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The impact of heatwaves on workers' health and safety in Adelaide, South Australia

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A B S T R A C T

This study aims to investigate the impact of heatwaves on worker's health and safety; to identify workers at higher risk of prevalent illnesses and injuries due to heatwaves; and to provide evidence for policy-makers and service providers. South Australian workers' compensation claims data for 2001–2010 were transformed into time series format, merged with meteorological data and analysed using generalized estimating equation (GEE) models. For total injury claims there was no significant difference detected between heatwave and non-heatwave periods. However, for outdoor industries, daily claims increased significantly by 6.2% during heatwaves. Over-represented in hot weather were male labourers and tradespersons aged ≥ 55 years, and those employed in 'agriculture, forestry and fishing' and 'electricity, gas and water'. Occupational burns, wounds, lacerations, and amputations as well as heat illnesses were significantly associated with heatwaves. Similarly, moving objects, contact with chemicals, and injuries related to environmental factors increased significantly during heatwaves, especially among middle-aged and older male workers. With the predicted increase of extremely hot weather, there is a need for relevant adaptation and prevention measures at both practice and policy levels for vulnerable work groups.

1. Introduction

Many epidemiological studies have confirmed that heatwaves may result in excess morbidity and mortality in the general population (Nitschke et al., 2007; Hansen et al., 2008a, 2008b; Basu, 2009; Ye et al., 2012). Recently, there have been growing concerns about the impact of extreme heat on workers' health and safety (WHS) under the context of extreme heat and climate change (Kjellstrom et al., 2009a, 2009b), as exposure to extreme heat in the workplace can increase the risk of work-related injuries and accidents, particularly for those working outdoors or close to heat sources.

South Australia (SA) has a population of 1.65 million with labour force of 820,300 in 2012 (Australian Bureau of Statistics, 2013). The majority (77.1%) of the state's population lives within the Adelaide metropolitan area, which has an arid climate characterised in summer by hot daytime temperatures and mild nights. Although South Australians are likely acclimatized to extreme heat, several studies in Adelaide have found that heatwaves, which can be defined in a number of ways, have been associated with excess mortality and significant increases in hospital admissions and ambulance call-outs (Nitschke et al., 2007; Hansen et al., 2008a, 2008b).

Recently, the empirical association between daily ambient temperature and work-related injuries has been investigated in Australia and Italy (Morabito et al., 2006; Xiang et al., 2014). However, so far little is known about the extent to which workers are affected by heatwaves i.e. when ambient temperatures remain high over several consecutive days. It is possible this may have an effect on worker's level of fatigue and compromise health and safety. According to the weather projections for Adelaide, the average number of days with temperatures over 35 °C and the frequency of heatwaves will triple by 2070 (Commonwealth Scientific and Industrial Research Organization and Australian Bureau of Meteorology, 2007). Thus, extremely hot weather may present a growing challenge for occupational health and safety (Kjellstrom et al., 2009a, 2009b).

The aim of this study was to assess to what extent workers are impacted by heatwaves in Adelaide, to identify vulnerable workers, to examine which types of work-related illnesses and injuries are associated with heatwaves in the workplaces, and to compare the differences between two different heatwave definitions on effect estimates. Understanding the impact of heatwaves on WHS may provide valuable information to decision makers and relevant stakeholders to formulate extreme heat preparedness and emergency response plans in the workplace.

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2. Materials and methods

2.1. Workers' compensation claim data

Workers' compensation data have been used as a tool monitoring work-related injuries and diseases in South Australia since 1987. The Type of Occurrence Classification System (TOOCS2) for claims was introduced in 1999 as coding guidelines for describing details of reported workers' compensation cases (Australian National Occupational Health and Safety Commission, 2011), which includes the nature of injury (based on the International Classification of Diseases, ICD-9), bodily location, mechanism, and agency of injury/disease.

As in our previous study (Xiang et al., 2014), de-identified workers' compensation claim data were obtained from Safe Work South Australia (SWSA) for the period from 1st July 2001 to 30th June 2010. Compensation claims were restricted to those in the Adelaide metropolitan areas as identified by location postcode. The study was approved by the Human Research Ethics Committee of the University of Adelaide (H-111-2011) and the SWSA data custodian.

2.2. Meteorological data

Climatic data for Adelaide including daily maximum and minimum temperatures for the study period were obtained from the Australian Bureau of Meteorology. As in previous studies (Nitschke et al., 2007; Hansen et al., 2008a, 2008b; Xiang et al., 2014), an observation station near the central business district was selected to represent weather conditions across the Adelaide metropolitan area.

