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Contribution of health status and prevalent chronic disease to individual risk for workplace injury in the manufacturing environment

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ABSTRACT

Objectives An 'information gap' has been identified regarding the effects of chronic disease on occupational injury risk. We investigated the association of ischaemic heart disease, hypertension, diabetes, depression and asthma with acute occupational injury in a cohort of manufacturing workers from 1 January 1997 through 31 December 2007.

Methods We used administrative data on real-time injury, medical claims, workplace characteristics and demographics to examine this association. We employed a piecewise exponential model within an Andersen–Gill framework with a frailty term at the employee level to account for inclusion of multiple injuries for each employee, random effects at the employee level due to correlation among jobs held by an employee, and experience on the job as a covariate.

Results One-third of employees had at least one of the diseases during the study period. After adjusting for potential confounders, presence of these diseases was associated with increased hazard of injury: heart disease (HR 1.23, 95% CI 1.11 to 1.36), diabetes (HR 1.17, 95% CI 1.08 to 1.27), depression (HR 1.25, 95% CI 1.12 to 1.38) and asthma (HR 1.14, 95% CI 1.02 to 1.287). Hypertension was not significantly associated with hazard of injury. Associations of chronic disease with injury risk were less evident for more serious reportable injuries; only depression and a summary health metric derived from claims remained significantly positive in this subset.

Conclusions Our results suggest that chronic heart disease, diabetes and depression confer an increased risk for acute occupational injury.

INTRODUCTION

Despite evidence that the workforce in developed countries is aging, and includes increasing numbers of workers with established chronic health risk factors and conditions,¹ there is scant literature on the contribution of health to risk for occupational injury. As succinctly framed in the concluding paragraph of a 2008 systematic review of the subject, 'the information gap is both surprising and urgent to fill.'²

There are some relevant studies. Starting with disease risk factors, our group and others have shown that obesity is an independent risk factor^{3–4} with some suggestion of a dose-response relationship, but whether this increased risk is due to obesity per se or to obesity-related diseases, such as

What this paper adds

- ▶ Despite an aging population, there is scant literature on the effects of chronic disease on occupational injury risk.
- ▶ Some studies have shown higher risk of injury for those with depression, obesity, diabetes and asthma.
- ▶ We investigated the association of ischaemic heart disease, hypertension, diabetes, depression, asthma and acute occupational injury in a cohort of manufacturing workers for a 10-year period between 1997 and 2007.
- ▶ After adjusting for potential confounders, presence of these diseases was significantly associated with increased hazard of injury: heart disease (HR 1.23), diabetes (HR 1.17), depression (HR 1.25) and asthma (HR 1.14).
- ▶ Our results suggest that chronic heart disease, diabetes and depression confer an increased risk for acute occupational injury. Employees may benefit from strategies to reduce chronic disease.

diabetes, depression, asthma or cardiovascular disease, is unknown. A single controlled fitness intervention trial at an aluminium plant in Australia⁵ showed short-term injury reduction associated with weight loss, suggesting the former. Tsai *et al*⁶ has suggested that smoking is associated with increased risk, however, they did not control for social and medical covariates.

Specifically among health disorders, depression is the best studied with some consistency that depressed workers have higher risk of injury.^{7–8} Depending on the population studied, relative risks of injury among those with depression range from just above 1 to slightly over 3.^{9–10} All these studies relied on subject self-report of depression and other known risk factors for injury, including differences in physical hazards of the work itself, were inconsistently managed, leading Palmer *et al*² in review to infer that there is likely a higher risk associated with depression, but that evidence remains inconclusive. A recent study from Korea¹¹ supports that conclusion, demonstrating modest but non-significant excess risks for occupational injury among those reporting depression on surveys.



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Diabetes has been less well studied, but there is also some evidence suggesting that affected workers are at excess injury risk, with relative risks in the 1.3–1.4 range.² Notably, in the National Health Interview Survey results reported from 1996–2005, covering almost 200 000 adult Americans, the risk was not significantly distinguished from 1 overall, though subgroups of sicker patients with diabetes had elevated risk.¹² In none of these studies could the potential negative bias introduced by differential job selection of those in poorer health be addressed.

Asthma, hay fever and the medications used to treat them have been the subject of several reported studies with mixed results. Sprince *et al*¹³ show an odds ratio of 1.6 for asthma for injury among farmers, with even a higher risk among those working with livestock, but studies of allergy more generally in farmers and industrial workers have been contradictory.^{14–15} The evidence for hypertension and cardiovascular disease is even more limited, with no single study of sufficient quality or size to lend guidance.

