Effort–reward imbalance and incidence of low back and neck injuries in San Francisco transit operators

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ABSTRACT

Objectives: Effort–reward imbalance (ERI) has been associated with musculoskeletal disorders in cross-sectional and case–control studies, but no longitudinal studies have been published yet. The effect of ERI on the incidence of compensated low back and neck injuries was examined in a 7.5-year follow-up study among 1179 San Francisco transit operators.

Methods: Data from medical examination and a survey on working conditions and health were linked to administrative workers' compensation databases. HRs for first low back and first neck injury were calculated with multivariate Cox regression models. Additional analyses accounted for severity of injury based on medical diagnosis.

Results: A 1 SD increase in ERI was associated with compensated low back (HR 1.13, 95% CI 1.02 to 1.26) and neck injuries (HR 1.14, 95% CI 1.02 to 1.27) after adjusting for gender, age, height, weight, years of professional driving, weekly driving hours, vehicle type, ergonomic problems, pain at baseline and job strain. The highest quartile of ERI showed an HR of 1.32 (95% CI 0.94 to 1.86) for low back injuries and an HR of 1.66 (95% CI 1.16 to 2.38) for neck injuries after adjustment for all covariates. The associations between ERI and low back injury were stronger for more severe injuries (HR 1.23, 95% CI 1.03 to 1.46 for a 1 SD increase in ERI) than for less severe injuries (HR 1.11, 95% CI 0.96 to 1.28). For neck injuries, stronger relationships were found for less severe injuries (HR 1.15, 95% CI 1.02 to 1.29) than for more severe injuries (HR 1.10, 95% CI 0.86 to 1.41).

Conclusions: ERI is associated with low back and neck injuries in San Francisco transit operators independently of individual worker characteristics, physical workload, ergonomic problems, baseline pain and job strain. Effect sizes differ by injury severity.

It is a widely shared concept in occupational epidemiology that musculoskeletal disorders (MSD) have a multifactorial aetiology, involving exposure to both physical and psychosocial working conditions.[1–4] Empirical evidence for a causal role for psychosocial working conditions, however, is inconclusive. Until a few years ago, this research area was characterised by an over-reliance on cross-sectional studies.[5 6] In recent years, a considerable number of new longitudinal studies have been conducted, but findings are inconsistent. A review on 18 longitudinal studies on psychosocial workplace factors and low back pain found "insufficient evidence for an association between stress at work and low back pain".[5, p. 9] A review that analysed 19 studies on psychosocial workplace factors and neck and shoulder symptoms concluded that "this relationship is neither very strong nor very specific".[6, p. 290] The two reviews also showed that in the majority of studies, both working conditions and MSD were assessed by self-report, which renders these studies vulnerable to bias due to common method variance.[7] There has also been criticism that many studies have not sufficiently controlled for exposure to high physical workload and ergonomic problems.[4 8] Finally, it is notable that many studies defined psychosocial working conditions based on the demand–control (job strain) model[9] or its expansion, the demand–control–support model,[10] and that there is a lack of research on alternative theoretical models of psychosocial workplace stressors.

In recent years, the model of effort–reward imbalance (ERI) at work has emerged as a new theoretical approach for conceptualising health-hazardous psychosocial working conditions. The model posits that a "high cost/low gain" situation at work, in which individuals spent high effort while receiving low rewards (in terms of monetary gratification, career opportunities, esteem, respect and job security) elicits severe psychological distress, which consequently affects both mental and physical health.[11–14] It is further assumed in the model that ERI has, in particular, adverse health consequences when it co-occurs with a motivational disposition called "work-related overcommitment".

The ERI model has been tested foremost with regard to cardiovascular disease, but has recently also been used in research on other health outcomes, including studies on MSD. ERI was associated with back and neck pain in cross-sectional studies with urban transit operators,[15 16] police officers,[17] dental technicians[18] and nurses[19] in Europe. In the USA, a case–control study among hospital workers showed that ERI was associated with risk of neck and upper extremity injuries.[20]

Whereas these cross-sectional and case–control studies provide important information regarding a potential relationship between ERI and MSD, the studies do not allow conclusions to be drawn on the causal nature of this relationship. It is possible that ERI had caused MSD in these studies, but it is also possible that the presence of MSD had caused employees to perceive their work environment as more demanding and less rewarding. Longitudinal analyses, in which ERI is measured before the onset of MSD, are needed, but to our knowledge such studies have not been conducted yet.

