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Individual-level and plant-level predictors of acute, traumatic occupational injuries in a manufacturing cohort

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ABSTRACT

Objectives Workplace and contextual factors that may affect risk for worker injury are not well described. This study used results from an employee job satisfaction survey to construct aggregate indicators of the work environment and estimate the relative contribution of those factors to injury rates in a manufacturing cohort.

Methods Principal components analysis was used to construct four plant-level factors from responses to a 32 question survey of the entire workforce, administered in 2006. Multilevel Poisson regression was used to evaluate the relationship between injury rate, individual-level and plant-level risk factors, unionisation and plant type.

Results Plant-level 'work stress' (incident rate ratio (IRR)=0.50, 95% CI 0.28 to 0.90) was significant in the multilevel model, indicating the rate of injury for an average individual in that plant was halved (conditional on plant) when job stress decreased by a tertile. 'Overall satisfaction', 'work environment' and 'perception of supervisor' showed the same trend but were not significant. Unionisation was protective (IRR=0.40, 95% CI 0.17 to 0.95) as was any plant type compared with smelter.

Conclusions We demonstrated utility of data from a human resources survey to construct indicators of the work environment. Our research suggests that aspects of the work environment, particularly work stress and unionisation, may have a significant effect on risk for occupational injury, emphasising the need for further multilevel studies. Our work would suggest monitoring of employee perceptions of job stress and the possible inclusion of stress management as a component of risk reduction programmes.

What this paper adds

- While risk factors for acute occupational injury related to job and demographic characteristics are increasingly well studied, less is known about the impact of workplace and contextual factors on injury risk. We used responses to an employee job satisfaction survey of 30 163 employees at 56 locations of a single aluminium company under long-standing injury surveillance.
- Principal components analysis was used to construct plant-level factors from responses to the 32 question survey of the entire workforce administered in 2006. We used multilevel Poisson regression to evaluate the relationship between injury rate, individual-level factors and plant-level risk factors.
- Four dimensions around quality of work life emerged from the PCA: 'overall satisfaction with company', 'positive work environment', 'positive perception of supervisor' and 'job is stressful'.
- As average plant-level perceptions of job stress increased from poor to average or from average to good, the rate of injury for an average individual in that plant was halved, conditional on plant. Unionisation was also associated with lower risk (IRR=0.40, 95% CI 0.17 to 0.95).

INTRODUCTION

Occupational injuries are a significant source of mortality, morbidity, disability and economic losses in the USA and worldwide. Concha-Barrientos[1] estimated that occupational risk accounts for 8.1% of the global burden of morbidity and mortality (combined) from all unintentional injuries. In 2007, according to the Bureau of Labor Statistics, two million work-related injuries and illnesses (the vast majority of which are injuries) resulted in lost work time for workers in private industry.[2] However, Leigh *et al*., taking into account widely recognised undercounting and underreporting of occupational injuries, estimated more than eight million non-fatal injuries actually occurred during that time period.[3] Physical job demands, worker characteristics such as age, sex, health, job experience and work hours are among the types of predictors that have been linked to risk for occupational injury.[4–7] Others have reported on the roles of job strain[8] and workplace factors such as safety climate,[9 10] training[11] and unionisation[12] in different settings. A meta-analysis found that employee 'engagement' and job satisfaction were inversely and significantly correlated with lost workdays due to safety incidents.[13 14] Studies of organisational 'climate' and particularly 'safety climate', concepts that refer to workers' shared perceptions of the culture of their workplace, have been linked to workplace injury experience.[14] In the USA, manufacturing workplaces account for 17% of all injuries and illnesses, slightly higher than their 13% share of the workforce.[2] This paper

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describes analyses of injury rates among production and maintenance employees working within 56 plants of a large aluminium manufacturing company that has locations distributed throughout the contiguous USA. Previous research in this cohort found associations between risk for occupational injury and worker characteristics such as age, sex, health, job experience and work hours, as well as physical job demand.[4–7] During the study period, we observed great differences in injury rates across plant locations, including sixfold injury rate differences within plants of the same type. The observed differences in injury rate are consistent with previous research in this setting.[15] These differences in injury experience were incompletely explained by compositional factors (ie, what kind of people work in the plant) or differences in occupation, assuming risk levels comparable to those previously reported. To help explain these differences, data on plant-level indicators of work environment were constructed from a questionnaire administered to all employees. These data were then incorporated into a multilevel regression model including established and suspect individual risk factors for acute, traumatic injury in this workforce, plant unionisation and plant type.