In an effort to address this gap in the scientific literature, all the more pressing as the workforce ages and suffers high rates of chronic diseases,¹ we have exploited our rich data on almost 40 000 manufacturing workers of Alcoa at a range of medium to heavy production facilities in 24 states between 1997 and 2007; we truncated follow-up at this juncture to avoid any specific effects of the recession which impacted the industry heavily beginning in 2008. In previous reports, we have assessed the roles of overtime, job demand, sex, work organisation and time on job, in addition to the study of obesity referenced above (Souza *et al*, unpublished data, 2013).^{4–16–18} Using an Andersen–Gill (AG) model with a piecewise exponential baseline hazard, and employee-level frailty term, we explore here the possibility that one or more prevalent chronic diseases or overall health status measured from health claims may explain some of the ‘within-individual’ risks previously modelled using a random frailty term.^{19–20–21} Unlike previous studies, the use of exclusive and complete administrative health, injury and covariate data on the workers, and extensive knowledge about the jobs and their intrinsic risks, allows us to circumvent many of the limitations of the studies summarised above.

METHODS

Study population

The study population includes hourly—blue collar— manufacturing workers of a global aluminium company at 195 locations within the USA that were actively employed during the study period from 1 January 1997 through 31 December 2007. Data were obtained from a variety of sources including the employer’s human resources databases, medical insurance claims data capturing each personal medical service, procedure, test or treatment provided and physician diagnosis for same, and a real-time incident management system established in 1989 in which details of every near-miss, first aid, or OSHA-recordable injury or incident are recorded within 48 h of occurrence. These sources are described in greater detail in previous publications.^{17–22–23} None of the data included are obtained from self-report.

As time to injury and experience on the job were of interest, only jobs that began after 1 January 1997 (incident jobs) were included in the cohort. For a given job to be included in the analysis, the employee needed to be eligible for company insurance during the duration of the job. Over 95% of the employees did, in fact, use the company plan except at three locations where a health maintenance organisation was heavily subscribed, so those plants were excluded. If, for a given job, the employee

was missing only 1 year of health insurance data, the last observation carried forward was used to impute the missing year of data.

Primary outcome

The primary outcome is the time in months from the start of a particular job to any acute injury on that job. All occupational injuries, including first aid only and Occupational Safety and Health Administration (OSHA)-reportable injuries, are recorded in the real-time incident management system soon after they occur. Acute injuries include events, such as chemical/thermal burns, bruises, cuts/abrasions, fractures, instantaneous musculoskeletal injuries, and other incidents of sudden onset. Chronic conditions or events that are cumulative in nature, those classified as ‘near-misses’, or not directly related to work, do not meet the criteria for acute injury.

Employees who were not injured during the study period were censored at the first occurrence of: job change (defined as a significant change in job title), death, change to non-active status, or the end of the study period on 31 December 2007. To be included as distinct outcomes, injuries had to occur at least 1 day apart.

Primary exposure

The primary ‘exposures’ of interest were the presence of one of five disease states. Disease states were defined using medical claims data during the study period. We required one inpatient visit or two outpatient visits in the same calendar year of disease incidence; the disease was presumed to be present in every subsequent year as well. Asthma was defined using ICD9 codes of 493.XX and 496.XX; hypertension using 401.XX–404.XX; heart disease using 410.XX–414.XX; depression using 296.XX, 309.XX, and 311.XX; and diabetes using 250.XX.

Secondary exposure

Risk score measures were calculated for each year based on medical claims data and provide a measure of general health. Scores are based on an algorithm provided by Verisk for prediction of subsequent health claims based on a previous year in commercially insured populations.²⁴ The risk score is a general metric for prediction of medical spending in the next year relative to the average employee at the company, and has been demonstrated by us and others to be a strongly associated, monotonically increasing predictor of absenteeism, disability and mortality (unpublished data). We incorporated risk score by year, aligning the previous year’s risk score to the calendar year, and categorised scores into deciles in each year.

Other covariates

Calendar year, age at start of job, race, sex, whether the job was the first job at the company for the employee, and several plant-level characteristics including: business type, smelter plant type, and union status of the plant were all considered as potential confounders of the relationship between disease states and acute injury. Further, as the hazard of injury decreases after 1 year on the job,¹⁹ we adjusted for more than 1 year of experience as a potential confounder.

Statistical analysis

To compare employees with chronic conditions to those without, we used χ^2 tests of association for categorical variables, and t tests for continuous variables. All comparisons are to the group that did not have the disease in question during the study period (eg, for the heart disease column, the comparison is with those who did not have heart disease during the study period).

