both physical and psychological pathways were significantly associated with musculoskeletal disorders (adjusted OR = 2.86, p = .002), back and neck pain (adjusted OR = 1.99, p = .015), lower back pain (adjusted OR = 2.00, p = .014), upper ex-

Table 5
Associations of Job Barriers Pooled by Potential Pathway With 12-Month Prevalence of Musculoskeletal Disorders in 66 Urban Transit Operators

Hypothesized pathway	MSD	BNP	LBP	NP	UPEXP	LOEXP
Biomechanical						
OR	2.55*	2.89*	2.96*	1.65	1.57	1.84*
95% CL	(1.22)	(1.35)	(1.43)	(0.76)	(0.77)	(1.01)
Psychophysiological						
OR	1.14	1.19	1.25	0.56	1.15	1.26
95% CL	(0.87)	(0.90)	(0.95)	(0.22)	(0.86)	(0.97)
Combined biomechanical and psychophysiological						
OR	2.86*	1.99*	2.00*	1.20	1.85*	1.89*
95% CL	(1.58)	(1.19)	(1.20)	(0.69)	(1.06)	(1.17)

Note. Barriers are measured in 10-min increments of extra work per 4 hr. Adjusted odds ratios (ORs) were controlled for age, gender, years of driving as a professional driver, vehicle type (rail or street), and weekly driving hours. Values in parentheses indicate one-tailed 95% lower confidence limits (CLs). MSD = musculoskeletal disorders (general); BNP = back and neck pain; LBP = low back pain; NP = neck pain; UPEXP = pain in the upper extremities; LOEXP = pain in the lower extremities.
$^* p < .05$, one-tailed.

tremities (adjusted OR = 1.85, p = .035), and lower extremities (adjusted OR = 1.89, p = .014).

Discussion

The discussion is organized by study objectives, limitations and strengths of the study, and implications for research and prevention.

Objective 1

The first objective of this study was to determine whether observational stressors were correlated with increased odds for musculoskeletal disorder in general. Our study confirmed a general association between observed job stressors across all stressor categories with musculoskeletal disorders. To our knowledge, this is the first study to demonstrate a relationship between observational stressor measures and musculoskeletal outcomes. The results support findings from the literature that job stress is associated with musculoskeletal disorders in general (Ariens et al., 2001; Bernard, 1997; Bongers et al., 1993; Davis & Heaney, 2000; Hoogendoorn et al., 2000), and in this study population in particular (Krause, Ragland, et al., 1998, Krause et al., 1997; Rugulies & Krause, 2005). Results with the barrier summary measure also parallel findings based on the demand/control model, showing that high job strain is associated with musculoskeletal disorder (Krause, Ragland, et al., 1998, Krause et al., 1997; Rugulies & Krause, 2005). Although based on a different theoretical framework, job barriers are conceptually similar to high strain, with a combination of high demands and low control. Job barriers are conceptualized as job situations during which the worker cannot meet job demands as expected because of poor job design and insufficient worker control. The summary measure of job barriers was significantly correlated with self-reported job strain, as reported in another study with the same population (Greiner et al., 2004). In contrast to studies using the conventional demand/control model, in this study job stressors were further differentiated into specific stressors. Specifically, operators with barriers to sight, vehicle movement, timeliness, physical movement, maintenance of posture, equipment handling, and operating controls were more likely to have some musculoskeletal disorder.

Several theoretical assumptions were made in the generation of barrier measures. One assumption was that minor barriers, that is, barriers that occur less than once a week and/or require less than 2 min of extra work per 4 hr, are negligible. Therefore, minor barriers were excluded from the barrier measures. To test the appropriateness of this assumption, we computed an alternative summary barrier measure that included the extra work of minor barriers. When this variable was entered into the logistic regression models, the associations with the outcomes became slightly smaller, although they remained statistically significant. This finding suggests that minor barriers are indeed not very important for predicting musculoskeletal disorders. We also felt more confident to use measures that excluded minor barriers because they had been excluded from the interrater reliability estimations (Greiner et al., 1997). Another assumption was to assign a default value of 7 min extra work per 4-hr shift for intensified effort that was not measured directly. To test the appropriateness of this assumption, we computed another summary barrier measure that excluded barriers with intensified effort. Logistic regression analyses with this modified measure showed slightly attenuated effects, although the associations remained statistically significant. This finding suggests that the estimate of 7 min of extra work for intensified effort is an acceptable proxy measure that increased the predictive power of the measurement instrument slightly.