Like residents in communities and children in schools, worker cohorts and job groups can be viewed as nested within workplaces. In occupational health investigations, group-level covariates have most often been treated as fixed effects, though there are recent examples of multilevel analysis.[16–18] Although some researchers have called for the treatment of job strain as a group-level variable,[16 17 19] this exposure is most often analysed as an individual-level variable. The first published study investigating job strain at the level of the workgroup (as a predictor of work disability) that accounted for correlated outcomes within workgroup was a 2009 report from the Finnish Public Sector Study.[18] In this paper, we present results side-by-side from individual-level and multilevel regression models, each containing individual job-level and plant-level variables.

METHODS

Cohort

We examined injury and employment records for all production and maintenance workers at 56 plants, located throughout the USA, involved in the production of aluminium metal, aluminium products and related consumer products. Employment records (n=47 645) were obtained from the human resources (HR) data system for the time period from 1 October 2006 to 31 December 2007. Duplicate records (n=2590) were deleted. Production and maintenance employees (n=30 506) at manufacturing locations were identified; rolled up hourly payroll data needed to create the underlying time scale for the Poisson regression models (ie, total number of hours worked) were available for 30 163 workers, who made up the final eligible cohort. These data were derived from complete payroll for start and stop time (total number of hours in a shift), overtime, vacation and sick time.[4 7]

Outcome data

Incident acute, traumatic work-related injuries (injury) occurring between 1 October 2006 through 31 December 2007 was the outcome studied. The incident management system (IMS) system that captures detailed information on injuries is described by Pollack *et al* in previous work.[20] Records of injury incidents were obtained from the company's real-time IMS. The IMS database, established in 1989 and modified over time, contains information on all reported work-related injuries that received any treatment including first aid, for all employees. The IMS system is considered real time since incidents are recorded shortly after an incident occurs, depending on the level of severity.

Injury data are maintained by the company for purposes unrelated to this research and provided to the investigators under a research/service agreement in place since 1997.[5] For this analysis, injuries were limited to instantaneous sprains, strains, burns, contusions, abrasions, fractions, lacerations, eye injuries, fractures, amputations, blisters, foreign bodies, punctures, bites and stings. Chronic injuries, sometimes classified as disease, particularly musculoskeletal disorders whose inception could not be traced to any one time or event were excluded.

Employee satisfaction and organisational climate

From 18 September to 6 October 2006, a company that offers HR research services administered a 32 question, employee job satisfaction survey to the study company's entire US workforce. The Yale research team provided input on survey questions, in particular recommending survey items from the CDC-NIOSH Quality of Work Life Module of the General Social Survey (http://www.cdc.gov/niosh/topics/stress/pdfs/QWLsurvey.pdf). However, the wording of the final survey was determined by the HR research firm and their client. Employees were given paid work time to complete the survey in either an online or paper format. Overall response to the survey was 70% (N=29 247). Responses to questions 1–28 were provided on a five-point Likert scale of agreement (1='strongly disagree', 2='disagree', 3='neither agree nor disagree', 4='agree', 5='strongly agree').

Organisational climate (questions 29–32) was formatted with a frequency scale rather than a Likert scale: 1='always', 2='often', 3='sometimes', 4='rarely', 5='never'. For all questions, lower responses scores indicated more negative responses, that is, lower satisfaction, more stress, etc. The survey data set also contains the following demographic information associated with each record (one record per anonymous respondent): sex, minority (yes or no), years tenure at the company (categorical), function (operation/production, maintenance, administrative or professional), pay-type (hourly or salary, supervisory or non-supervisory), department within plant and geographic region. Because the survey was anonymous, responses were available for analysis only at the aggregate plant level.

Exposure data

Demographic and employment information were obtained from the employer's HR system. This data system contains fields for employee's sex, race, age, date of hire, hourly rate, W-2 income, plant, department and job title, job grade, and dates for all changes in job, job grade, compensation, disability leave, etc. Data obtained from the HR data system as of 1 October 2006 were used to create the following variables for regression modelling: sex (female, male), race (black, Hispanic, Asian, other), age (modelled in continuous 10-year groupings), time since hire (<1 year, 1–2 years, 2–3 years 3–5 years, 5–10 years and >10 years, as dummy variables comparing each category to >10 years) and job grade (ranging from 1 to 71 and modelled as continuous quintiles).