Models

Survival methods were used to estimate relative rates of injury. Several complicating factors make the more typical Cox proportional hazards (PH) model inappropriate. First, we have recurrent events because we included all injuries for a given person-job. Second, each person was allowed to have multiple jobs, meaning that we potentially have correlation among observations. Finally, based on previous work,¹⁹ we included an indicator for employee experience (12 months on that job) as a covariate. Such a variable is collinear with time, and cannot be included in a Cox PH model.

To address these issues, we used an AG model, which is an extension of Cox PH models. AG models allow for inclusion of multiple events per person (complication 1).²⁵ For each model, we included a frailty term per individual which addresses correlation among jobs for the same employee (complication 2).^{20 21} Finally, we employed a two-piece exponential hazard with a change of hazard at 12 months (complication 3). Two-piece exponential models are a special case of the Cox PH model; our model assumes a constant baseline hazard from 0–12 months on the job, and a separate constant baseline hazard from 12 months onward.^{19 26} Therefore, the final model was an AG model with a piecewise exponential baseline hazard, including a frailty term at the employee level. Calendar year and presence of disease in a year were incorporated in models as time-varying variables. Having more than 1 year of experience was incorporated as a time-varying variable by month.

We fit a series of models; the first (base model) adjusted for calendar year, 1 year of experience on the job, ethnicity, sex, whether the job was the employee's first at the company, the employee's age at the start of the job and whether the plant was a smelter, part of the union, or an original Alcoa business. In the next set of models, we examined the effect of the five diseases separately; here, each disease was included in a separate model. As disease state varied for a given employee by calendar year, these variables are incorporated as time-varying variables. A secondary analysis includes time-varying risk score, but none of the disease-status variables.

Handling of missing data

We excluded 150 employees from the analysis for the following reasons; sex could not be determined for 48 employees and ethnicity could not be determined for 122 employees. We performed a complete case analysis using all employees who were not missing any variables.

Sensitivity analyses

We performed a series of sensitivity analyses. First we restricted the outcome to injuries reportable to OSHA (more serious non-first-aid injuries). We also removed the job experience variable from the model, allowing us to fit a more traditional Cox PH model in the AG framework. A further sensitivity analysis restricted disease status to the year of incident disease diagnosis, defined as the year of the first inpatient claim or second of two outpatient claims. In these analyses, person-jobs are excluded if the start of the job occurred before the first diagnoses of a given disease. The final sensitivity analysis considered indicators for the five disease states in the same model to examine each disease of interest adjusted for the presence of the others.

RESULTS

Table 1 describes the entire cohort, which is comprised of 37 900 distinct employees performing 83 435 jobs at 195

Table 1 Characteristics of the cohort of hourly manufacturing workers from 1997 through 2007

Characteristics	Frequency/ count	Percent/mean (SD) median
Total employees	37 900	
Total jobs	83 435	
Total locations	195	
Total injuries	17 785	
Employee-level		
Sex		
Male	30 245	79.80
Female	7655	20.20
Ethnicity/race		
American-Indian	269	0.71
Asian/Pacific Islander	631	1.66
Black/African-American	5658	14.93
Hispanic/Latino	3098	8.17
Caucasian	28 102	74.15
Other/multiple	142	0.38
Job level		
Age at start of job		41.21 (10.69) 41.38
Tenure at start of job		10.73 (10.68) 6.47
Length of job		1.88 (1.92) 1.22
Location level		
Original plant	46	23.59
Union plant	10	5.13
Smelter plant	9	4.62
Injury level		
Severity		
First aid (non-reportable)	13 078	73.53
Medical treatment	2425	13.64
Restricted work	2021	11.36
Lost work day	261	1.47
Injury type		
Abrasion/scratch	1497	8.42
Burn (chemical/thermal)	2371	13.33
Contusion/bruise	3999	22.49
Foreign body	1250	7.03
Laceration/cut	3076	17.30
Instantaneous sprain/ strain	3515	19.76
Other	2077	11.68

locations in the USA during the observation period. The cohort is largely male (79.8%) and Caucasian (74.2%). On average, employees were 41.2 years old when starting a new job, and had been at the company for 10.7 years. Jobs lasted nearly 2 years on average.

Table 2 presents descriptive statistics for employees who had any of the five diseases during the study period, and those who specifically had heart disease, hypertension, diabetes, depression, or asthma during the study period (non-mutually exclusive). For all diseases except depression, employees who had a disease were older and had a longer tenure at the company than those who did not. For all diseases, job length was significantly longer for those with a disease than for those without the disease. A higher percentage of women had depression and asthma during the study period. For all other diseases, the percentage of women who had the disease was lower. While severity of injury is not associated with most diseases, those with heart disease have a higher percentage of lost work days due to injuries than those without heart disease.