The aim of this study is to fill this research gap and to examine if ERI predicts incidence of doctor-diagnosed low back and neck injuries in a 7.5-year follow-up study of San Francisco transit operators. We restricted the analyses of workers' compensation records to neck and back injuries in this study for the following reasons: (1) they are the most common and expensive compensated work-related injuries in this occupational group; (2) they have been the subject of previous investigations regarding physical workload, ergonomic problems and job strain in this cohort and in an earlier cohort of San Francisco transit operators;[8 21–24] (3) we had developed a medical measure of severity with predictive validity for low back injuries[8] that could be easily adapted to neck injuries but was not as easily adaptable to injuries in other body regions; and (4) because the existing evidence of an association between psychosocial work factors and MSD was based predominantly on these specific conditions.[5 6]

In previous analyses of the two cohorts of San Francisco transit operators, we found that physical and ergonomic exposures, as well as job strain and its components, were independently related to prevalence and incidence of spinal, low back and/or neck injuries.[8 21–24] Therefore, we also investigated in the present study to what extent an association between ERI and low back and neck injuries is independent not only of individual worker characteristics, but also of physical workload, ergonomic problems and job strain.

MATERIALS AND METHODS

Study design and population

This is a 7.5-year longitudinal cohort study of 1974 transit vehicle operators employed by the San Francisco Municipal Railway (Muni) who completed a physical examination and medical history forms required for commercial driver's licence renewal between 1993 and 1995. Seventy-three employees were excluded, because a review of their data showed that they certainly or very probably held other jobs in the company (eg, supervisors). Sixty additional employees were excluded because their social security number was missing and therefore could not be linked to an injury data set. This yielded a total eligible study population of 1841 transit operators. Of these, 1503 (81.6%) responded to an additional (optional) occupational questionnaire immediately after their medical examinations. We excluded 59 drivers who reported less than 20 h of driving per week, because the reduced hours might be an indication of modified duty due to an existing injury. Finally, 265 drivers were excluded because of missing data on one or more of the variables used in the multivariate analysis, yielding a final study sample of 1179 participants. Mean age was 47 years (SD 8 years) and 86% were men. Participants had worked as professional drivers for 13 years on average (SD 8 years), and mean time of weekly driving was 45 h (SD 10 h). More detailed descriptions of the study population have been published elsewhere.[8 24] The study protocol was approved by the Committee on Human Research of the University of California San Francisco.

Data sources and collection

Data were obtained from five different sources: (1) a baseline health survey and medical examination of all Muni drivers between 30 August 1993 and 29 September 1995, administered during the mandatory biannual medical relicensing examination providing demographic and anthropometric variables, years of professional driving, vehicle type operated, ergonomic problems and self-reported low back pain and neck pain; (2) a voluntary baseline occupational questionnaire, administered after completion of the medical examination, which provided information on weekly driving hours and ERI; (3) company employment records for all drivers providing information on separation dates between 1 March 1986 and 28 April 2001; (4) the workers' compensation insurer's database, containing information on work-related injuries sustained by Muni drivers, based on accepted claims to 13 February 2001; and (5) a medical bill review file containing all doctor diagnoses made throughout the course of each worker's compensation claim based on the ninth revision of the International Classification of Disease (ICD-9) for the injuries in the workers' compensation database.

Definition and measurement of the outcomes

The outcomes of the study were the first incidence of low back injury and the first incidence of neck injury during 7.5 years of follow up. The observation time for each subject started on the day of the baseline health survey and medical examination, and was censored by the day of the injury, the day of separation from active duty as a transit operator or 13 February 2001, the day of workers' compensation data reading, whichever came first. Observation time was calculated separately for low back and neck injuries; therefore, it was possible for an individual to become both a low back and a neck injury case.

Low back injury cases were defined by matching the following administrative and diagnostic criteria: (1) a date of injury after the baseline medical examination recorded in the worker's compensation file, and (2) an ICD-9 code in the medical bill review file, indicating a non-traumatic injury relating to the lumbar or sacral region of the spine, according to a list of codes compiled by Cherkin and coworkers.[25] This list contains codes indicative of both "possible" and "definite" spinal injuries in the low back. Only cases with a "definite" ICD-9 code on any doctor's bill record during the course of the claim were included (for details see Krause *et al*[8]). Neck injury cases were defined by similar administrative and diagnostic criteria to include non-traumatic injuries of the neck occurring after the baseline examination and with "definite" ICD-9 codes. The list of neck injury codes was developed by the doctor-epidemiologist of the author team in a fashion parallel to the list of low back pain codes mentioned above, and is presented in the Appendix.

Cases were excluded if, during the course of the claim, (1) any ICD-9 code indicated a vertebral fracture, neoplasm, infection or inflammatory disease; or (2) the "nature of accident" or "nature of injury" code indicated a burn, open wound or fracture. In other words, injuries caused by an acute trauma visibly disrupting the integrity of skin or bones were excluded.

Severity of injury was defined by the most severe definite low back or neck injury diagnosis during the course of the claim. A list of low back injury ICD-9 codes rank-ordered by severity has been published elsewhere[8]; a list of neck injury codes by severity is given in the Appendix.