Employees were assigned age and time since hire as of 1 October 2006, and likewise compensation and job characteristics at the start of the study period were used. HR and IMS data were linked deterministically using encrypted personal identifiers.

The plant-level predictors included the workplace indicators derived from the survey, plant type and unionisation status of

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the hourly workers at each plant. Plant-level variables were constructed from survey responses first by using principal components analysis (PCA) to identify unique dimensions of response. We extracted components with an eigenvalue of 1.0 or higher.[21] We identified four dimensions of response in the survey data set, which we named 'overall satisfaction', 'work environment', 'positive perception of supervisor' and 'job stress'. Questions included in each component are described in online supplementary table 1. The components were then rotated orthogonally using varimax to maximise their independence. For ease of interpretability, the dimensions were modelled as scales rather than as linear equations. The scales and the dimensions performed similarly in the models, and the interpretation of each scale and its corresponding dimension is the same.

Fifty-six plants were categorised into eight categories, depending on plant type: smelting of raw aluminium; rolling of aluminium into product; production of consumer products (eg, foil); production of fastener systems or closure systems; production of engineered products; production of rigid packaging and metal-casting. Plant type of smelter was chosen as the referent because these plants involve the heaviest physical demand and have the highest injury rates. Plant unionisation status was coded as yes or no. All classifications of covariates were calculated in the same manner for all models.

Sensitivity analysis: unavailable occupational demand

We conducted an analysis to assess the potential sensitivity of effect estimates to confounding by a missing occupation variable. For this cohort, information on occupational demand is provided by a physical job demand survey (JDS) score. The physical demand required to perform a job was assessed by a single expert rater within each plant and rated 1 to 5, sedentary to very heavy. JDS scoring had been conducted at six smelters by a health and safety manager trained by one of the authors (LC), but JDS scores were only available for 5322 workers employed during 2006–2007. We ran regression models with and without JDS scores within the data set of 5322 records and observed the effects on the estimates of sex, race/ethnicity, age, time since hire and job grade.

Data analysis

We used Poisson regression to model incident rate ratios (IRRs). All demographic and occupational characteristic variables that have been previously shown to be associated with occupational injury in data from this workforce and were included in analyses a priori. Random intercept log-linear models were fit to the injury data as Poisson-distributed, conditional on the plant variables. Model fit, following the addition of each predictor variable, was evaluated with pseudo-AIC criteria. Total hours worked during the study period was the offset variable (underlying person-time) for regression models.

The Poisson distribution fit the data adequately and the data were only slightly over-dispersed (ratio χ^2/df=1.3). As a sensitivity analysis, all regressions were repeated with negative binomials models.[22] All risk ratios and their associated 95% CI and p values were unchanged, so we report the results of Poisson models.

Four different models were constructed in order to find the optimal model to examine plant-level risk factors. Model 1 was an ordinary Poisson regression with individual-level factors only; model 2 incorporated a random effect for plant into model 1. Model 3 included both individual-level and plant-level variables but treated the latter as fixed effects in an individual-level model, and model 4, the full multilevel model, adds several plant-level risk factors.

These studies received Institutional Review Board approval for research involving human subjects from Yale University and the Harvard School of Public Health where the research was conducted. Analysis was conducted using SAS V.9.1.

RESULTS

The distribution of acute, traumatic injuries among the cohort is described in table 1. In total, 91% of the cohort sustained no injuries over the 15-month period, 7.5% sustained one injury, 1.3% two injuries and 0.3% three or more injuries. A higher proportion of men sustained injuries than women. There were statistically significant differences in proportion of workers sustaining an injury by race, age, time since hire, job grade, plant unionisation, plant type and by three of the four scales: overall satisfaction, perception of supervisor and job stress.

