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ORIGINAL ARTICLE

Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010

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ABSTRACT

Objectives (1) To investigate the association between temperature and work-related injuries and (2) to identify groups of workers at high risk of work-related injuries in hot environments in Adelaide, South Australia.

Methods Workers' compensation claims in Adelaide, South Australia for 2001–2010 were used. The relationship between temperature and daily injury claims was estimated using a generalised estimating equation model. A piecewise linear spline function was used to quantify the effect of temperature on injury claims below and above thresholds.

Results Overall, a 1°C increase in maximum temperature between 14.2°C and 37.7°C was associated with a 0.2% increase in daily injury claims. Specifically, the incidence rate ratios (IRRs) for male workers and young workers aged ≤24 were (1.004, 95% CI 1.002 to 1.006) and (1.005, 95% CI 1.002 to 1.008), respectively. Significant associations were also found for labourers (IRR 1.005, 95% CI 1.001 to 1.010), intermediate production and transport workers (IRR 1.003, 95% CI 1.001 to 1.005) and tradespersons (IRR 1.002, 95% CI 1.001 to 1.005). Industries at risk were agriculture, forestry and fishing (IRR 1.007, 95% CI 1.001 to 1.013), construction (IRR 1.006, 95% CI 1.002 to 1.011), and electricity, gas and water (IRR 1.029, 95% CI 1.002 to 1.058).

Conclusions There is a significant association between injury claims and temperature in Adelaide, South Australia, for certain industries and groups. Relevant adaptation and prevention measures are required at both policy and practice levels to address occupational exposure to high temperatures.

What this paper adds

- Despite increasing concerns about heat-related effects of climate change on occupational health and safety, the extent to which categories of workers are affected by ambient temperature at population level is not well documented.
- Analysis of workers' compensation claim data and weather data can be a useful tool for investigating the association between ambient temperature and workers' health and safety.
- We found a reversed U-shaped relationship between daily maximum temperature and total workers' injury claims. The overall risk of work-related injuries was positively associated with daily maximum temperature up to 37.7°C. However, daily injury claims fell noticeably when the weather was extremely hot.
- Identified vulnerable subgroups in the workplace include: male workers; young workers aged ≤24 years; those working in industries such as 'agriculture, forestry and fishing', 'construction' and 'electricity, gas and water'; labourers, production and transport workers, and tradespersons in small and medium-sized businesses.
- This study provides valuable epidemiological evidence for policy-makers and relevant stakeholders for reducing the potential effects of the projected increase in global average temperature due to climate change.

INTRODUCTION

The relationship between high temperatures and population health has been well documented. Epidemiological evidence suggests that extremely hot weather may contribute to excess morbidity and mortality,[1–6] particularly among the elderly, patients with chronic diseases and those taking certain medications. Physically active workers are also vulnerable during extreme heat.[7] Short-term acute extreme heat exposure may disrupt core body temperature balance and result in heat-related illnesses. Adverse long-term health effects of chronic workplace heat exposure have also been reported.[8] Moreover, workplace heat exposure can increase the risk of occupational injuries and accidents.[9 10]

Heat gain can be a combination of heat from the external thermal environment and internal heat generation by metabolism associated with physical activity. In the workplace, there are two types of external heat exposure sources: weather-related and process-generated. With predicted increased heat waves with global warming, weather-related heat exposure is presenting an increasing challenge for occupational health and safety. Evidence shows that Australia would be one of the countries at high risk of increased heat stress in the population if temperatures increase by 3°C.[11] In particular, for workers undertaking manual work outdoors or around heat sources, 'dangerous days' (days when there is a 2.5°C increase in body temperature in less than 2 h) are predicted to increase to 15–27 days/year by 2070 compared with 1 day/year at present according to one Australian study.[12] The

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potential impact of climate change on workplaces may be even worse in South Australia (SA) than the Australian national average level, as the average maximum temperature has increased at a faster rate than the national average since 1950: 0.17°C in SA compared with 0.13°C per decade nationally.[13]

There has been a growing research concern in the literature about the impact of heat-related events on workers' health and safety in recent years,[7 9 14] and its importance has been addressed in the 2007 Intergovernmental Panel on Climate Change Report.[15] However, so far the extent to which categories of workers are affected by heat exposure at the population level remains unknown. It is valuable for policy-makers and occupational health and safety practitioners and officers to have scientific evidence to inform development of heat-related regulations and guidelines for workplace heat exposure prevention and adaptation to a warming climate. The analysis of occupational injury surveillance data and weather data can be a useful tool to investigate the association between temperature and workers' health and safety. The purpose of this study was to: (1) examine the association between hot weather and work-related injuries in SA; and (2) identify which industrial sectors, occupations, genders and age groups are more vulnerable to heat exposure in order to provide evidence for relevant stakeholders for adaptation purposes.