Objective 2

The second objective was to determine whether associations between job stressors and musculoskeletal disorders show patterns specific to body region. Low back pain and pain of the lower extremities accounted for most of the statistically significant associations with stressors, whereas pain of the upper extremities was not significantly related to stressors. Most strong associations (OR $\geq$ 2) and most statistically significant associations were found for low back pain and for back and neck pain. The latter finding was mainly driven by low back pain, and evidence for an association between stressors and neck pain is limited to classical ergonomic stressors. This is in contrast to findings from a prospective study in this population indicating that self-reported job stress (job strain and isostrain) is more strongly associated with neck pain than with low back pain (Rugulies & Krause, 2005). Although what causes these different patterns is not clear, one needs to conclude that there may be effects specific to different body regions, occupations, and stress measurement methods that warrant further investigation in studies differentiating between specific musculoskeletal disorders and also employing self-report and observational stress measures simultaneously. In addition, an investigation of interactions between physical and psychosocial job factors may help to clarify inconsistent effect patterns (Devereux, Buckle, & Vlachonoikolis, 2002).

With respect to inner psychological processes linking job stressors to musculoskeletal disorders, it is not known whether the experience of stress partly mediates (provides the pathway for) the association of job stressors and pain or moderates (amplifies) the effects of stressors on pain. For example, one study found that the report of pain was moderated but not mediated by well-being correlates of stress (Randall et al., 2002).

Objective 3

The third objective was to compare the role of biomechanical versus psychophysiological pathways in the association between job stress and musculoskeletal disorders. Biomechanical and psychophysiological mechanisms were represented in our job barrier categories to varying degrees. Biomechanical processes were assumed to operate in movement/handling barriers and in barriers for operating controls. Psychophysiological mechanisms were hypothesized as the main pathway in barriers to providing passenger service, focused attention, and timeliness. For example, an insufficient number of vehicles available on the line or failure to replace missing drivers on time result in canceled runs and delays. The operator driving after a cancelled run has to pick up more passengers than usual and is exposed to increased anger levels of passengers who have been waiting at the stop for longer than expected. Barriers to focused attention on driving included, for example, situations where an operator has to divide attention between watching the traffic situation and observing unruly passengers (e.g., schoolchildren) in the rear of the vehicle.

Biomechanical and psychophysiological processes might also be simultaneously operative, for example in barriers to vehicle movement. Physical obstacles in the street may force the driver to perform elaborate maneuvers with the vehicle, leading to increased physical workload (e.g., extra trunk twisting while steering the vehicle around an obstacle). Such obstacles might also result in dangerous maneuvers (e.g., steering the vehicle into oncoming traffic in an attempt to pass an obstacle), as observed in several instances, and thereby put higher mental and emotional loads on drivers. Likewise, sight barriers might initiate both biomechanical and psychophysiological pathways. They might put extra biomechanical postural demands on the workers due to awkward postures that may be necessary to compensate for poor mirrors and obstructed views. In addition, psychological stress might be induced when operators continuously fear that they are not able to see all necessary information in the traffic environment.