Table 2 Characteristics of employees who had any of the diseases of interest at any point during the study period

Characteristics	Heart disease	Hypertension	Diabetes	Depression	Asthma
Count (%) with each disease					
Total employees (employee had disease ever)	1544 (4.07)	6715 (17.72)	2373 (6.26)	1215 (3.21)	1127 (2.97)
Total jobs (employee had disease on that job)	3701 (4.44)	16 223(19.44)	5554 (6.66)	3343 (4.01)	2871 (3.44)
Total injuries (employee had disease at time of injury)	695 (3.91)	2757 (15.50)	1094 (6.15)	642 (3.61)	537 (3.02)
Employee level (count (%))					
Sex	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001
Male	1414 (91.58)	5524 (82.26)	2005 (84.49)	846 (69.63)	834 (74.00)
Female	130 (8.42)	1191 (17.74)	368 (15.51)	369 (30.37)	293 (26.00)
Ethnicity/race	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001
American-Indian	11 (0.71)	32 (0.48)	12 (0.97)	8 (0.66)	6 (0.53)
Asian/Pacific Islander	8 (0.52)	67 (1.00)	29 (1.22)	1 (0.08)	7 (0.62)
Black/African-American	156 (10.10)	1426 (21.24)	505 (21.28)	107 (8.81)	147 (13.04)
Hispanic/Latino	59 (3.82)	283 (4.21)	241 (10.16)	50 (4.12)	72 (6.39)
Caucasian	1308 (84.72)	4887 (72.78)	1564 (65.91)	1045 (86.01)	891 (79.06)
Other/multiple	2 (0.13)	20 (0.30)	11 (0.46)	4 (0.33)	4 (0.36)
Job level (mean, SD)					
Age at start of job	52.36*** 6.46	48.32*** 8.74	49.45*** 8.60	41.18 9.51	44.62*** 10.08
Tenure at start of job	20.20*** 11.10	17.12*** 11.53	18.38*** 11.89	11.05 9.91	14.12*** 11.11
Length of job	2.45*** 2.29	2.46*** 2.29	2.47*** 2.29	1.99** 2.13	2.25*** 2.20
Location level (count (percent))†					
Original plant	925*** (59.91)	3396*** (50.57)	1211*** (51.03)	662*** (54.49)	631*** (55.99)
Union plant	718*** (46.50)	2564*** (38.18)	949*** (39.99)	478*** (39.34)	441*** (39.13)
Smelter plant	561*** (36.33)	2102*** (31.30)	746*** (31.44)	322*** (26.50)	318*** (28.22)
Injury level (count (percent))					
Severity	p=0.013	p=0.761	p=0.004	p=0.473	p=0.426
First aid (non-reportable)	528 (75.97)	2048 (74.28)	836 (76.42)	487 (75.86)	396 (73.74)
Medical treatment	85 (12.23)	364 (13.20)	156 (14.26)	75 (11.68)	67 (12.48)
Restricted work	64 (9.21)	303 (10.99)	88 (8.04)	70 (10.90)	62 (11.55)
Lost work day	18 (2.59)	42 (1.52)	14 (1.28)	10 (1.56)	12 (2.23)
Injury type	p=0.019	p=0.236	p=0.145	p=0.109	p=0.380
Abrasion/scratch	77 (11.08)	245 (8.89)	102 (9.32)	64 (9.97)	43 (8.01)
Burn (chemical/thermal)	70 (10.07)	340 (12.33)	138 (12.61)	84 (13.08)	68 (12.66)
Contusion/bruise	148 (21.29)	623 (22.60)	265 (24.22)	151 (23.52)	127 (23.65)
Foreign body	44 (6.33)	172 (6.24)	71 (6.49)	29 (4.52)	33 (6.15)
Laceration/cut	119 (17.12)	483 (17.52)	203 (18.56)	100 (15.58)	78 (14.53)
Instantaneous sprain/strain	155 (22.30)	573 (20.78)	211 (19.29)	138 (21.50)	114 (21.23)
Other	82 (11.80)	321 (11.64)	104 (9.51)	76 (11.84)	74 (13.78)

*p value less than 0.001.

**p value less than 0.01.

***p value less than 0.05.

†Categories of location level variables are not mutually exclusive.

Of the 17 785 injuries that occurred during the study period, the majority were treated with first aid, that is, not reportable to OSHA. Overall, 27 410 (72.3%) employees did not experience an injury during the study period; of the 10 490 employees who experienced an injury 6469

experienced only one injury and 4021 experienced multiple injuries (with a maximum of one employee who had 14 injuries). The most common injury types were contusions and bruises, instantaneous sprains and strains, and lacerations and cuts.

Figure 1 Prevalence of diseases of interest by calendar year.