Principal component analysis

Four components (or dimensions) accounted for approximately 60% of the variability in the responses. The first component (eigenvalue=14/32) loaded heavily on feelings of satisfaction regarding the employer and was labelled 'overall satisfaction with company'. Component 2 (eigenvalue=2.5/32) was weighted towards questions about the job and the workplace climate and was labelled 'positive work environment'. The third component (eigenvalue=2.2/32) loaded heavily only on questions related to the respondents' supervisor and was therefore labelled 'positive perception of supervisor'. The final retained component (eigenvalue=1.1/32) loaded heavily only upon a set of four questions about psychological job demands and stress. This fourth component was labelled 'job is stressful'. Table 2 shows the Cronbach α scores for each component, and the distribution of plant-aggregated values of each of the four scales. Lower values indicate a more negative response. These four components were then included as plant-level covariates in models 3 and 4 described below.

Models

Results of the four different models of IRR are shown in table 3. The individual-level Poisson (model 1) suggests that Hispanic workers have an increased rate of injury (IRR=1.27, 95% CI 1.08 to 1.49). Increasing age is protective (IRR=0.93, 95% CI 0.88 to 0.99) and shorter time since hire increases risk (IRR range from 2.73 (<1 year) to 1.21 (11–20 years) compared with >20 years). Here, there is little evidence of a relationship between sex and injury rate (IRR (Female)=0.94, 95% CI 0.82 to 1.09). Compared with white workers, Asian workers appear to have lower injury rates (IRR=0.68, 95% CI 0.47 to 0.98), and black race is not associated with injury rate (IRR=1.05, 95% CI 0.89 to 1.20). Increasing job grade (in quintiles) is positively associated with injury (IRR=1.37, 95% CI 1.31 to 1.43).

Model 2 contains the same terms as model 1, adding a random effects term for plant. This model allowed for variation in the intercept across plants in order to observe the differences in risk ratios and/or their p values. In this model, some substantial contributions to the outcome appear to be occurring at the plant level (variance for the random effect=1.90, SE=0.43).

Model 2 indicates that women experience significantly higher injury rates than men (IRR=1.44, 95% CI 1.23 to 1.67) after adjusting for race, age, time since hire and job grade. Correlations within plants were obscuring this relationship. Accounting for within-plant correlations also provides evidence that Asian workers do not have a lower rate of injury

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Table 1 Distribution of employees with acute, traumatic occupational injuries in a cohort of aluminium manufacturing workers (N=30 163)