Combined barriers hypothesized to act through both physical and psychological pathways and pooled barriers hypothesized to act mostly through biomechanical pathways were both statistically significant when associated with all outcomes except neck pain. The pooled barriers hypothesized to act mainly through psychophysiological pathways were not associated with any of the outcomes. Our results do not confirm findings from a study of engineering workers, which reported that pain in the upper body was related to both biomechanical and stress-related factors whereas pain in the lower body was only related to biomechanical factors (Randall et al., 2002). Although the absence of an association with the pooled measure of barriers hypothesized to act through psychophysiological pathways in our study does not support the existence of a psychological pathway, this finding also cannot be interpreted as proof of an absence of a psychological pathway. It is likely that there are distinctly different psychological pathways and that different barrier types need to be analyzed separately in relation to musculoskeletal disorders. Based on action regulation theory, Semmer (1984) differentiated between regulation uncertainties, overtaxing regulations, and regulation obstacles. Regulation uncertainties are characterized by a lack of certainty about the consequences of actions due to lack of feedback, high complexity of the job, or role ambiguity and may lead to increased anxiety and fear. Regulation uncertainties may be present in sight barriers and barriers to providing passenger service. Overtaxing regulations are characterized by an overload of mental demands, such as high concentration required to deal with obstacles to focused attention on driving. Obstacles that impede or even thwart the pursuit and achievement of a goal lead to increased effort and thereby to frustration if the effort consistently fails. For example, the timeliness barrier in our study were significantly associated with several musculoskeletal disorders. Future studies with larger sample sizes and the ability to study individual barriers of each pathway type may be able to resolve the question of alternative pathways more definitively.

Movement-and-handling barriers, mainly including ergonomic factors that operate through biomechanical mechanisms, exhibited very high effect sizes with all outcomes. This is a remarkable result, given the limitations of the work analysis procedure that determines the intensity of stressors predominantly caused by ergonomic factors. The measurement instrument was developed mainly for the assessment of stressors caused by the organizational, social, psychological, and traffic environment of driving tasks and allowed for only crude estimates of ergonomic stressors. Extra work caused by movement-and-handling barriers included mainly intensified effort, specifically the application of more physical force. Increased force was estimated by the default value of 7 min because the analyst was neither trained nor equipped to perform direct measures of these factors. This procedure resulted in imprecise measurement and low variance of the estimated amount of extra work regarding this barrier type. Clearly, the parallel use of observational ergonomic instruments to measure physical force more precisely could greatly complement our observational methods in future job analyses.

Objective 4

The fourth objective was to control for the possible confounding role of demographic factors and physical workload in multivariate analyses. When adjusting for the demographic and workload variables, the ORs for the stressor variables increased in all models, indicating some confounding. The model fit also improved in all models. These results suggest that careful control for cumulative and current workload is important for obtaining good risk estimates for psychosocial risk factors. Among the physical workload variables used in the present study, the number of years as professional driver was the strongest confounder in the association of stressors and musculoskeletal disorders. Duration of professional driving in years was a statistically significant independent risk factor in most models, except in models using lower extremities and low back pain as outcomes. The effect of years of professional driving on musculoskeletal disorders cannot be attributed to age because analyses also adjusted for age, and collinearity between age and driving years was small because workers tend to become professional drivers at all ages.

Objective 5

The fifth objective was to identify specific job stressors in the work of urban transit operators. Several specific stressors were identified that were highly associated with musculoskeletal disorders in transit operators. As expected, the theoretical model used in this research identified stressors in the work environment that can be prevented by specific organizational changes and community involvement rather than employee behavior modification. They are discussed in more detail in the *Prevention of Work-Related Musculoskeletal Disorders* section of this article.

Limitations and Strengths of the Study

Several limitations of this study are considered in the following paragraphs.

1. The study was clearly limited by its small sample

size. Consequently, the statistical power was small for testing the associations of the individual barrier categories with the outcomes and too small for testing interactions between psychosocial and biomechanical factors that have been demonstrated in experimental studies (Melin & Lundberg, 1997). However, we explored the possibility of interactions between the barrier summary measure and each of the three physical workload measures. None of the interaction terms was statistically significant at the 10% level, and the deviances comparing the likelihood measures of models with and without an interaction term showed no major impact of the interaction.

2. The study was based on a convenience sample. Although the sample represented the entire MUNI population reasonably well with respect to age, gender, vehicle type, and distribution of musculoskeletal disorders, the sample included more experienced drivers with more years of professional driving and more weekly driving hours on average. However, the association between stressors and musculoskeletal disorders should be applicable to the entire population because we controlled for years of professional driving and weekly driving hours in the multivariate analyses. Although the participating drivers were not different with regard to prevalence of musculoskeletal disorder, the unadjusted prevalence rates should be interpreted cautiously with regard to the entire population. The estimates for barriers were most likely conservative estimates because operators with higher seniority tended to occupy the less stressful transit runs in the MUNI population.