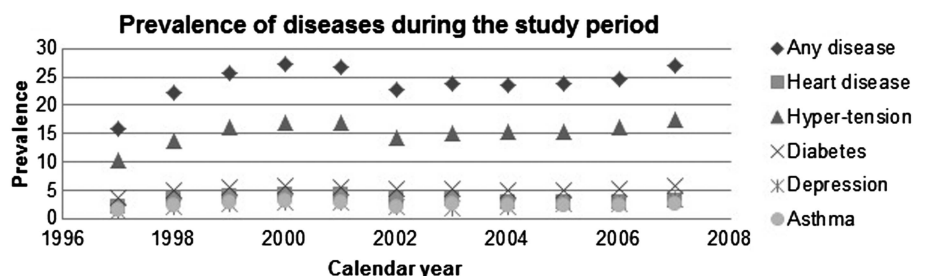


Table 3 HRs from Andersen–Gill models with piecewise exponential baseline hazard and employee-level frailty term of time-varying disease status

Variable	Base model	Heart disease	Hypertension	Diabetes	Depress-ion	Asthma
	HR (95% CI) ^p value	HR (95% CI) ^p value	HR (95% CI) ^p value	HR (95% CI) ^p value	HR (95% CI) ^p value	HR (95% CI) ^p value
<i>Comorbidities</i>						
Any comorbidity						
Heart disease		1.23 (1.11 to 1.36)***				
Hypertension			0.97 (0.92 to 1.02)			
Diabetes				1.17 (1.08 to 1.27)***		
Depression					1.25 (1.12 to 1.38)***	
Asthma						1.14 (1.02 to 1.27)*
Calendar year (ref is 1997)	***	***	***	***	***	***
1998	0.94 (0.83 to 1.06)	0.93 (0.83 to 1.06)	0.94 (0.83 to 1.06)	0.93 (0.83 to 1.06)	0.93 (0.83 to 1.05)	0.93 (0.83 to 1.06)
1999	0.83 (0.74 to 0.94)	0.83 (0.74 to 0.94)	0.83 (0.74 to 0.94)	0.83 (0.74 to 0.94)	0.83 (0.74 to 0.94)	0.83 (0.74 to 0.94)
2000	0.92 (0.81 to 1.04)	0.91 (0.81 to 1.03)	0.92 (0.81 to 1.04)	0.92 (0.81 to 1.03)	0.91 (0.81 to 1.03)	0.92 (0.81 to 1.03)
2001	0.49 (0.43 to 0.56)	0.49 (0.43 to 0.55)	0.49 (0.43 to 0.56)	0.49 (0.43 to 0.55)	0.49 (0.43 to 0.55)	0.49 (0.43 to 0.55)
2002	0.52 (0.46 to 0.59)	0.52 (0.46 to 0.58)	0.52 (0.46 to 0.59)	0.52 (0.46 to 0.59)	0.52 (0.46 to 0.58)	0.52 (0.46 to 0.59)
2003	0.48 (0.43 to 0.54)	0.48 (0.42 to 0.54)	0.48 (0.43 to 0.55)	0.48 (0.42 to 0.54)	0.48 (0.42 to 0.54)	0.48 (0.42 to 0.54)
2004	0.55 (0.48 to 0.62)	0.54 (0.48 to 0.62)	0.55 (0.49 to 0.62)	0.54 (0.48 to 0.62)	0.54 (0.48 to 0.61)	0.55 (0.48 to 0.62)
2005	0.57 (0.50 to 0.64)	0.57 (0.50 to 0.64)	0.57 (0.50 to 0.64)	0.57 (0.50 to 0.64)	0.56 (0.50 to 0.64)	0.57 (0.50 to 0.64)
2006	0.50 (0.44 to 0.56)	0.50 (0.44 to 0.56)	0.50 (0.44 to 0.56)	0.50 (0.44 to 0.56)	0.49 (0.44 to 0.56)	0.50 (0.44 to 0.56)
2007	0.47 (0.42 to 0.53)	0.47 (0.41 to 0.53)	0.47 (0.42 to 0.53)	0.47 (0.41 to 0.53)	0.47 (0.41 to 0.53)	0.47 (0.41 to 0.53)
First 12 months on the job (inexperienced)	1.22 (1.17 to 1.26)***	1.22 (1.18 to 1.26)***	1.21 (1.17 to 1.26)***	1.22 (1.18 to 1.26)***	1.22 (1.18 to 1.26)***	1.22 (1.18 to 1.26)***
Non-white ethnicity	1.05 (1.00 to 1.10)*	1.05 (1.00 to 1.10)*	1.05 (1.00 to 1.10)	1.04 (0.99 to 1.09)	1.05 (1.00 to 1.10)*	1.05 (1.00 to 1.10)*
Male gender	0.74 (0.70 to 0.78)***	0.73 (0.70 to 0.77)***	0.74 (0.70 to 0.78)*	0.74 (0.70 to 0.77)***	0.74 (0.71 to 0.78)***	0.74 (0.70 to 0.78)***
First job at company	1.01 (0.96 to 1.06)	1.01 (0.96 to 1.06)	1.01 (0.96 to 1.06)	1.01 (0.96 to 1.06)	1.01 (0.96 to 1.06)	1.01 (0.96 to 1.06)
Age at start of job	0.98 (0.98 to 0.98)***	0.98 (0.98 to 0.98)***	0.98 (0.98 to 0.98)***	0.98 (0.98 to 0.98)***	0.98 (0.98 to 0.98)***	0.98 (0.98 to 0.98)***
Smelter plant	1.40 (1.33 to 1.47)***	1.40 (1.33 to 1.47)***	1.40 (1.33 to 1.47)***	1.40 (1.33 to 1.47)***	1.40 (1.33 to 1.47)***	1.40 (1.33 to 1.47)***
Union plant	1.52 (1.42 to 1.63)***	1.52 (1.42 to 1.64)***	1.52 (1.41 to 1.63)***	1.52 (1.41 to 1.63)***	1.52 (1.41 to 1.63)***	1.52 (1.42 to 1.64)***
Original plant	1.05 (0.98 to 1.12)	1.05 (0.98 to 1.12)	1.05 (0.98 to 1.12)	1.05 (0.98 to 1.12)	1.05 (0.98 to 1.12)	1.05 (0.98 to 1.12)
Frailty at employee level	0.99 (0.94 to 1.05)	0.99 (0.94 to 1.05)	0.99 (0.94 to 1.05)	0.99 (0.93 to 1.05)	0.99 (0.93 to 1.05)	0.99 (0.94 to 1.05)