Characteristic	Subjects in category	Number of injuries (per cent)			
		Not injured	One injury	Two injuries	More than three injuries
Sex*					
Male	23 301	21 286 (91.4)	1674 (7.2)	274 (1.2)	67 (0.3)
Female	6862	6146 (89.6)	578 (8.4)	109 (1.6)	29 (0.4)
Race*					
White	20 911	19 040 (91.1)	1553 (7.4)	260 (1.2)	58 (0.3)
Black	4420	4021 (91.0)	320 (7.2)	59 (1.3)	20 (0.5)
Hispanic	3625	3257 (89.9)	299 (8.3)	54 (1.5)	15 (0.4)
Asian	1002	937 (93.5)	61 (6.1)	3 (0.3)	1 (0.1)
Other	205	177 (86.3)	19 (9.3)	7 (3.4)	2 (1.0)
Age*					
Under 25	1368	1226 (89.6)	113 (8.3)	25 (1.8)	4 (0.3)
25 to 34	4862	4354 (89.6)	409 (8.4)	75 (1.5)	24 (0.5)
35 to 44	7884	7165 (90.9)	598 (7.6)	92 (1.2)	29 (0.4)
45 to 54	10 261	9400 (91.6)	706 (6.9)	124 (1.2)	31 (0.3)
Over 55	5788	5287 (91.3)	426 (7.4)	67 (1.2)	8 (0.1)
Time since hire (years)*					
<1	5525	4893 (88.6)	488 (8.8)	117 (2.1)	27 (0.5)
1–2	2020	1805 (89.4)	182 (9.0)	24 (1.2)	9 (0.5)
3–5	2901	2645 (91.2)	211 (7.3)	34 (1.2)	11 (0.4)
6–10	6076	5493 (90.4)	483 (8.0)	79 (1.3)	21 (0.4)
11–20	6177	5703 (92.3)	393 (6.4)	66 (1.1)	15 (0.2)
>20	7464	6893 (92.4)	495 (6.6)	63 (0.8)	13 (0.2)
Job grade*					
1–3	5608	5229 (93.2)	332 (5.9)	36 (0.6)	11 (0.2)
4–7	6071	5556 (91.5)	420 (6.9)	74 (1.2)	21 (0.4)
8–12	6649	6078 (91.4)	486 (7.3)	68 (1.0)	17 (0.3)
13–21	5686	5051 (88.3)	480 (8.4)	120 (2.1)	35 (0.6)
22–71	6149	5518 (89.7)	534 (8.7)	85 (1.4)	12 (0.2)
Unionised*					
Yes	14 409	13 299 (92.3)	872 (6.1)	186 (1.3)	52 (0.4)
No	12 100	11 780 (97.4)	301 (2.5)	16 (0.1)	3 (0.02)
Plant type*					
Rigid packaging	2580	2244 (87.0)	278 (10.8)	51 (2.0)	7 (0.3)
Casting	6476	6360 (98.2)	112 (1.7)	3 (0.05)	1 (0.02)
Closure systems	456	452 (99.3)	2 (0.44)	2 (0.22)	–
Engineered products	3730	3474 (93.1)	203 (5.4)	42 (1.1)	11 (0.3)
Fasteners	2298	2271 (98.8)	25 (1.1)	2 (0.1)	–
Consumer products	2700	2565 (95.0)	124 (4.6)	8 (0.3)	3 (0.1)
Rolled products	2361	2314 (98.0)	37 (1.6)	7 (0.3)	3 (0.1)
Smelter	2785	2346 (84.2)	325 (11.7)	84 (3.0)	30 (1.1)
Satisfaction scale†					
Low	15 309	14 194 (92.7)	893 (5.8)	172 (1.1)	50 (0.3)
Medium	8057	7803 (96.9)	225 (2.8)	25 (0.3)	4 (0.05)
High	3143	3082 (98.1)	55 (1.8)	5 (0.2)	1 (0.03)
Work environment scale					
Poor environment	17 381	16 352 (94.1)	838 (4.8)	149 (0.9)	42 (0.2)
Average environment	7993	7607 (95.2)	321 (4.0)	52 (0.7)	13 (0.2)
Good environment	1135	1120 (98.7)	14 (1.2)	1 (0.1)	–
Supervisor scale†					
Poor perception	19 204	17 969 (93.6)	1007 (5.2)	177 (0.9)	51 (0.3)
Average perception	5950	5783 (97.2)	140 (2.3)	23 (0.4)	4 (0.1)
Good perception	1355	1327 (97.9)	26 (1.9)	2 (0.1)	–
Stress scale*					
High stress	8395	7611 (90.7)	615 (7.3)	133 (1.6)	36 (0.4)
Medium stress	10 790	10 315 (95.6)	398 (3.7)	61 (0.6)	16 (0.2)
Low stress	7323	7153 (97.7)	160 (2.2)	8 (0.1)	2 (0.04)

* $p<0.05$.
†All employees in plant assigned average values, for descriptive purposes.

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Table 2 Distribution of survey responses in the cohort, by plant, n=56

Scale	Mean (SD)	Range	Cronbach α
Satisfaction scale	26.5 (9.0)	1–45	0.94
Work environment scale	31.7 (5.8)	1–50	0.90
Supervisor scale	19.6 (6.3)	2–30	0.93
Stress scale	11.0 (3.6)	1–20	0.80

(IRR=0.83, 95% CI 0.55 to 1.25). In model 2, age (in 10-year groupings) shows the same risk ratio, although no longer statistically significant (IRR=0.92, 95% CI 0.92 to 1.04).

All categories of time since hire are significant in model 2. Increasing job grade, which was associated with an increased injury rate in model 1, has changed sign; model 2 indicates that a quintile increase in job grade is associated with a *decrease* in injury rate (IRR=0.91; 95% CI 0.85 to 0.97).

Model 3 includes individual-level and plant-level predictors. In this model, women are at greater risk for injury than men (IRR=1.51, 95% CI 1.31 to 1.75). As in model 1, Hispanic workers have higher injury risk (IRR=1.45, 95% CI 1.22 to 1.71) than white workers. The estimates for black and Asian workers are near 1.0. Age was not significant (IRR=1.02, 95% CI 0.96 to 1.08). Time since hire remains a strong and significant predictor within all categories of tenure. Job grade is not significant in this model (IRR=0.96, 95% CI 0.91 to 1.02).