3. This was a cross-sectional study, and therefore the temporal relationship between stressors and outcomes is not defined by study design, limiting causal inference. However, it is reasonable to assume that job stressors were present on these lines before symptoms were reported, given the fact that neither vehicle type nor tracks changed in the years preceding the study. Furthermore, reverse causation can be ruled out because the exposure was assessed objectively by external observers. Therefore, a causal interpretation of the observed associations is justifiable. Nevertheless, to test this interpretation we are currently conducting a prospective study of observational stressors and formally reported musculoskeletal injuries in the same study population.

4. This study did not exhaustively cover all psychosocial stress factors in this occupational group. It focused on stressors that could appropriately be assessed by observational task analysis and that were likely to vary within this occupational group. Other stressful work characteristics prevalent among urban transit operators, such as shift work, prolonged sitting, or social isolation, were not considered. Therefore, current risk estimates associated with psychosocial stressors need to be considered conservative. Future studies should combine observational and self-report measures of job stress that address work environment factors, which cannot be assessed by direct observation.

Significance and Implications

To our knowledge this is one of the first studies that measured psychosocial job stressors by observational methods rather than self-report and showed significant associations between job stressors and musculoskeletal disorders. The advantage of the observational measures of job stressors is that the effects of several biases can be avoided, including common methods variance bias, which can potentially inflate the associations between job characteristics and musculoskeletal disorders in studies using self-report measures of job stress and musculoskeletal disorders. This method also avoids distortions of results potentially caused by denial and unawareness of stress. A recent study with the same population of transit operators found that operators who had difficulty in perceiving and expressing emotions were more likely to have low back pain. It is likely that those operators underreport job stress, a bias that can attenuate the association between self-reported job stress and musculoskeletal disorders (Mehling & Krause, 2005). As pointed out by Greiner et al. (2004), it is useful to apply both self-reported and observational measurement methods to learn from disparate findings produced by both approaches. In contrast to studies using only self-reported stressor measures, we can also rule out reverse causality, that is, that the prevalence of musculoskeletal pain impacted the reporting of job stressors. Final analyses were adjusted for past and current physical workload, thereby overcoming another major methodological limitation of most earlier studies on job stress and musculoskeletal disorders.

The results have implications for measurement methods in future studies and for intervention.

Measurement Methods

Biomechanical and psychophysiological pathways leading from work stressors to impaired musculoskeletal health are closely intertwined and difficult to separate. As shown in a recently published study with 410 white-collar and blue-collar workers, physical and psychological job stressors often coexist, suggesting that these stressors manifest from common work organization factors that govern the structure of work (Mac-

Donald, Karasek, Punnett, & Scharf, 2001). Isolating the separate effects of both physical and psychological stressors on the development of musculoskeletal disorder, though important for the establishment of their independent causal roles, may be of limited practical value when combined exposure conditions are prevalent. The parallel use of instruments to measure both ergonomic stressors and psychosocial job stressors based on the same theoretical and methodological framework, however, would be of great practical value for planning comprehensive worksite interventions. The method of observational job analysis presented here uses detailed mapping and detailed observational analysis of task activities, and thereby follows principles similar to the ergonomic instrumentation used in ergonomic field studies. The method of task analysis might serve as a basis for combined analyses of biomechanical and psychosocial stress factors in the future. Even stress factors assumed to operate through physical pathways alone, such as barriers that obstruct driving, may at least in part operate through psychological pathways (and vice versa), calling into question the validity of the common distinction between physical and psychososcial risk factors. In our study we used separate analyses for barrier categories hypothesized to act through different pathways, but we failed to show that both pathways can operate independently in the observed associations between such barriers and musculoskeletal disorders.

We also suggest the use of multimethod studies using self-reported and observational measures in the same study to obtain a full picture on the interplay of objective stressors, perceived stressors, and subjective feelings of stress. As research shows (Greiner et al., 2004), discrepancies between self-reported and observational measures can be useful for examining potential stressor denial.