Definition and measurement of ERI

Because the San Francisco Transit Operator Study did not include the original ERI questionnaire, we assessed effort and reward with proxy measures. Effort was measured with four questions, which were developed for this study and which asked the respondents to rate the frequency of specific demands originating from their work schedule: (1) spread of shift more than 10 h a day; (2) working through recovery time; (c) having an actual recovery time of less than 5 min; (4) being required to drive without a break for more than 6 h. Response categories were 1 = almost never; 2 = less than half the time; 3 = half the time; 4 = more than half the time; and 5 = almost always.

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Responses were summed, resulting in an effort score with a potential range from 4 to 20.

Rewards were measured with two items from the job content questionnaire,[26] including one item on esteem reward ("Superintendent/dispatchers are paying attention to what I am saying") and one item on job security reward ("My job security is good"). Response categories were 1 = strongly disagree; 2 = disagree; 3 = agree; and 4 = strongly agree. Responses were summed, resulting in a reward score with a potential range from 2 to 8.

Following recommendations from the literature,[12] we constructed an ERI ratio with the mean of the effort score in the nominator and the mean of the reward score in the denominator. Hence, a higher ratio indicates a higher level of imbalance between high effort and low reward. For the purpose of the analyses, we used this continuous ERI ratio variable and also the ERI ratio divided into quartiles.

Definition and measurement of covariates

As covariates we included demographic (age, gender) and anthropometric (height, weight) characteristics, physical workload, ergonomic problems, 12 month prevalence of low back and neck pain at baseline, and job strain.

Physical workload was measured by vehicle type (diesel bus, electric trolley bus, light rail trains and the historic cable cars), years of professional driving and weekly driving hours. 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.[21 27 28] Years of professional driving was used as a proxy measure of past (cumulative) physical workload. Weekly hours of professional driving during the last 12 months was used as a proxy measure for current physical workload. These three components of physical workload have been found to be associated with low back and spinal injuries and self-reported low back and neck pain in previous cross-sectional and longitudinal analyses of San Francisco transit operators.[8 21 23]

Ergonomic problems in the workplace were assessed by a self-reported eight-item questionnaire that was based on an ergonomic evaluation of the vehicle fleet by an ergonomist in an earlier study.[21] The items address problems in (1) adjusting the seat; (2) back support; (3) vibration, rocking or bouncing of the seat; (4) steering; (5) reaching across the wheel; (6) position of the cash box and transfer cutter; (7) adjusting mirrors; and (8) heat, cold or draft. Respondents were asked to rate each problem on a scale from 1 ("no problem") to 4 ("a big problem"). Scores were summed to create an "ergonomic problem score".

Pre-existing low back pain was assessed in the baseline health survey by asking the respondents if they had pain, ache or discomfort in their lower back during the last 12 months. Neck pain was assessed in the same way.

Job strain was assessed based on a 5-item scale on psychological demands and a 9-item scale on decision latitude from the Job Content Questionnaire.[26] Following an established procedure from the literature, we classified respondents as being exposed to job strain when they simultaneously scored above the median on the psychological demands and below the median on the decision latitude scale.[29]

Data analysis

Correlations between the ERI ratio and the other measures of the work environment were calculated by Pearson's correlations. Cox proportional hazards regression was used to estimate hazard ratios (HRs) and 95% CI for the effect of ERI on the rate of first low back and first neck injury during 7.5 years of follow-up. Respondents contributed time at risk until the first incidence of low back or neck injury, separation as an active driver or end of follow-up, whichever came first.

The associations between ERI and low back and neck injuries were analysed separately in four incrementally adjusted models. The first model adjusted for sociodemographic and anthropometric variables (gender, age, height and weight), the second model additionally adjusted for physical workload (years of professional driving, driving hours per week, vehicle type) and ergonomic problem score, the third model further adjusted for baseline low back pain (if the end point was low back injury) or baseline neck pain (if the end point was neck injury) and the fourth model also adjusted for job strain. We repeated these analyses stratified for less severe and more severe injuries as defined by medical diagnoses. All analyses were calculated with the statistical software program STATA 8.0 for Windows.

RESULTS

ERI ratio distribution and correlation with other measures of working conditions

The mean ERI ratio was 1.14 (SD 0.63). Cable car operators had substantially lower ERI ratios (0.81, SD 0.44) than diesel bus (1.15, SD 0.65), electric trolley bus (1.19, SD 0.61) and light rail train (1.17, SD 0.68) operators. The ERI ratio correlated positively with weekly driving hours (0.23) and ergonomic problem score (0.26) and slightly negatively with years of professional driving (−0.04). With regard to the demand–control model, the ERI ratio correlated positively with psychological demands (0.36), negatively with decision latitude (−0.17) and positively with the job strain ratio (psychological demands divided by decision latitude, 0.34).

Frequency of injuries

Table 1 lists the number and diagnoses of first time compensated low back and neck injury during the 7.5-year follow-up period. There were 312 low back and 295 neck injuries. Ninety-five (30.5%) of the low back injuries and 60 (20.3%) of the neck injuries were scored as "more severe injuries", based on their ICD-9 codes.