2.3. Heatwave definition

Currently, there is no universal definition of a heatwave although generally it can be broadly defined as a prolonged period of excessive heat. In this study, we have defined a heatwave as ≧3 consecutive days with daily maximum temperatures (T_{max})≧35 °C as in our previous studies (Nitschke et al., 2007; Hansen et al., 2008a, 2008b). We also used the Australian Bureau of Meteorology (BOM) definition of ≧5 consecutive days of $T_{max} \geq 35$ °C; or ≧3 consecutive days of $T_{max} \geq 40$ °C to compare findings (Australian Bureau of Meteorology, 2010).

2.4. Statistical analyses

The impacts of heatwaves on daily workers' compensation claims were assessed by using generalized estimating equation models with negative binominal distribution accounting for over-dispersion, a log link function and a first order autocorrelation structure. A goodness-of-fit test was applied to the model. The analyses were stratified by gender, age group, industrial sector, occupation and nature and mechanism of illness/injury. Seasonality was controlled for by restricting the analysis to the warm season (1 October–31 March). Relative humidity was not adjusted, as Adelaide is characterized as dry hot weather (Xiang et al., 2014).

As work-related compensation claims reduced significantly 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 (with calendar year as a categorical variable). As those working outdoors are presumably at high risk of weather-related heat exposure, the impact of temperature on 'outdoor industries' was analysed. These were defined as 'agriculture, forestry and fishing', 'construction', and 'electricity, gas and water' and were combined into one variable named 'outdoor industries'. Accordingly, data for remaining other industries were named 'indoor industries'. As almost all mine sites are located in remote areas of the state, mining claims were therefore excluded from the analysis to avoid misrepresentation.

The 0.05 level of statistical significance was adopted for each test. Results are expressed as incidence rate ratios (IRR) with 95% confidence interval (CIs), and interpreted as per cent change in the number of daily work-related injury claims during heatwave periods compared with non-heatwave periods. All analyses were conducted using Stata v12.0 (StataCorp LP, College Station, Texas).

3. Results

The mean daily T_{max} during the period of 1st July 2001–30th June 2010 was 22.8 °C, with the corresponding mean T_{max} during the cool season (1 April–30 September), warm season (1 October–31 March) and heatwaves being 18.6 °C, 27.0 °C and 38.8 °C, respectively. A total of 21 heatwaves (≧3 consecutive days over 35 °C) were identified during the 9-financial year period, with a maximum of four heatwaves in one calendar year. The highest temperature was 45.7 °C on 28 January, 2009 during a 9-day heatwave with six continuous days over 40 °C. The duration of individual heatwaves ranged from 3 to 15 days, with a mean of 4.9 days.

This study included 252,183 accepted workers' compensation claims recorded during the 9-financial year period in Adelaide metropolitan area, accounting for 76.7% of all claims in South Australia during the same period. Of these, 7043 (2.8%) claims occurred during 103 heatwave days (21 heatwaves), representing a daily mean of 95 claims compared with 100 during non-heatwave periods in the warm season. By contrast, using the stricter heatwave definition of the BOM, 3885 (1.5%) claims occurred during 59 heatwave days (8 heatwaves), with a daily mean of 91 claims compared with 100 during non-heatwave periods.

3.1. Effect estimates by gender, age, occupation and industry

As shown in Table 1, the number of compensation claims for male workers was more than twice that for female workers. During heatwaves, there were no significant changes in the number of compensation claims among male workers. By contrast, female workers had a significant decrease of 6.5% (95% CI 2.6%–10.3%) in claims during heatwaves. Almost half of the claims were from middle-aged workers (35–54 years). Overall no particular age group showed a significant increase of compensation claims during heatwave periods compared with control periods.

Regarding occupations, 'tradespersons and related workers' had the highest number of claims during heatwaves, followed by 'intermediate production and transport workers' and 'labourers and related workers'. The latter showed a significant increase in claims during heatwaves of 5.4% (95% CI 2.3–8.6%) compared to 5.6% (95% CI 2.8–8.4%) for 'tradespersons and related workers'. Significant decreases of 11.6% (95% CI 5.9–16.9%) were observed in claims for 'intermediate clerical and service workers' and 9.4% (95% CI 1.5–16.7%) for 'professionals' during heatwaves. In terms of industries, overall 'outdoor industries' showed a 6.2% (95% CI 2.2–10.3%) increase in claims during heatwaves. 'Agriculture, forestry and fishing' and 'electricity, gas and water' had increases of 44.7% (95% CI 12.5–86.1%) and 29.7% (95% CI 4.9–60.4%) respectively.