Prevention of Work-Related Musculoskeletal Disorders

Observational job analysis data from stress research can complement questionnaire and ergonomic data in the development of detailed suggestions for job redesign aiming at the prevention of work-related musculoskeletal disorders. Job stressors specified in this study were caused by different environmental factors, including work organization, ergonomics of the vehicle, traffic conditions in the street, and the social environment. Interventions to reduce musculoskeletal disorders in transit operators should address these factors and simultaneously target stressors operating through biomechanical or psychophysiological pathways. Specifically, our results suggest vehicle redesign to ensure unimpeded sight (e.g., better mirrors, better windshield design). Barriers for movement, maintenance of bodily posture, and equipment handling also require improvements in vehicle and equipment design. Timeliness barriers were mostly caused by a systemwide shortage of vehicles, resulting in a lack of functioning vehicles on the street so that drivers had to pick up more passengers than projected. To tackle this problem, organizational changes would be necessary, for example, better communication between drivers and central control to immediately replace missing vehicles, authorization of the operator to drive ahead of schedule in order to reduce waiting times for passengers, and, most important, purchase of additional vehicles to meet the number of runs required by the schedule. Most of the changes for reducing vehicle movement barriers involve changes in the traffic environment and require collaboration with public authorities and community groups, for example to initiate construction of transit lanes and provide better enforcement when these lanes are blocked by unauthorized vehicles. Reduction of barriers to focused driving requires collaboration with the social environment, for example, building liaisons with schools and informing and educating passengers (Ragland, Krause, Greiner, & Fisher, 1998).

Currently, there is insufficient evidence from intervention studies with transit drivers to demonstrate that reductions of psychosocial work stressors actually result in reduced musculoskeletal disorders. No effects on musculoskeletal health were found in a study of Stockholm's bus drivers, although the intervention resulted in significant effects on systolic blood pressure and heart rate. In this study, stressor reduction was mainly focused on changes in the traffic environment to take pressure off the driver, for example, construction of separate bus lanes, reconfiguration of parts of the route to minimize difficult turns and bottlenecks, construction of passenger peninsulas to avoid pullovers to the curb, installation of a traffic priority system favoring the bus, and the design and installation of an electronic passenger information system (Evans, Johansson, & Rystedt, 1999; Rystedt, Johansson, & Evans, 1998).

A review of 13 case studies on stress intervention programs for mass transit drivers showed significant reductions in absences due to illness for some companies; however, no numbers were provided specifically for musculoskeletal disorders (Kompier, Aust, van den Berg, & Siegrist, 2000). Only one case study with transit operators in Munich specifically evaluated musculoskeletal outcomes before and after the intervention. A significant reduction of lumbar back pain and neck pain was found in the intervention group when compared with the control group (Ertl, 1994). The intervention included a reduction of weekly driving hours for older workers and participation in a health promotion program.

Similarly, a compilation of intervention case studies in German mass transit companies showed decreases in general absenteeism rates in several companies, but no data were provided specifically for musculoskeletal disorders (Aust, 2001; Aust & Ducki, 2004). Interventions reviewed included a wide range of organizational, environmental, and behavioral stressor reduction programs, such as participation of drivers in designing the rotas and shift plan, mixed work, and reduced driving hours. Considering the high percentage of absenteeism due to illness and disability cases that are due to musculoskeletal disorders in mass transit operators (Kompier et al., 1990), it is likely that the reported reductions in absenteeism are partially due to a reduction in musculoskeletal disorders.

To our knowledge, the current literature is devoid of well-controlled published intervention studies specifically addressing psychosocial job factors and musculoskeletal disorders in any occupational group (for reviews, see Battie, 1992; Frank et al., 1996). However, indirect evidence for the potential of these interventions is provided by studies evaluating the effectiveness of ergonomic and organizational work modifications in facilitating return-to-work for workers who experienced a disabling occupational injury or illness of the musculoskeletal system (Krause, Dasinger, & Neuhauser, 1998). Clearly, our results also suggest a considerable potential for primary prevention of musculoskeletal disorders through worksite interventions addressing specific psychosocial job stressors. Observational job analysis can contribute to the development of specific intervention strategies for the prevention of musculoskeletal disorders. The specificity of observer-based job analysis can be a valuable tool in the identification and operationalization of task and equipment redesign to be used in future intervention studies.

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