Associations of ERI with incidence of low back injury

Table 2 shows the association between ERI and the incidence of all 312 low back injuries. A 1 SD increase of the ERI ratio was associated with a 13% increased risk of low back injury ($p = 0.026$) in the fully adjusted model. Transit operators scoring in the highest quartile of the ERI ratio had an HR of 1.32 (95% CI 0.94 to 1.86) in this model.

Table 3 shows the association between ERI and low back injuries separately for the 217 less severe and the 95 more severe injuries in the fully adjusted model. There was a trend towards an association between ERI and less severe low back injuries (11% increased risk for a 1 SD increase of the ERI ratio), but this result was not statistically significant at the 0.05 level. With regard to more severe injuries, however, a 1 SD increase of the ERI ratio was associated with a statistically significant 23% increased injury risk ($p = 0.020$). Respondents scoring in the highest quartile of the ERI ratio had an HR of 2.17 (95% CI 1.10 to 4.28) for more severe injuries.

Table 1 Incidence of first compensated low back and neck injury in 1179 urban transit operators during 7.5 years of follow-up (1993–2001) by specific diagnosis and severity

	n (%)
First time low back injury	312 (26.46)
Type of low back injury	
(1) Postlaminectomy syndrome	1 (0.32)
(2) Spinal stenosis	7 (2.24)
(3) Herniated disc with myelopathy	8 (2.56)
(4) Herniated disc without myelopathy	58 (18.59)
(5) Sciatica	20 (6.41)
(6) Possible instability	1 (0.32)
(7) Probable degenerative changes	12 (3.85)
(8) Non-specific backache	205 (65.71)
Severity of low back injury	
More severe low back injury (type of injury numbers 1–5)	95 (30.45)
Less severe low back injury (type of injury numbers 6–8)	217 (69.55)
First time neck injury	295 (25.02)
Type of neck injury	
(1) Postlaminectomy syndrome	2 (0.68)
(2) Spinal stenosis	6 (2.03)
(3) Herniated disc with myelopathy	3 (1.02)
(4) Herniated disc without myelopathy	27 (9.15)
(5) Brachial neuritis or radiculitis not otherwise specified	22 (7.46)
(6) Possible instability	0 (0.00)
(7) Probable degenerative changes	13 (4.41)
(8) Non-specific neckache	222 (75.25)
Severity of neck injury	
More severe neck injury (type of injury numbers 1–5)	60 (20.34)
Less severe injury (type of injury numbers 6–8)	235 (79.66)

Associations of ERI with incidence of neck injury

Table 4 shows the association between ERI and the incidence of all 295 neck injuries. A 1 SD increase of the ERI ratio was associated with a 14% increased risk of neck injury in the fully adjusted model (p = 0.021). Transit operators scoring in the highest quartile of the ERI ratio had an HR of 1.66 (95% CI 1.16 to 2.38) in this model.

Table 5 shows the association between ERI and neck injuries separately for the 235 less severe and the 60 more severe injuries in the fully adjusted model. A 1 SD increase of the ERI ratio predicted a 15% increased risk of less severe neck injuries (p = 0.027). Respondents scoring in the highest ERI quartile had an HR of 1.49 (95% CI 1.01 to 2.20). With regard to more severe injuries, a 1 SD increase of the ERI ratio was associated with a 10% increased injury risk, which was not statistically significant (p = 0.452). However, respondents scoring in the medium–high and the highest ERI quartile showed statistically significant increased risks of more severe injuries, with HRs of 2.67 (95% CI 1.07 to 6.69) and 3.31 (95% CI 1.28 to 8.58), respectively.

DISCUSSION

Summary of results

ERI predicted the incidence of both low back injury and neck injury in this cohort of 1179 urban transit operators, after adjustment for age, gender, height, weight, years of professional driving, weekly driving hours, vehicle type, ergonomic problems, pain at baseline and job strain. When we stratified the analyses by severity of injury, ERI showed a statistically significant association with incidence of more severe low back injury and incidence of both less severe and more severe neck injuries, but not with incidence of less severe low back injuries.

Causal inference and potential biases

To our knowledge, this is the first time that the impact of ERI on MSD was analysed in a prospective cohort study. A prospective design allows the establishment of temporal order between exposure and outcome variables, a central criterion for causal inference.[30]

It has been argued that associations between psychosocial working conditions and health outcomes might be biased by a tendency of certain study participants to over-report both adverse exposure and illness symptoms, because of an underlying third factor, most notably negative affectivity.[7] We accounted for this potential bias, by using doctor-diagnosed occupational injuries coded according to the standard ICD-9 codes in the course of an accepted workers' compensation claim. In addition, we adjusted for self-reported low back and neck pain at baseline, in order to control further for residual effects of negative affectivity and also to control for the possibility that subclinical low back or neck disorders might have influenced both the perception of the psychosocial work environment and the risk of subsequent occupational injury. This was a conservative approach, which consciously accepted the possibility of overadjustment, because it is possible that subclinical low back and neck pain are intermediate steps in a pathway leading from psychosocial exposure to the risk of occupational injuries. As it turned out in the analyses, effect estimates were similar before (model 2) and after (model 3) adjustment of pain at baseline. Finally, reporting bias due to negative affectivity or other psychological states of the respondents also seems unlikely, because, at least for low back injuries, the strongest associations were found for more severe injuries, which were