MATERIALS AND METHODS

Adelaide (latitude 34°55′ S and longitude 138°35′ E) is the capital city of SA, with a population of 1.23 million and a labour force of 576 823 in 2011.[16] Characterised by the influences of heat and aridity from the north and moisture and coolness from the south and west, Adelaide has a Mediterranean climate. Of all Australian capital cities, Adelaide is the driest with very limited rainfall during hot dry summers and maximum temperatures reaching as high as 46.1°C.

Workers' compensation claim data

Under the SA WorkCover Scheme directed by the Workers Rehabilitation and Compensation Act 1986,[17] injured workers can lodge a compensation claim to WorkCover SA. All reported compensation cases are required to be aggregated to the government-run regulator SafeWork SA (SWSA). In this study, workers' injury claim data for Adelaide were obtained from SWSA for the period 1 July 2001 to 30 June 2010. The data include all accepted injury claims from both registered and self-employed employers in the Adelaide metropolitan area during the 9-year financial period.

The study was approved by the Human Research Ethics Committee at the University of Adelaide (H-111-2011) and the SWSA data custodian. Information identifying individual workers or employers was removed before receipt of the data. The collected data included demographic and employment information (including age, gender, occupation and industry), injury information (where and when the injury occurred, the nature and bodily location of the injury, and details of the cause) and outcome information (ie, time lost from work and total medical expenditure).

Meteorological data

Weather data for Adelaide including daily maximum and minimum temperatures, and daily average relative humidity for the study period, were obtained from the Australian Bureau of Meteorology Kent Town observation station near the central business district of Adelaide.[4 5] In this study, daily maximum temperature (T_{max}) was selected as the heat exposure indicator to facilitate the understanding of the heat–injury relationship. Evidence has shown that different heat indices have similar predictive abilities,[18] although some composite heat indices such as WBGT (wet bulb globe temperature) and AT (apparent temperature) take account of the combined effects of temperature, relative humidity, wind speed and solar radiation.

Statistical analysis

The workers' injury claim data were transformed into a time series format and merged with daily meteorological data. The crude relationship between daily injury claims and maximum temperatures was explored graphically using a LOWESS (locally weighted scatter plot smoothing) smoother performing a locally weighted non-parametric regression, with a bandwidth of 0.8 (using 80% of the data).[4]

The association of temperature with daily workers' injury claims was assessed by using generalised estimating equation (GEE) models with negative binominal distribution accounting for over-dispersion, a log link function and a first-order autocorrelation structure. The GEE approach extends generalised linear models to the analysis of longitudinal data with the assumption that observations are independent among summers of different years and correlated within each summer. The relationship between temperature and health outcomes is usually non-linear, being described as U-, V- or J-shaped.[1 3 5 6 10 19] Thus, a simple log-linear function is not adequate to capture the real relationship between temperature and work-related injury risk. A piecewise linear spline function with one knot (the junction between two splines) was used to account for non-linearity and quantify the effect of workplace heat exposure on work-related injuries below and above a threshold temperature.[20] The threshold temperatures were estimated by using a hockey-stick model.[4]

To minimise the impact of seasonality, the study period was restricted to the warm season for Adelaide (1 October–31 March). As work-related injury claims were significantly reduced during weekends and public holidays, all analyses were focused on week days. Confounding factors were adjusted for, including day of the week, calendar month, and long-term trends (putting calendar year in the GEE model as a categorical variable). Stratified analyses were conducted on the basis of gender, age, business size, and specific industrial sectors and occupations. Business size categories based on the number of employees are defined by the Australian Bureau of Statistics as 1–19 employees for a small business, 20–199 employees for a medium business, and ≥200 employees for a large business.[21] As those working outdoors are at high risk of weather-related heat exposure, the impact of temperature on 'outdoor industries' was analysed. Data for industrial sectors—'agriculture, forestry and fishing', 'construction', and 'electricity, gas and water'—were combined into one variable named 'outdoor industries'. Accordingly, data for the remaining industries were combined into one variable named 'indoor industries'. As almost all mine sites were located in rural areas of the state, to avoid misrepresentation, mining claims were excluded from the analysis.