* p Value less than 0.001.
 ** p Value less than 0.01.
 ***p Value less than 0.05.

Table 4 HRs from Andersen Gill models with piecewise exponential baseline hazard and employee-level frailty term of time-varying risk score

Risk score	HR	95% CI	p Value
Risk score decile (%)			<0.001
0–10	Ref		
10–20	1.11	1.03 to 1.20	
20–30	1.07	0.99 to 1.15	
30–40	1.04	0.97 to 1.12	
40–50	1.13	1.05 to 1.22	
50–60	1.15	1.07 to 1.24	
60–70	1.20	1.11 to 1.30	
70–80	1.29	1.19 to 1.39	
80–90	1.25	1.15 to 1.35	
90–100	1.32	1.22 to 1.43	

All models are adjusted for calendar year, experience on the job, gender, ethnicity, whether the job was the first at the company, employee's age at the start of the job, whether the plant was a smelter, whether the plant was a union plant, whether the plant was an original company plant, and a frailty term at the employee level.

Figure 1 depicts the prevalence of each disease by calendar year. All diseases exhibit an increase from 1997 through 2001, a slight drop in 2002, and a gradual increase from 2003 through 2007; these trends likely reflect the very low rate of turnover in an aging workforce, combined with a group of plant acquisitions which joined the cohort in 2001. One-third of employees were diagnosed with at least one of the five considered comorbid conditions at some point during the study period. The most common comorbidity was hypertension; presence of comorbidities in this cohort was similar to prevalence of comorbidities in the general population.²⁷

In the first model, calendar year is significantly associated with acute injury ($p < 0.001$) (table 3). Compared to 1997, hazard of acute injury decreased significantly starting in 2001. Factors associated with increased hazard of acute injury include non-white race, female sex, younger age, working at a smelter plant, working at a union plant, and having less than

1 year of experience on the job as previously shown in this workforce.

When modelled individually, presence of heart disease increased the hazard of injury by 23% (HR 1.23, 95% CI 1.11 to 1.36, $p < 0.001$), presence of diabetes increased hazard of injury by 17% (HR 1.17, 95% CI 1.08 to 1.27, $p < 0.001$), presence of depression increased the hazard of injury by 25% (HR 1.25, 95% CI 1.12 to 1.38, $p < 0.001$), and presence of asthma increased the hazard of injury by 14% (HR 1.14, 95% CI 1.02 to 1.27, $p = 0.021$). Hazard of injury did not differ significantly by presence of hypertension. Estimates for calendar year, age, sex, race, first job at company, smelter plant, union plant, and original plant did not change significantly when we adjusted for presence of comorbidities.