Table 2 Effort–reward imbalance and incidence of low back injuries in 1179 urban transit operators (1993–2001)

	At risk	Incident low back injury	Model 1	Model 2	Model 3	Model 4
	n	n (%)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
ERI ratio continuous (1 SD increase)	1179	312 (26.5)	1.13 (1.02 to 1.24) p = 0.016	1.11 (1.00 to 1.23) p = 0.052	1.13 (1.01 to 1.25) p = 0.028	1.13 (1.02 to 1.26) p = 0.026
ERI ratio divided into quartiles						
Low ERI (reference)	312	71 (22.8)	1	1	1	1
Medium–low ERI	313	76 (24.3)	1.00 (0.73 to 1.39)	1.01 (0.73 to 1.41)	1.01 (0.72 to 1.41)	1.01 (0.72 to 1.41)
Medium–high ERI	286	79 (27.6)	1.16 (0.84 to 1.61)	1.15 (0.82 to 1.61)	1.15 (0.82 to 1.61)	1.15 (0.82 to 1.62)
High ERI	268	86 (32.1)	1.35 (0.99 to 1.86)	1.30 (0.93 to 1.82)	1.31 (0.93 to 1.84)	1.32 (0.94 to 1.86)

Cox proportional hazard analyses: model 1 is adjusted for gender, age, height and weight; model 2 is further adjusted for physical workload (years of professional driving, driving hours per week, vehicle type) and ergonomic problems; model 3 is further adjusted for low back pain at baseline; and model 4 is further adjusted for job strain.
ERI, effort–reward imbalance.

Table 3 Effort–reward imbalance and incidence of less severe and more severe low back injuries in 1179 urban transit operators (1993–2001)

	Less severe low back injuries			More severe low back injuries		
	At risk	Incident low back injury		At risk	Incident low back injury	
	n	n (%)	HR (95% CI)	n	n (%)	HR (95% CI)
ERI ratio continuous (1 SD increase)	1084	217 (20.0)	1.11 (0.96 to 1.28) p = 0.153	962	95 (9.9)	1.23 (1.03 to 1.46) p = 0.020
ERI ratio divided into quartiles						
Low ERI (reference)	298	57 (19.1)	1	255	14 (5.5)	1
Medium–low ERI	287	50 (17.4)	0.86 (0.58 to 1.27)	263	26 (9.9)	1.68 (0.87 to 3.25)
Medium–high ERI	261	54 (20.7)	1.01 (0.68 to 1.49)	232	25 (10.8)	1.81 (0.92 to 3.57)
High ERI	238	56 (23.5)	1.13 (0.75 to 1.69)	212	30 (14.2)	2.17 (1.10 to 4.28)

Cox proportional hazard analyses: The model is adjusted for gender, age, height, weight, physical workload (years of professional driving, driving hours per week, vehicle type), ergonomic problems, low back pain at baseline and job strain.
ERI, effort–reward imbalance.

mostly intervertebral disc herniations that are typically diagnosed and verified by objective clinical and radiological tests.

Differential effect of ERI on site of injury

Previously, associations between ERI and MSD have been found in a case–control study with hospital workers in the USA,[20] and in cross-sectional studies with German transit operators,[15 16] German police officers,[17] Japanese dental technicians[18] and nurses from seven European countries.[19] Three of these studies had analysed low back and neck disorders separately. Whereas associations between ERI and low back and neck pain were similar in the study with German police officers,[17] the two other studies found stronger effects of ERI for neck disorders. In the hospital worker study, ERI was significantly associated with neck and upper extremity injuries, but not with low back and lower extremity injuries.[20] The German transit operator study by Joksimovic *et al* found higher odds ratios for neck pain than for back pain.[15] These results suggest that exposure to an adverse psychosocial work environment might have more adverse effects on the neck than on the low back region. This is in line with results from a previous study on San Francisco transit operators that found psychosocial working conditions, measured with the demand–control–support model, more strongly related to neck injuries than to low back injuries.[24] In the present study, however, there was no clear tendency for a differential effect of ERI on site of injury. The continuous ERI ratio showed similar HRs for low back (HR = 1.13) and neck injuries (HR = 1.14), when severity of injury was not taken into consideration. For less severe injuries, the continuous ERI ratio showed stronger associations with neck injuries (HR = 1.15) than low back injuries (HR = 1.11), whereas for more severe injuries, associations were stronger with low back (HR = 1.23) than neck injuries (HR = 1.10). However, when we used quartiles of the ERI ratio as the predictor variable, HRs in the highest ERI quartile were consistently higher for neck injuries than for low back injuries, regardless of severity of injury.