The potential lagged effect of temperature on injury claims for entire and outdoor industries was investigated for temperatures above the threshold, with appropriate lagged effects considered. The number of lags (15) was determined by the Schwarz's Bayesian information criterion, the Akaike's information criterion and the Hannan–Quinn information criterion, using the Stata command 'varsoc'. The 0.05 level of statistical significance was adopted for each test. Results for the GEE models are expressed as incidence rate ratios (IRRs) with 95% CIs, and interpreted as percentage change in daily injury claims

Table 1 Summary statistics for meteorological indicators in Adelaide, South Australia, Australia, 2001–2010

Meteorological indicator	Warm season Mean (SD)	Warm season 5% centile	Warm season 95% centile	All seasons Mean (SD)	All seasons 5% centile	All seasons 95% centile
Daily maximum temperature (°C)	27.0 (6.2)	17.9	38.5	22.8 (6.8)	14.2	36.1
Daily minimum temperature (°C)	15.2 (4.4)	8.8	23.3	12.4 (4.7)	5.1	21.3
Daily average temperature (°C)	20.6 (5.1)	13.3	30.6	17.2 (5.5)	10.0	27.9
Daily mean relative humidity (%)	50.6 (15.2)	23.0	73.5	59.2 (17.0)	28.0	85.0

per °C increase in T_{max} below or above threshold temperatures. All analyses were conducted using Stata V.12.0.

RESULTS

The daily average maximum and minimum temperatures during the period 1 July 2001 to 30 June 2010 were 22.8°C and 12.4°C, respectively. The average daily relative humidity (09:00 and 15:00 readings) was 59.2%. The corresponding indicators in the warm season were 27.0°C, 15.2°C and 50.6%, respectively (table 1). This study included 252 183 workers' injury claims reported during the 9-year financial period in Adelaide metropolitan area, representing 76.7% of all injury claims during the same period in SA. Figure 1 demonstrates the characteristics of daily injury claims for Adelaide. Overall, the scatter plot of daily claims shows a gradually downward trend with two clusters, the upper cluster representing daily claims during week days, the lower representing weekends and public holidays.

As shown in table 2, during the study period, the percentage of workers' injury claims for men was twice that for women. About half (48.8%) of all injury claims in Adelaide occurred in the 35–54 age group. A total of 65 798 injury claims occurred in the large enterprises, representing about half (52.5%) of all claims. Mean daily injury claims on weekdays (121.1) were more than three times those at weekends (35.1) and twice those on public holidays (47.8) during the study period.

Threshold temperature

A reversed U-shaped exposure–response relationship between T_{max} and overall daily injury claims was observed (figure 2A). Daily workers' injury claims increased with the increase in T_{max}, but declined markedly when temperatures were extremely hot. In principle, three or more piecewise regressions may more accurately reflect the shape of temperature–claim associations, but the introduction of two or more cut-off points may make the interpretation of results and comparison within each stratum more difficult.[22] Therefore, we used one cut-off point (threshold) to reduce the impact of non-linearity. Usually, extreme heat has been defined as above the 95% centile of local maximum temperature,[5 23 24] which was 38.5°C in this study. The threshold estimated by a hockey-stick model was 37.7°C for all claims (table 3). Therefore, 37.7°C was determined as the threshold temperature above and below which the association between temperature and all injury claims was quantified.

As threshold temperatures may differ in different subgroups, we estimated specific thresholds by different strata to quantify the temperature–claim association (table 3). The threshold temperatures ranged from 31.8°C to 38.9°C, with an average of 37.1°C.

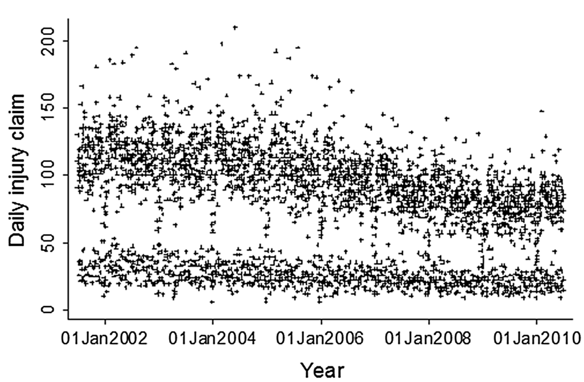

Figure 1 Characteristics of daily injury claims in 2001–2010, Adelaide, South Australia, Australia.