Results from this model indicate a strong association between plant-level variables and individual injury rate. Unionisation at the plant level appears to be protective (IRR=0.68, 95% CI 0.54 to 0.85). Plant type (referent=smelter) is a strong predictor of injury. The estimates for all plant types are below 1, ranging from IRR=0.03 (95% CI 0.01 to 0.08) for closure systems to IRR=0.70 (95% CI 0.60 to 0.80) for rigid packaging. All four derived work environment scales are also significantly associated with lower risk. Plant-level increases of one tertile (ie, low to medium, or medium to high) in job satisfaction (IRR=0.68, 95% CI 0.57 to 0.80), positive work environment (IRR=0.82,

Table 3 Individual-level and plant-level predictors of acute traumatic occupational injury in an aluminium manufacturing cohort: individual-level and multilevel models.

	Model†							
Variable	Model 1: individual-level model (N=22 681 workers)		Model 2: random intercepts model (N=22 681 workers, 56 plants)		Model 3: individual-level model		Model 4: random intercepts model	
Sex								
Female	0.94	(0.82 to 1.09)	1.44	(1.23 to 1.67)***	1.51	(1.31 to 1.75)***	1.44	(1.23 to 1.67)***
Male	1.0	–	1.0	–	1.0	–	1.0	–
Race								
Black	1.04	(0.89 to 1.20)	1.10	(0.94 to 1.31)	0.94	(0.81 to 1.10)	1.07	(0.91 to 1.27)
Hispanic	1.27	(1.08 to 1.49)**	1.28	(1.06 to 1.54)**	1.45	(1.22 to 1.71)***	1.30	(1.08 to 1.57)**
Asian	0.68	(0.47 to 0.98)*	0.83	(0.55 to 1.25)	0.93	(0.63 to 1.37)	0.85	(0.57 to 1.28)
White	1.0	–	1.0	–	1.0	–	1.0	–
Age (10-year groupings)	0.93	(0.88 to 0.99)*	0.98	(0.92 to 1.04)	1.02	(0.96 to 1.08)	0.99	(0.93 to 1.05)
Time since hire (years)								
<1	2.73	(2.28 to 3.28)***	2.41	(1.98 to 2.94)***	2.67	(2.20 to 3.25)***	2.44	(2.00 to 2.97)***
1–2	1.18	(0.91 to 1.53)	2.00	(1.52 to 2.64)***	2.15	(1.64 to 2.83)***	2.08	(1.57 to 2.75)***
3–5	1.64	(1.32 to 2.04)***	1.60	(1.28 to 2.01)***	1.63	(1.28 to 2.00)***	1.64	(1.31 to 2.06)***
6–10	1.59	(1.34 to 1.88)***	1.63	(1.36 to 1.95)***	1.71	(1.43 to 2.05)***	1.65	(1.38 to 1.98)***
11–20	1.21	(1.02 to 1.43)*	1.29	(1.08 to 1.53)**	1.22	(1.08 to 1.45)*	1.29	(1.08 to 1.54)**
>20	1.0	–	1.0	–	1.0	–	1.0	–
Job grade (quintiles)	1.37	(1.31 to 1.43)***	0.91	(0.85 to 0.97)**	0.96	(0.91 to 1.02)	0.87	(0.81 to 0.94)**
Unionised plant (Y/N)					0.68	(0.54 to 0.85)***	0.40	(0.17 to 0.95)*
Plant type								
Rigid packaging					0.70	(0.60 to 0.80)***	0.87	(0.19 to 3.92)
Casting					0.09	(0.07 to 0.13)***	0.08	(0.03 to 0.22)***
Closure systems					0.03	(0.01 to 0.08)***	0.03	0.005, 1.21***
Engineered products					0.46	(0.38 to 0.54)***	0.23	(0.09 to 0.62)**
Fastener					0.05	(0.03 to 0.08)***	0.05	(0.01 to 0.19)***
Consumer products					0.41	(0.33 to 1.51)***	0.44	(0.15 to 1.25)
Rolled products					0.04	(0.03 to 0.07)***	0.02	0.004, 0.14***
Smelter					1.0	–	1.0	–
Satisfaction scale (tertiles)					0.68	(0.57 to 0.80)***	0.94	(0.46 to 1.95)
Work environment scale (tertiles)					0.82	(0.69 to 0.98)*	0.49	(0.22 to 1.22)
Supervisor scale (tertiles)					0.43	(0.37 to 0.50)***	0.70	(0.25 to 2.02)
Stress scale (tertiles)					0.60	(0.47 to 0.76)***	0.50	(0.28 to 0.90)*

†Results are presented in the format of incidence rate ratio (95% CI).
*p<0.05; **p<0.01; ***p<0.001.