Strengths and weaknesses

A major strength of the study is its longitudinal design and the use of Cox regression models, which ensured that risk estimates took the length of the injury-free periods into account.

We measured psychosocial exposure based on the model of ERI, a well-established theoretical approach to conceptualise potential health-hazardous psychosocial stressors at the workplace.[12–14] Because the ERI questionnaire was not available at the time of the baseline survey, we assessed effort and reward based on proxy measures. With regard to the measurement of rewards, this may be considered a weakness of the study, because proxy measures were only available regarding respect and job security, but not for other important aspects of rewards such as monetary gratification or promotion prospects.[12] Effort was measured with four items addressing demanding work situations related to the drivers' schedule. We believe that these items, which were specifically developed for research in transit operators, allowed a more precise measurement of high effort in the study population than the items in the generic ERI questionnaire, and consequently we consider the use of these proxy items a strength rather than a weakness of the study.

With regard to the response options to both the effort and reward items, one has to note that in the original ERI questionnaire, effort and reward are assessed by first asking the respondents about the occurrence of a specific aspect of

Table 4 Effort–reward imbalance and incidence of neck injuries in 1179 urban transit operators (1993–2001)

	At risk	Incident neck injury	Model 1	Model 2	Model 3	Model 4
	n	n (%)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
ERI ratio continuous (1 SD increase)	1179	295 (25.0)	1.14 (1.04 to 1.26) p = 0.007	1.16 (1.05 to 1.29) p = 0.004	1.15 (1.04 to 1.28) p = 0.007	1.14 (1.02 to 1.27) p = 0.021
ERI ratio divided into quartiles						
Low ERI (reference)	312	66 (21.2)	1	1	1	1
Medium–low ERI	313	62 (19.8)	0.90 (0.64 to 1.28)	0.97 (0.68 to 1.38)	0.95 (0.66 to 1.36)	0.94 (0.66 to 1.34)
Medium–high ERI	286	78 (27.3)	1.32 (0.95 to 1.83)	1.39 (0.99 to 1.96)	1.36 (0.97 to 1.93)	1.34 (0.95 to 1.89)
High ERI	268	89 (33.2)	1.61 (1.17 to 2.22)	1.77 (1.25 to 2.50)	1.72 (1.21 to 2.44)	1.66 (1.16 to 2.38)

Cox proportional hazard analyses: model 1 is adjusted for gender, age, height and weight; model 2 is further adjusted for physical workload (years of professional driving, driving hours per week, vehicle type) and ergonomic problems; model 3 is further adjusted for neck pain at baseline; and model 4 is further adjusted for job strain.
ERI, effort–reward imbalance.

Table 5 Effort–reward imbalance and incidence of less severe and more severe neck injuries in 1179 urban transit operators (1993–2001)

	Less severe neck injuries			More severe neck injuries		
	At risk	Incident neck injury		At risk	Incident neck injury	
	n	n (%)	HR (95% CI)	n	n (%)	HR (95% CI)
ERI ratio continuous (1 SD increase)	1119	235 (21.0)	1.15 (1.02 to 1.29) p = 0.027	944	60 (6.4)	1.10 (0.86 to 1.41) p = 0.452
ERI ratio divided into quartiles						
Low ERI (reference)	305	59 (19.3)	1	253	7 (2.8)	
Medium–low ERI	295	44 (14.9)	0.76 (0.51 to 1.13)	269	18 (6.7)	2.39 (0.98 to 5.84)
Medium–high ERI	269	61 (22.7)	1.21 (0.83 to 1.76)	225	17 (7.6)	2.67 (1.07 to 6.69)
High ERI	250	71 (28.4)	1.49 (1.01 to 2.20)	197	18 (9.1)	3.31 (1.28 to 8.58)

Cox proportional hazard analyses: The model is adjusted for gender, age, height, weight, physical workload (years of professional driving, driving hours per week, vehicle type), ergonomic problems, neck pain at baseline and job strain.
ERI, effort–reward imbalance.

effort or reward and then further asking the respondents to rate how much they feel "distressed" about this aspect.[12] In the present study, however, we measured occurrence and frequency of an effort or reward aspect, but not the level of self-reported distress. This can be considered as a weakness, because it has been argued that for understanding health-hazardous effects of stressors, it is crucial to measure how these stressors are perceived and appraised by the individual.[31] On the other hand, researchers have warned against measuring the level of distress, because this involves the risk of blending exposure assessment (stressor) with outcome assessment (stress reaction).[7 32]

Finally, it has to be noted that this study did not include items that would allow construction of a proxy measure for the motivational disposition work-related overcommitment. This might be regarded as a weakness, because it is conceptually assumed in the ERI model that the presence of overcommitment heightens the health-hazardous effects of ERI.[12] On the other hand, by not including this motivational disposition, we kept the focus of the analyses on the main effect of working conditions that act independently of personality aspects of the worker.