Total effects

As shown in table 3 (IRR estimates for 0 lagged effect), overall there was an average of 100 injury claims lodged per day during the study period in Adelaide. A 0.2% (IRR 1.002, 95% CI 1.001 to 1.004) increase in daily injury claims was observed with an increase of 1°C in T_{max} below 37.7°C. However, the overall daily injury claims decreased by 1.4% (IRR 0.986, 95% CI 0.975 to 0.998) per °C when the T_{max} was above 37.7°C.

Age and gender

Daily claims increased by 0.4% for male workers (IRR 1.004, 95% CI 1.002 to 1.006) per °C increase in T_{max} below 37.7°C. In contrast, no significant change for female workers was observed. When the temperature exceeded threshold

Table 2 Number and percentage of workers' injury claims in Adelaide, South Australia, Australia, 2001–2010

	Warm season	All seasons
Total	125 267	252 183
Gender, n (%)		
Male	85 138 (68.0)	170 864 (67.8)
Female	40 129 (32.0)	81 319 (32.2)
Age group, n (%)		
≤24	21 526 (17.2)	42 641 (16.9)
25–34	28 026 (22.4)	56 268 (22.3)
35–54	61 088 (48.8)	123 881 (49.1)
≥55	14 627 (11.7)	29 393 (11.7)
Business size, n (%)		
Large	65 798 (52.5)	132 685 (52.6)
Medium	39 660 (31.7)	79 448 (31.5)
Small	19 809 (15.8)	40 050 (15.9)
Daily claims, mean (SD)		
Weekdays	121.1 (35.0)	122.0 (32.2)
Weekends	35.1 (14.3)	34.6 (14.2)
Public holidays	47.8 (26.0)	47.6 (26.5)

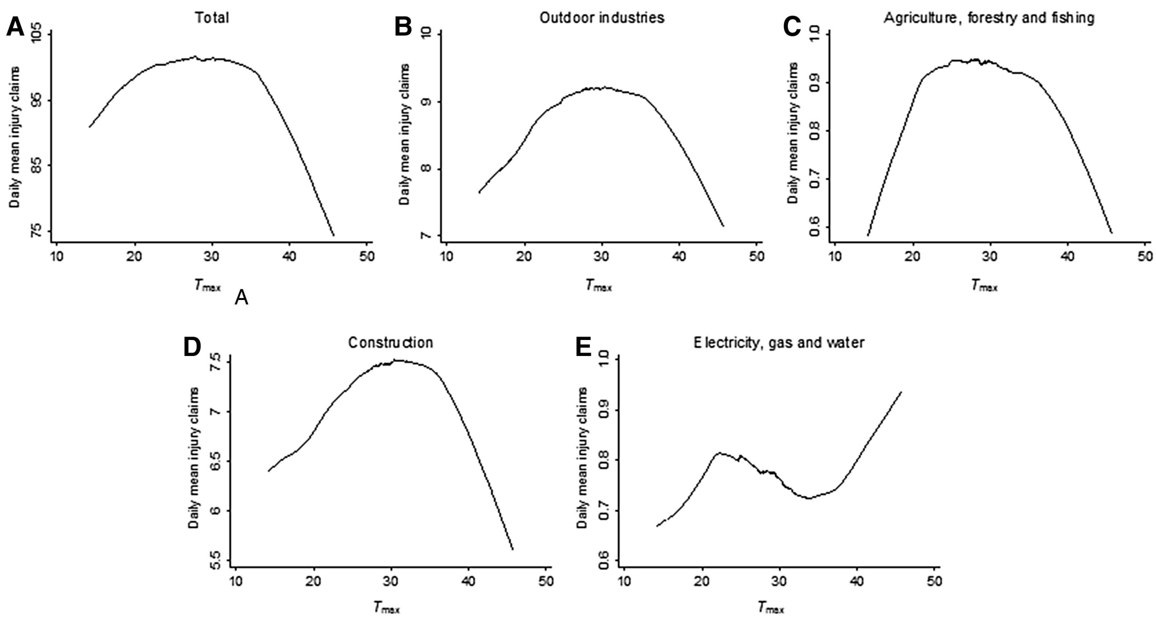

Figure 2 Exposure–response relationships between daily maximum temperature and daily injury claims for (A) total effects, (B) outdoor industries, (C) agriculture, forestry and fishing, (D) construction and (E) electricity, gas and water. Data were smoothed using a LOWESS (locally weighted scatter plot smoothing) smoother, bandwidth=0.8.

temperatures, daily injury claims significantly decreased by 1.8% (IRR 0.982, 95% CI 0.964 to 0.999) for male workers.