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95% CI 0.69 to 0.98), positive perception of the supervisor (IRR=0.43, 95% CI 0.37 to 0.50) and plant-level decreases in job stress (IRR=0.60, 95% CI 0.47 to 0.76) are all associated with reductions in individual injury rate.

Model 4 is a multilevel Poisson model containing terms for all individual-level and plant-level variables and plant as a random effect. In contrast to model 3, job grade is protective (IRR=0.87, 95% CI 0.81 to 0.94). Apart from job grade, the largest differences between models 3 and 4 are observed with plant-level variables. Though the magnitude and direction of all associations remain similar, CIs widen for plant-level variables generally when modelled as random effects.

Unionisation is again associated with a lower individual injury rate (IRR=0.40, 95% CI 0.17 to 0.95). All plant types have a lower risk ratio compared with smelters, though for rigid packaging and consumer products, IRRs are no longer significant. Finally, though low work stress (IRR=0.50, 95% CI 0.28 to 0.90) and positive work environment (IRR=0.49, 95% CI 0.22 to 1.22) still appear to be protective, the estimates for overall job satisfaction and perception of supervisor are attenuated and no longer significant. The risk ratios for all three of the four variables—the work environment, perception of supervisor and job stress—are relatively large. Interpretation of the IRR for stress is that as plant-level job stress decreases from high stress to medium stress or medium stress to low stress, the rate of injury for an average individual in that plant is halved, conditional on plant. The interpretation for the work environment variable would be nearly identical quantitatively, although this variable was not significant. As average plant-level perceptions of the work environment increase from poor to average or from average to good, the rate of injury for an individual in that plant is halved, conditional on plant.

When analyses stratified by injury severity are conducted (results not shown), the IRR for work environment (eg, higher score) and lower stress scores are both protective and significant within the set of first aid only injuries; only stress remains a protective factor against the less prevalent, more serious grades of injury.

Sensitivity analysis

In a subset of smelters, a rich job-level measure of overall physical demand from the JDS was available (data not shown). Adding JDS score did not change estimates of sex, race/ethnicity, age or job grade; however, the IRR for time since hire decreased among the newest hires by 7%. This may reflect the concentration of jobs requiring high physical exertion among newer hires; 35% of the newest hires hold jobs rated as 'very heavy' compared with 4% of those employed for 1–2 years, 11% of those employed 2–3 years, 2% employed for 3–5 years, 2% employed 5–10 years and 1% employed more than 10 years (the relationship between tenure categories and JDS scores: Cramer's V correlation=0.24; $\chi^2 < 0.0001$).

DISCUSSION

Using multilevel modelling and a rich data source, we have shown that plant type, plant unionisation and perceptions of job stress are associated with individual rate of acute occupational injuries among employees distributed across 56 plant locations of an aluminium manufacturing company. We have also corroborated the findings of relationships of female sex, Hispanic race and short time since hire previously reported for subsets of this workforce.[20] An additional variable, job grade, recently found to be associated with hypertension in a subset of this workforce,[23] also appears to be a risk factor for acute injuries. Multilevel modelling of risk factors for acute, traumatic occupational injuries revealed relationships that were obscured by within-plant correlations; even when plant-level variables were absent. When both individual-level and plant-level variables were modelled accounting for the random effect of plant in a multilevel model, we saw adjustments to the estimates for plant-level predictors of individual injury rate that clarifies the contributions of both individual and plant level to individual injury rate compared with more traditional approaches to the data.

The analysis has several limitations. Confounding by unmeasured predictors of injury rate may be present in this data. A measure of specific job content/demand was not available for the whole cohort. Therefore, the sensitivity analysis, while reassuring, is limited to the subset of workers for whom physical job demand scores were available. It is possible that, in the larger workforce, the relationship between tenure and JDS score could be stronger or weaker than in the smelters, so the extent of confounding of the tenure effect could be more or less than that seen here.

Several other worker characteristics that have been associated with injury risk in this cohort, BMI/obesity, smoking status, education and overtime were missing for many in the workforce employed during this study period.