We conclude that the incomplete measure of the reward component, the lack of an assessment of individual appraisal of the exposures and the lack of a measurement of overcommitment have more probably resulted in an underestimation than an overestimation of the effect size of ERI as it is defined by Siegrist and colleagues.[12]

We adjusted the analyses for physical workload and ergonomic problems in order to disentangle the physical and psychosocial working conditions, thereby overcoming a major limitation characteristic of earlier studies.[5 6] We used years of professional driving, and vehicle type (obtained from company records) and driving hours per week (assessed by self-report) as proxy measures for physical workload. These variables were chosen to conceptualise cumulative past (long-term) and current (short-term) exposure to biomechanical risk factors such as uncomfortable working postures, repeated upper body twisting and bending, and whole body vibration.[8] Ergonomic problems were assessed by asking the transit operators to fill out a checklist on common ergonomic problems of professional drivers. We did not include observer-based measurements of physical and ergonomic exposure,[33] which may be considered as a weakness. This is, unfortunately, a typical limitation of large-scale epidemiological studies, because of the high costs associated with individual standardised measurements. However, at least physical demands do not vary appreciably between transit operators who operate the same vehicle type, a factor which was accounted for in this study.

Including years of professional driving and driving hours per week as proxy measures for physical workload and using these variables as potential confounders in the analyses might be considered overadjustment, because these variables also assess psychosocial working conditions to a certain extent. Years of professional driving measures history of exposure not only to physical but also to psychosocial working conditions. Long working hours not only indicate physical loads, such as duration of trunk movements or exposure to whole body vibration, but are also an indicator of high effort spent at work.[12] In addition to this, it is possible that the effect of ERI is not only confounded but also modified by exposure to physical workload, which would further argue against adjusting for these exposures. We were aware of these issues but chose deliberately the more conservative approach by treating physical workload as a confounder. This was motivated both by our theoretical approach to disentangle the effects of psychosocial and physical exposures and by our earlier findings that physical workload had a strong effect on risk of low back injuries among the study participants.[8]

In our previous study with this cohort, job strain and iso-strain (the combination of job strain and low social support) were related to low back and neck injuries.[24] When ERI was adjusted for job strain in the present analysis, effect estimates changed only slightly. This is in line with other studies that have found that ERI and job strain have largely independent effects on health.[34 35] We did not adjust for iso-strain, because social support is conceptually a part of the reward construct in the ERI model.[12] Moreover, there was also a methodological overlap, because the reward item measuring respect from supervisors was also used as a measure of social support, when constructing the iso-strain variable.

Possible explanations of how ERI contributes to risk of low back and neck injuries

It is a central assumption in the ERI model that exposure to high ERI triggers psychophysiological stress reactions, most notably activation of the autonomous nervous system and the hypothalamic–pituitary–adrenal (HPA) stress axis, and that this activation increases the risk of ill health.[11 12] Although the role of psychophysiological stress reactions has been studied foremost with regard to cardiovascular disease,[11 36] these stress reactions might also be involved in the aetiology of MSD. It has been suggested that exposure to adverse psychosocial factors, such as ERI, increases the likelihood of muscle activity and muscle tension, which subsequently increases the risk of musculoskeletal pain and injury.[1 37 38] In experimental studies, a Swedish research group led by Ulf Lundberg, demonstrated that both

Main message

This is the first longitudinal study showing that effort–reward imbalance at work increases the risk of incident musculoskeletal disorders.

Policy implications

Improving the psychosocial work environment of transit operators with regard to effort (less demanding schedules) and reward (increasing respect and job security) might contribute to the prevention of work-related musculoskeletal disorders.

self-reported stress levels and measured sympathetic arousal were related to increased electromyographic (EMG) activity of the trapezius muscle,[39 40] and that EMG activity was related to neck and shoulder pain.[41] Other researchers have suggested that the release of the stress hormone cortisol might increase the vulnerability of muscles to mechanical load.[42]

An alternative explanation for the findings in our study is that ERI is not causally related to risk of injury, but is related to filing a workers' compensation claim. In line with the theoretical definition of ERI as a high cost/low gain situation at work,[12] one can speculate that drivers with high ERI are more motivated to increase their gain in seeking workers' compensation benefits than drivers with low ERI. However, this explanation seems unlikely for two reasons: first, injuries were defined not based on filed claims, but on accepted claims, which means that a doctor has diagnosed the injury and that workers' compensation authorities had assessed the injury as work related. Secondly, with regard to low back injuries, ERI was only weakly related to less severe injuries, which mostly included the diagnoses "non-specific backache", but was strongly related to more severe injuries, which mostly include herniated disc, a diagnosis that was objectively verifiable through clinical and radiological tests.