Among all age groups, only young workers aged ≤24 years were significantly affected by temperature, with a 0.5% (IRR 1.005, 95% CI 1.002 to 1.008) increase in injury claims per °C of T_{max} below 37.9°C. When the T_{max} exceeded threshold temperatures, a significant decrease in injury claims was observed in all age groups except the ≥55 year age group.

Business size

As shown in table 3, significant associations of temperature with injury claims were observed in small and medium-sized enterprises, with daily claims increased by 0.7% (IRR 1.007, 95% CI 1.003 to 1.011) and 0.4% (IRR 1.004, 95% CI 1.002 to 1.006), respectively, per °C increase in T_{max} below thresholds. In contrast, no significant change for large enterprises was observed.

Industry and occupation

As shown in table 3, there was considerable variation between industries in daily injury claims (from 0.1 to 28.4). The top three industries with the highest number of daily average claims were community services (28.4), manufacturing (27.2), and wholesale and retail trade (16.9). In terms of occupation, tradespersons (21.5) recorded the highest number of daily claims, followed by labourers (20.4) and intermediate production and transport workers (19.8).

For overall outdoor industries (IRR 1.005, 95% CI 1.001 to 1.009), a 0.5% increase in injury claims was observed per °C increase in T_{max} below 37.8°C; however, daily claims decreased by 3.4% when T_{max} exceeded 37.8°C (figure 2B). In contrast, no significant association between claims and temperature was detected in overall indoor industries. Industry-specific analysis showed that the following two industries had an increase in injury claims with increasing T_{max} below the threshold: agriculture, fishing and forestry (IRR 1.007, 95% CI 1.001 to 1.013) (figure 2C); construction (IRR 1.006, 95% CI 1.002 to 1.011) (figure 2D). However, a significant increase of 2.9% (IRR 1.029, 95% CI 1.002 to 1.058 was observed in 'electricity, gas and water' (figure 2E), when T_{max} was above 37.2°C, indicating that the workers in this industry may have been working outside for service purposes. Occupation-specific analysis showed that there was a significant increase in injury claims with an increase in T_{max} below threshold temperatures for labourers (IRR 1.005, 95% CI 1.001 to 1.010), intermediate production and transport workers (IRR 1.003, 95% CI 1.001 to 1.005) and tradespersons (IRR 1.002, 95% CI 1.001 to 1.005). Significant decreases in injury claims were observed in associate professionals when T_{max} exceeded thresholds.

In addition, we found no delayed effects of hot weather (T_{max} above thresholds) on injury claims for all and outdoor industries, indicating that the effect of temperature on workers' health was acute.

DISCUSSION

Despite increasing concerns about heat-related effects on occupational health,[7 9 25] few studies have examined the extent to which workers are affected by heat exposure, perhaps because of the limited availability and quality of occupational health and safety databases.[14] This study, the first of its kind in Australia, uses workers' injury claim data to investigate the association between temperature and work-related injuries in a temperate city.

The results from this study demonstrate a reversed U-shaped relationship between daily T_{max} and total workers' injury claims, which is consistent with findings from a study of Italian workplaces.[10] Australia currently has no released, mandatory, relevant regulations and guidelines specifying standards for maximum temperature in the workplace,[7] leaving some industrial sectors at high risk of heat stress in hot weather. Therefore the identified threshold temperatures may provide preliminary evidence for planning local, specific, workplace, extreme-heat early warning guidelines. These, however, may vary in different industries and countries because of the variations in work environments, preventive measures, heat acclimatisation level and public health infrastructure.

Table 3 Daily injury claims, thresholds and incidence rate ratio (IRR)* estimates of maximum temperature (T_{max}) (lag 0) on daily injury claims by gender, age group, industry and occupation in warm season (October–March), Adelaide, South Australia, Australia, 2001–2010