This analysis was conducted at two levels only—the level of the individual and the level of the plant within company. While workers at these plants are organised into at least one, and arguably more, level of organisation, department information was not available to us. We collapsed 56 plants into types according to the nature of the work done in the plant and modelled unionisation of the plants, with the hypothesis that stronger safety programming at unionised plants would result in lower injury rates.[12 24] While we do not know if these plant-level variables are the most meaningful plant-level exposures in this workforce, by using available data from an existing survey, we have made some progress in parsing plants' contributions to individuals' injury rates.

CONCLUSIONS

Our measure of plant-wide job satisfaction includes indicators of the work environment that echo familiar occupational health constructs, namely, job demand, decision latitude and safety climate, from the results of a survey aimed at gauging employees' job satisfaction.[25 26] While there is an abundant literature on the role of psychosocial factors in injury risk, especially for musculoskeletal injuries,[10 27–29] there is less in the literature for direct comparison of plant-level measures of these constructs with which to directly compare. Nonetheless, our findings do appear consistent with our priors and the broad perception that enhanced safety climate, worker satisfaction, supervisor support and less stress are conducive to lower organisation-wide injury rates and better outcomes. In particular, we find employee perceptions of work stress to be the most salient of these plant-level factors and the only one that remained significant in the final model.

The finding of a reduced risk ratio with unionisation in the multilevel model is also consistent with recent publications, although the issue remains unresolved.[12] While there are many possible pathways by which such an association might result, one possible explanation is the association between union participation and a culture of safety.[30]

Our work highlights the value of multilevel modelling as a way to address location-level effects with less bias. It would also suggest monitoring of employee perceptions of job stress and the possible inclusion of stress management as a component of risk reduction programmes.

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Contributors All authors contributed to this work. KS designed the study, implemented all methods, helped to interpret the results, and participated in the drafting and editing of the paper at every stage. MRC posed the question, coordinated the research team and participated in all stages of study design as well as the writing and editing of the paper. LFC was responsible for classifying the physical demand of jobs, creating curating the survey data, data analysis and review of the final manuscript. MDS oversaw the management of the data, assisted with the analysis and provided feedback on the paper. EAE and DC assisted in study design, advised on the analysis methods and made substantive editorial contributions at all stages of manuscript preparation.

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Data sharing statement As an alternative to providing a de-identified data set to the public domain, we allow access for the purpose of re-analyses or appropriate follow-on analyses by any qualified investigator willing to sign a contractual covenant with the host Institution limiting use of data to a specific agreed upon purpose and observing the same restrictions as are limited in our contract with Alcoa, such as 60-day manuscript review for compliance purposes.

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Supplemental Table 1. HR survey questions and Dimensions 1-4	**Cronbach Alpha**
Dimension 1: Overall satisfaction with the company	0.94
Overall, I am extremely satisfied with the company as a place to work.	
I am proud to work for the company.	
I would gladly refer a good friend or family member to the company for employment.	
I believe the company has an outstanding future.	
The leadership of the company has communicated a vision of the future that motivates me.	
I trust the leadership of the company.	
In the company there is open and honest two-way communication.	
The company provides me with the opportunity for learning and development.	
I feel valued as an employee of the company.	
Dimension 2: Positive work environment	0.90
I can see a clear link between my work and the company's objectives.	
My ideas and suggestions count.	
My job makes good use of my skills and abilities.	
I am appropriately involved in decisions that affect my work.	
I feel encouraged to come up with new and better ways of doing things.	
My workgroup has a climate in which diverse perspectives are valued.	
I have the authority to correct problems as they occur.	
Customer problems are dealt with quickly.	
I work in an environment that promotes safety.	
We do not compromise EHS values for the sake of production or profit.	
Dimension 3: Positive perception of supervisor	0.93
My immediate supervisor is an outstanding leader.	
My immediate supervisor keeps his/her commitments.	
I trust my immediate supervisor.	
My immediate supervisor clearly communicates what is expected of me.	
My immediate supervisor gives me feedback that helps me improve my performance.	
My immediate supervisor treats me with respect and dignity.	
Dimension 4: Job is stressful	0.80
I find my work stressful.	
I find that I am worn out at the end of the day.	
I find that my work demands often interfere with my family life.	
I find that work issues remain on my mind after hours.	