In secondary analyses, risk score decile was a significant predictor of acute injury ($p < 0.001$) (table 4). Increasing by one decile carried an increase in hazard of 3% (HR 1.03, 95% CI 1.02 to 1.04, $p < 0.001$). Compared with the lowest decile of risk score, those with the highest decile of risk score had an increased hazard of injury of 32% (HR 1.32, 95% CI 1.22 to 1.43).

In sensitivity analyses restricted to reportable injuries, only depression was borderline significantly associated with increased hazard of reportable injury ($p = 0.065$); all the other HRs were close to 1. Risk score decile, however, remained a consistent and significant predictor of reportable injury ($p < 0.001$) (table 5). Increasing by one decile resulted in a 4% increase in hazard of reportable injury (HR 1.04 m 95% CI 1.02 to 1.05, $p < 0.001$).

A sensitivity analysis employing Cox PH models was also performed. In these models, the frailty term and experience on the job were removed. Results when all prevalent cases were included are unchanged from the main analysis (table 6, top panel). When only incident cases of disease (diagnosis after the start of a job) are included, results are virtually identical to the prevalence classification model (table 6, middle panel). A further sensitivity analysis incorporated the five indicators for presence of each disease state in the same model. Results and interpretation are unchanged using this model (table 6, bottom panel).

DISCUSSION

Our results, including the several sensitivity analyses, suggest that chronic heart and lung disease, diabetes and depression confer mild increased risk of acute occupational injury. Moreover, the analyses suggest that those with more health problems, or more severe ones as indicated by the general risk score, are at progressively higher risk for injuries of both first aid and more serious categories.

There are limitations to our observations that must be considered before interpreting these results. Most notably, although we control for general work environment, and are operating in a setting in which job comparability is known, we are unable to adjust for specific physical or psychosocial job demands. Although such data are available for a portion of our overall cohort²⁸ (Souza *et al*, unpublished data, 2013), they are unavailable for many of the locations, so we cannot be certain that there is not some confounding by actual job demand. That said, it is far more likely that sicker workers have either been assigned, or have chosen jobs with fewer physical demands; indeed, because of workplace policy, many with cardiovascular risks are excluded from hot jobs, and ongoing studies of dust suggest that those with diabetes, and ischaemic heart disease have less exposure to dust after diagnosis. This suggests that, if anything, this bias likely results in *underestimation* of the

Table 5 Sensitivity analysis of reportable injuries only

Prevalent disease	HR	95% CI	p Value
Heart disease	1.02	0.86 to 1.20	0.843
Hypertension	0.92	0.84 to 1.00	0.058
Diabetes	1.00	0.87 to 1.14	0.968
Depression	1.18	0.99 to 1.40	0.065
Asthma	1.12	0.94 to 1.34	0.213
Risk score	HR	95% CI	p Value
Risk score decile (%)			<0.001
0–10	Ref		
10–20	1.07	0.93 to 1.22	
20–30	1.04	0.91 to 1.20	
30–40	1.09	0.95 to 1.26	
40–50	1.14	0.99 to 1.31	
50–60	1.26	1.10 to 1.45	
60–70	1.25	1.09 to 1.45	
70–80	1.22	1.06 to 1.42	
80–90	1.34	1.16 to 1.55	
90–100%	1.37	1.18 to 1.58	

Table 6 Sensitivity analyses: The top panel shows the HRs using Cox proportional hazards models without frailty term, not adjusted for experience on the job. The bottom panel shows the HRs using incident rather than prevalent disease as the exposure

Prevalent disease	HR	95% CI	p Value
Heart disease	1.23	1.14 to 1.33	<0.001
Hypertension	0.98	0.94 to 1.03	0.444
Diabetes	1.19	1.12 to 1.27	<.001
Depression	1.31	1.21 to 1.41	<.001
Asthma	1.14	1.04 to 1.24	0.003

Cox proportional hazards model. Results when all prevalent cases were included are unchanged from the main analysis

Incident disease	HR	95% CI	p Value
Heart disease (n=80 881 jobs)	1.34	1.17 to 1.52	<0.001
Hypertension (n=74 613 jobs)	0.98	0.92 to 1.06	0.667
Diabetes (n=79 896 jobs)	1.18	1.06 to 1.31	0.003
Depression (n=81 049 jobs)	1.28	1.12 to 1.47	<0.001
Asthma (n=81 107 jobs)	1.24	1.08 to 1.44	0.003

Here any employee-job with a disease diagnosis before the start of the job was excluded from analysis separately for each disease. All models are adjusted for calendar year, experience on the job, gender, ethnicity, whether the job was the first at the company, employee's age at the start of the job, whether the plant was a smelter, whether the plant was a union plant, whether the plant was an original company plant, and a frailty term at the employee level

Prevalent disease	HR	95% CI	p Value
Heart disease	1.21	1.10 to 1.34	<0.001
Hypertension	0.95	0.90 to 1.01	0.077
Diabetes	1.17	1.08 to 1.26	<0.001
Depression	1.25	1.13 to 1.38	<0.001
Asthma	1.12	1.01 to 1.26	0.040

Model incorporating variables for presence of all five disease states in the same model.