Classification	Daily claims (mean (SD))	Threshold estimates (95% CI)	Below threshold IRR (95% CI)	Below threshold p Value	Over threshold IRR (95% CI)	Over threshold p Value
Total	100.0 (25.3)	37.7 (35.2 to 40.1)	**1.002 (1.001 to 1.004)**	**0.027**	**0.986 (0.975 to 0.998)**	**0.017**
Gender						
Male	69.1 (18.9)	37.7 (35.2 to 40.2)	**1.004 (1.002 to 1.006)**	**0.000**	**0.982 (0.964 to 0.999)**	**0.048**
Female	30.9 (9.1)	37.5 (34.8 to 40.1)	0.998 (0.994 to 1.001)	0.206	0.995 (0.981 to 1.011)	0.550
Age group						
≤24	17.1 (5.7)	37.9 (35.5 to 40.3)	**1.005 (1.002 to 1.008)**	**0.000**	**0.977 (0.960 to 0.994)**	**0.009**
25–34	22.5 (8.2)	37.4 (34.8 to 40.0)	1.002 (0.999 to 1.005)	0.206	**0.979 (0.961 to 0.998)**	**0.036**
35–54	48.7 (13.9)	37.7 (35.3 to 40.0)	1.001 (0.999 to 1.003)	0.211	**0.982 (0.967 to 0.998)**	**0.028**
≥55	11.6 (4.4)	38.2 (32.4 to 43.9)	1.000 (0.997 to 1.003)	0.928	1.020 (0.984 to 1.057)	0.284
Business size						
Large	51.8 (15.1)	36.2 (32.1 to 40.3)	1.000 (0.997 to 1.002)	0.741	0.996 (0.978 to 1.014)	0.656
Medium	32.1 (8.8)	37.1 (34.8 to 39.4)	**1.004 (1.002 to 1.006)**	**0.001**	0.978 (0.953 to 1.005)	0.110
Small	16.0 (5.6)	31.8 (27.9 to 35.6)	**1.007 (1.003 to 1.011)**	**0.001**	0.982 (0.958 to 1.007)	0.153
Industrial sectors						
Outdoor industries (sub-total)	8.9 (3.5)	37.8 (34.2 to 41.3)	**1.005 (1.001 to 1.009)**	**0.009**	**0.966 (0.956 to 0.977)**	**0.000**
Agriculture, forestry and fishing	0.9 (1.0)	37.9 (33.5 to 42.3)	**1.007 (1.001 to 1.013)**	**0.018**	0.905 (0.808 to 1.013)	0.083
Construction	7.3 (3.1)	37.7 (34.1 to 41.3)	**1.006 (1.002 to 1.011)**	**0.002**	**0.954 (0.936 to 0.972)**	**0.000**
Electricity, gas and water	0.8 (0.9)	37.2 (34.8 to 40.0)	0.992 (0.977 to 1.008)	0.328	**1.029 (1.002 to 1.058)**	**0.039**
Indoor industries (sub-total)	91.0 (23.6)	37.0 (34.9 to 39.1)	1.002 (0.999 to 1.004)	0.063	0.988 (0.977 to 1.000)	0.052
Communication	0.1 (0.3)	36.7 (26.0 to 47.4)	1.006 (0.975 to 1.038)	0.685	0.841 (0.449 to 1.576)	0.589
Community services	28.4 (8.5)	37.1 (34.4 to 39.9)	1.001 (0.998 to 1.004)	0.547	0.991 (0.976 to 1.006)	0.225
Finance, property and business services	4.4 (2.4)	38.3 (30.7 to 45.9)	1.008 (0.999 to 1.017)	0.073	0.905 (0.808 to 1.013)	0.083
Manufacturing	27.2 (10.9)	37.0 (34.7 to 39.4)	1.002 (0.998 to 1.006)	0.271	0.991 (0.957 to 1.026)	0.592
Public administration and defence	3.3 (2.1)	36.9 (30.0 to 43.8)	0.998 (0.993 to 1.004)	0.542	0.956 (0.894 to 1.023)	0.197
Recreational, personal and other services	4.7 (2.4)	37.7 (34.0 to 41.4)	1.002 (0.996 to 1.007)	0.576	0.965 (0.922 to 1.010)	0.124
Transport and storage	5.5 (2.7)	37.0 (33.4 to 40.6)	1.006 (1.000 to 1.012)	0.062	0.987 (0.945 to 1.030)	0.542
Wholesale and retail trade	16.9 (5.2)	37.9 (34.7 to 41.1)	1.001 (0.999 to 1.004)	0.304	0.991 (0.963 to 1.020)	0.554
Occupations						
Advanced clerical and service workers	1.3 (1.7)	35.0 (32.5 to 39.4)	1.014 (0.994 to 1.034)	0.180	0.974 (0.923 to 1.034)	0.342
Associate professionals	9.0 (4.8)	38.4 (35.7 to 41.0)	1.002 (0.999 to 1.005)	0.146	**0.970 (0.943 to 0.998)**	**0.037**
Elementary clerical, sales and service workers	7.6 (4.8)	35.2 (23.1 to 47.3)	0.998 (0.992 to 1.004)	0.466	1.003 (0.980 to 1.027)	0.788
Intermediate clerical and service workers	10.3 (4.4)	36.0 (32.6 to 39.4)	0.997 (0.992 to 1.002)	0.307	0.996 (0.967 to 1.026)	0.805
Intermediate production and transport workers	19.8 (7.5)	37.6 (34.1 to 39.5)	**1.003 (1.001 to 1.005)**	**0.004**	0.987 (0.965 to 1.009)	0.233
Labourers and related workers	20.4 (10.4)	36.8 (34.1 to 39.5)	**1.005 (1.001 to 1.010)**	**0.018**	0.988 (0.965 to 1.012)	0.323
Managers and administrators	1.6 (1.5)	38.9 (31.9 to 45.9)	1.002 (0.993 to 1.011)	0.622	0.995 (0.894 to 1.109)	0.933
Professionals	8.1 (3.8)	32.9 (28.4 to 37.5)	1.000 (0.994 to 1.006)	0.969	0.983 (0.965 to 1.001)	0.069
Tradespersons and related workers	21.5 (7.6)	37.3 (34.8 to 39.8)	**1.002 (1.001 to 1.005)**	**0.035**	0.988 (0.961 to 1.015)	0.379