Conclusion

We conclude that ERI is a risk factor for both low back and neck injuries. Because the measures both on effort (demanding schedule) and on reward (respect and job security) are amenable to change, these findings indicate an important potential for prevention of MSD, at least in the work environment of transit operators.

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APPENDIX

Definition of severity of neck injury by ICD-9 codes

Table AI lists the diagnostic codes used in this study to determine possible and definite neck injury 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*[25] The severity ranking is based on clinical judgement by the second author (Niklas Krause). A similar classification has been developed for low back problems and has been published elsewhere.[8]

Table AI Severity ranking of neck disorders classified by medical diagnoses (ICD-9 coded)

Clinical category	ICD-9 code(s)	Diagnosis	Severity rank*	Severity group†
Herniated disc	***722.0***	Displacement of cervical disc without myelopathy	4	2
	722.2	Displacement of unspecified disc without myelopathy	4	2
	722.70	Disc disorder with myelopathy, site unspecified	3	1
	722.71	Cervical disc disorder with myelopathy	3	1
Radicular syndrome without verified disc herniation	***723.4***	Brachial neuritis or radiculitis not otherwise specified	5	2
	721.1	Cervical spondylopathy with myelopathy	2	1
	723.5	Torticollis, unspecified	5	2
	353.0	Brachial plexus lesions (cervical rib, costoclavicular syndrome)	5	2
	353.2	Cervical root lesions, not elsewhere classified	5	2
	353.8	Other nerve root and plexus disorders	5	2
	353.9	Unspecified nerve root and plexus disorder	5	2
Probably degenerative changes	***721.0***	Cervical sypondylosis without myelopathy	7	3
	721.5–9	Unique or unusual forms of spondylosis	7	3
	722.4	Degeneration of cervical disc	7	3
	722.6	Degeneration of disc, site unspecified	7	3
	722.90	Other and unspecified disc disorder, site unspecified	7	3
	722.91	Other and unspecified cervical disc disorder	7	3
	720.10	Spinal enthesiopathy	7	3
Spinal stenosis	***721.1***	Cervical spondylosis with myelopathy	2	1
	721.91	Spondylogenic compression of spinal cord unspecified	2	1
	723.0	Spinal stenosis in cervical region	2	1
Possible instability	738.4	Acquired spondylolisthesis	6	2
	756.12	Spondylolisthesis	6	2
Non-specific neckache	307.81	Tension headache	8	3
	723.1	Cervicalgia	8	3
	723.2	Cervicocranial syndrome	8	3
	723.3	Cervicobrachial syndrom (diffuse)	8	3
	723.6	Panniculitis specified as affecting neck	8	3
	723.7	Ossification of posterior longitudinal ligament (neck)	7	3
	723.8	Other syndromes affecting cervical region	8	3
	723.9	Neckache, unspecified	8	3
	847.0	Sprains and strains, neck	8	3
	847.1	Sprains and strains, dorsal (spine)	8	3
	847.9	Sprains and strains, unspecified region	8	3
Sequelae of previous neck surgery	722.80	Postlaminectomy syndrome, unspecified region	1	1
	722.81	Postlaminectomy syndrome, cervical	1	1
	996.4	Mechanical complication of internal orthopaedic device, implant and graft	1	1

Continued

Table AI Continued

Clinical category	ICD-9 code(s)	Diagnosis	Severity rank*	Severity group†
Miscellaneous	722.30	Schmorl's nodes, unspecified region	9	3
	722.39	Other Schmorl's nodes	9	3
	737.9	Unspecific curvature of spine	9	3
	738.2	Acquired deformity of neck	9	3
	738.5	Other acquired deformity of back or spine	9	3
	739.0	Non-allopathic lesions, occipitocervical region	8	3
	739.1	Non-allopathic lesions, cervicothoracic region	8	3
	741.1	Spina bifida, cervical region	9	3
	754.1	Congenital deformities of m. sternocleidomastoideus	9	3
	756.10	Anomaly of spine, unspecified	9	3
	756.12–15	Various congenital anomalies	9	3
	756.16	Klippel–Feil syndrome	9	3
	756.17	Spina bifida occulta	9	3

Codes in bold italic type are classified as ''definitely neck'', and other codes refer to ''possibly neck'' a classification method previously suggested for low back pain by Cherkin *et al*.[25]

*Severity 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 disc without myelopathy''; 5 = ''brachial neuritis or radiculitis not otherwise specified''; 6 = ''possible instability''; 7 = ''probably degenerative changes''; 8 = ''non-specific neckache''; 9 = ''miscellaneous''

†Severity ranks 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, nerve root and plexus syndromes, herniated disc without myelopathy'' (4–6); 3 = ''non-specific neckache, degenerative changes and miscellaneous''(7–9). Because of small numbers in the higher severity categories, multivariate analyses in this investigation collapsed the high and middle severity group into one category labelled ''more severe''; the low severity group was labelled ''less severe''.