All models are adjusted for calendar year, experience on the job, gender, ethnicity, whether the job was the first at the company, employee's age at the start of the job, whether the plant was a smelter, whether the plant was a union plant, whether the plant was an original company plant, and a frailty term at the employee level.

association, and may explain the weaker associations evident in the substudy of reportable injuries.

Our study may also suffer from data quality limitations. We have not individually normalised injury rates for actual hours worked per employee during each year; from a previous study, we know that large numbers of workers put in more than 40 or even 60 h a week.¹⁶ As with possible job differences, however, it is unlikely those with chronic disease worked, on average, longer than those without, so this bias too is far more likely to result in underestimate of the effect size. Although all our data are administrative, and maintained for business purposes, we cannot exclude the possibility that some of our results could spuriously emerge from incomplete reporting of both injuries and health; despite routine screening at work, we have evidence that men discovered at work to have hypertension or asthma, for example, often delay seeking medical attention^{22–29} rendering our classification flawed. We have no reason, however, to expect such behaviour would be differential with respect to *subsequent* injury. Likewise, although previous work with these data has been reassuring, concerns about differential reporting of injuries, especially the more minor first aid injuries, could distort the association between injury and health; the direction of such a bias is ambiguous. Since we are relying on medical claims data, we do not have direct clinical information on disease severity—for example test results—other than by means of our summary risk scores, which integrate all the claims data into a single rating.

The possibility that some or all of our observed association between injury and chronic disease might be due to confounding by social status has not been directly excluded; indeed there is evidence of a relationship even with the hourly workers of

higher rates of hypertension among those with lower ranking jobs.³⁰ However, previous injury analyses have not shown any relationship between job 'grade' and injury risk once other risks, such as tenure, time on job, age and job demand are accounted for directly, reducing this concern. It must be kept in mind, too, that while the Alcoa workforce is very diverse ethnically and geographically, the effects of health on injury may be somehow unique to the aluminium industry, or to the unique safety culture of our study company; we note only the general consistency of the result with previous literature but also our hypothesis that sensory impairment, whether from disease or its treatment, might place an industrial worker at excess risk of acute injury. In this regard, it is somewhat reassuring that effects are seen for the symptomatic disorders, such as diabetes or asthma, but not hypertension.

Balancing these limitations against our study strengths—rich, prospectively obtained administrative data from multiple sites over many years—our results suggest that each of the major chronic conditions of a priori interest, save hypertension, increases risk for injury in the year of initial recognition (incidence) and thereafter. Moreover, there appears to be a monotonic rise in risk as one ascends in overall health-insurance risk category; the highest decile having about a one-third higher risk than the bottom decile, possibly an underestimate for the reasons highlighted above. While we could offer various disease-specific hypotheses that might explain the observations, and cannot discount that such specific mechanisms may come to light with further study, the consistency in magnitude and direction *across* conditions suggest some more non-specific pathway or pathways are most likely at play including such factors as fatigue induced by disease or its treatments, common unifying

risks such as obesity—already identified as a specific risk factor^{4, 31}—and poor physical condition, distractions created by health concerns and needs for routine care and the like. Of these, fatigue, obesity and physical fitness would seem ample targets for initial intervention programmes to uncouple the health–injury relationship, even as further targeted research teasing out specific factors and causes proceed. Needless to say, as well, these findings demand confirmation in other workplaces where dangerous work is performed before more generalised interventions are developed and instituted among workforces with high rates of chronic disease. However, the trend towards workers retiring later in life,³² in part, a consequence of the demise of regular defined benefit pension plans supporting earlier retirements, render this line of research all the more urgent.

CONCLUSIONS

It appears likely that there is a real if small magnitude of association between symptomatic chronic disease and injury risk. While the observed effect is of modest size, development and testing of programmes designed to mitigate such risk offers yet another approach to the systematic control of workplace injury in manufacturing and possibly other sectors where serious injury risks remain intrinsic to work processes, and there are older workers with highly prevalent chronic diseases.

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Competing interests L Cantley, D Galusha, B Tessier-Sherman, IM Chu and MR Cullen receive a portion of their compensation at Yale and Stanford through a long-standing contractual agreement with Alcoa, Inc.

Ethics approval This study was approved by both Stanford and Yale University School of Medicine IRBs.

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Data sharing statement As an alternative to providing a deidentified dataset to the public domain, we allow access for the purpose of reanalyses 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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