*Bold values are significant at p<0.05.

Our results suggest that the overall risk of work-related injuries was positively associated with T_{max} below 37.7°C. However, daily injury claims fell noticeably when the weather was extremely hot, as some workplaces, industries and trade unions in SA may have in place effective protective measures, such as hot weather policies which advise the cessation of work when the temperature is extreme.[26] This may explain the observed decline in injury claims when the temperature reaches the threshold. The unexpected increase observed in 'electricity, gas and water' industries when T_{max} exceeded the threshold (37.2°C) may be attributable to the fact that workers need to keep working to ensure the continuous supply of electricity, gas and water when the weather is extremely hot, especially for outdoor power line and pipeline maintenance.

The vulnerable groups in workplaces during hot weather have been identified by gender, age group, business size, industry and occupation. Our results indicate a significant increase in injury claims from male workers with an increase in T_{max} up to 37.7°C. In contrast, no association between injury claims and T_{max} was found among female workers. This may be due to gender differences in the nature of work, with male workers being more likely to undertake outdoor work with an inherently high risk of heat-related injuries during hot days. Age-specific analysis in our study showed an increase in injury claims in association with temperature only in young workers (aged ≤24 years). However, studies elsewhere on heat tolerance suggest that middle-aged workers are more intolerant to work-related heat and suffer more from heat strain than younger individuals,[27] which was not evident in our study. The greater risk for the young experiencing work-related injuries in hot weather may be due to a number of reasons. First, young workers often undertake more strenuous tasks, have received less safety training, and have fewer skills than older workers. Second, some studies have shown that young workers may be less likely to recognise the risk of heat exposure and show low compliance with preventive measures.[28] [29] In addition, young workers may experience peer and supervisor pressure in the workplace and may feel they have to keep working beyond individual heat tolerance especially in male-dominated industries.

Our results suggest that workers in small and medium-sized enterprises were vulnerable to work-related injuries with increasing T_{max} below thresholds, which is consistent with findings of previous literature.[30] A study from Germany estimated that small and medium-sized enterprises had a 33% greater accident rate (from all origins) than large enterprises.[31] It is likely to be the same for heat stress problems. Small and medium-sized enterprises are usually the most common employers. The number of small businesses made up 44% of all businesses in SA in 2001, with about one-third of the state's labour force working in companies with fewer than 20 employees.[21] Therefore, it is essential to place more focus on small and medium-sized enterprises in terms of prevention of workplace heat exposure.

The association between injury claims and temperature varies by occupation and industry. Our results show that 'labourers and related workers' had the greatest risk of injury with increasing T_{max}. This is presumably due to the work generally being outdoors and physical in nature. The wearing of impermeable personal protective equipment by labourers may also increase the risk of injury in the heat. In addition to labourers, tradespersons and intermediate production and transport workers were also identified as having an increased injury risk. Even though some may work indoors and out of direct sunlight, working environments can become very hot when a cooling system is not available or ventilation is insufficient during hot days. This is especially the case for those working around heat sources such as furnaces, ovens, smelters and boilers.[32]

In terms of industrial sectors, our analyses showed that, for outdoor industries (combined 'agriculture, forestry and fishing', 'construction' and 'electricity, gas and water'), a 1°C increase in T_{max} below the threshold of 37.7°C was associated with a 0.5% increase in daily claims. The greatest risk of work-related injury was found in agriculture, forestry and fishing, with a 0.7% increase in daily injuries per °C increase in T_{max}. Workers in these industries are generally exposed to outdoor heat extremes for long periods of time because of the nature of the work, and often there is a lack of occupational health and safety guidelines. Up until now, there has been very limited published literature assessing heat stress in agricultural workers. A cross-sectional survey found that ~94% of farmers in North Carolina, USA reported working in extreme heat in 2009, among which 40% experienced heat-stress-related symptoms.[33] According to the US heat-related mortality statistics for the period 1992–2006, the heat-related death rate for crop production farmers was ~20 times higher than for all civilian workers.[34] These findings, together with our results, indicate the importance and necessity of the establishment of heat prevention and adaptation measures for workers in agriculture, forestry and fishing.

We also found that there was an association between injury claims and temperature in the construction industry. The constant use of machinery and power tools, working on elevated surfaces, heavy workload, being subcontracted on a daily payment basis, and constant and direct exposure to sunlight may all contribute to the higher injury rate. Many field studies have investigated the effects of heat exposure on construction workers' health and safety, most of which showed that construction workers were physiologically challenged by heat exposure and had heat strain symptoms.[35,36] However, if preventive measures were sufficient on building sites, workers could reduce the risk of heat-related illnesses and injuries.[37,38] Therefore, relevant regulations and guidelines should be established in all jurisdictions, together with occupational health and safety education among workers, to ensure protection of their health and safety.

LIMITATIONS

There are several limitations to this study. First, daily injury claims may be underestimated because of under-reporting of workers' compensation claims.[39] Second, the relatively small number of daily injury claims in some industries such as 'communication' and 'electricity, gas and water' dictates cautious interpretation of the results. Third, the analysis based on a time series format design in our study was characterised by aggregated daily observations.[40] This may result in the inherent risk of biases due to the lack of information about individual characteristics. Fourth, possible variations in the labour force during the study period may have biased the results, as it is usually assumed that the denominator does not change meaningfully when the exposure–count outcome association is analysed in a time series study,[41] although the effect of long-term trends has been adjusted for. The validity of effect estimates may be improved if daily injury claim rates are used. However, denominator data are not available for Adelaide. The number of people onsite in many workplaces declines over the summer period when workers take annual leave. Although this is an issue that could potentially bias our findings, the effect should be minimal, as an examination of Australian Bureau of Statistics data shows a non-significant decrease in the labour force during the summer quarter.[42] Different industries may have variations in the age profiles of employees, which may account for some age effects observed. Although this could not be accounted for methodologically, individual characteristic-related confounders such as age and gender are time-fixed and do not change on a daily basis.[41] In addition, some potential time-varying confounders such as air pollutants were not taken into account in this study. Lastly, only one weather station was selected to provide the daily temperature of the Adelaide metropolitan area; however, the Bureau of Meteorology advises that the station should be representative of the whole city.

CONCLUSION

Our results suggest that the risk of work-related injuries is significantly associated with heat exposure in SA, especially for the following vulnerable groups in the workplace: male workers; young workers aged ≤24 years; those working in industries such as 'agriculture, forestry and fishing', 'construction' and 'electricity, gas and water'; labourers, production and transport workers, and tradespersons in small and medium-sized businesses. This study provides essential epidemiological evidence for policy-makers, occupational health practitioners and industry that may assist in the formulation of heat adaptation policies to decrease the risk of relevant injuries. Industry-specific workplace, hot-weather alert and response mechanisms need to be developed through multi-sector cooperation to improve the risk perceptions and knowledge of vulnerable groups about harm minimisation strategies during extremely hot weather. Policies need to be formulated to strengthen workers' self-protection capability by providing heat-stress-relevant training via induction and ongoing education programmes. Consideration needs to be given to means of reducing workplace heat exposure through ergonomic design, and improving workers' heat adaptability and resilience through the adjustment of individual work habits.

Further research may be needed to assess the association between hot weather, relative humidity and work-related injuries in different regions with various climatic characteristics, to estimate the health burden and productivity loss due to heat exposure and work-related injuries, and to evaluate the potential cost-effectiveness of heat and work-related injury prevention plans and guidelines.

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