Table 2 shows the age and gender specific analyses for 'agriculture, forestry and fishing' and 'electricity, gas and water' industries. An increase of 65.3% (95% CI 19.8–228.1%) was observed for claims among male workers in 'agriculture, forestry and fishing'; and a significant increase of 67.3% (95% CI 4.9–266.7%) was seen among workers aged ≥ 55 years. In the 'electricity, gas and water' industry, male workers had a 38.7% (95% CI 16.5–65.2%) increase in claims during heatwaves;

Table 1
The incidence rate ratio (IRR) of workers' compensation claims by gender, age group, industry and occupation during heatwave periods compared with non-heatwave periods in the warm season, Adelaide, South Australia, 2001–2010.

Classification	H/W	Non-H/W	IRR (95% CI)	*p*-value
Total	7043	118,224	0.983 (0.943-1.024)	0.408
Gender				
Male	4794	80,344	1.001 (0.947-1.012)	0.960
Female$^{\Delta -}$	2249	37,880	0.935 (0.897-0.974)	0.001
Age group				
≤ 24	1250	20,276	1.035 (0.981-1.091)	0.213
25–34	1511	26,515	0.973 (0.928-1.019)	0.246
35–54	3369	57,719	0.951 (0.898-1.007)	0.086
≥ 55	913	13,714	1.024 (0.940-1.115)	0.583
Industrial sectors				
Outdoor industries (sub-total)$^{\Delta +}$	659	10,090	1.062 (1.022-1.103)	0.003
Agriculture, forestry and fishing$^{\Delta +}$	71	1059	1.447 (1.125-1.861)	0.004
Construction	521	8145	1.012 (0.936-1.093)	0.767
Electricity, gas and water$^{\Delta +}$	67	886	1.297 (1.049-1.604)	0.016
Indoor industries (sub-total)	6384	108,970	0.976 (0.930-1.025)	0.338
Communication	3	83	0.402 (0.096-1.679)	0.211
Community services$^{\Delta -}$	2061	34,769	0.931 (0.878-0.986)	0.015
Finance, property and business services	346	5184	1.067 (0.885-1.286)	0.498
Manufacturing	1780	32,115	1.009 (0.928-1.098)	0.832
Public administration and defence	192	3719	0.839 (0.722-0.975)	0.022
Recreational, personal and other services	385	6 440	0.987 (0.888-1.097)	0.811
Transport and storage	381	6635	0.932 (0.859-1.012)	0.094
Wholesale and retail trade$^{\Delta +}$	1236	20,025	1.015 (0.965-1.069)	0.559
Occupations				
Advanced clerical and service workers	101	1260	0.941 (0.789-1.121)	0.495
Associate professionals	731	11,517	0.950 (0.912-1.028)	0.203
Elementary clerical, sales and service workers	653	9510	0.990 (0.919-1.068)	0.803
Intermediate clerical and service workers$^{\Delta -}$	708	12,825	0.884 (0.831-0.941)	0.000
Intermediate production and transport workers	1335	22,674	1.021 (0.942-1.107)	0.615
Labourers and related workers$^{\Delta +}$	1332	23,583	1.054 (1.023-1.086)	0.000
Manager & administrators	120	1878	0.960 (0.842-1.096)	0.548
Professionals$^{\Delta -}$	554	9580	0.906 (0.833-0.985)	0.021
Tradespersons and related workers$^{\Delta +}$	1463	24,881	1.056 (1.028-1.084)	0.000

Abbreviations: H/W, heatwave; Non-H/W, non-heatwave. Shaded cells denote statistical significance at the $p < 0.05$ level when heatwaves defined as ≥ 3 consecutive days with $T_{max} \geq 35$ °C. $\Delta +/\Delta -$ represents IRR estimates are positively or negatively significant at the 0.05 level for heatwaves defined by the Australian Bureau of Meteorology for Adelaide as ≥ 5 consecutive days with $T_{max} \geq 35$ °C or ≥ 3 consecutive days with $T_{max} \geq 40$ °C, where detailed IRR estimates and *p* values were not listed in the table.

Table 2
Specific injury risk estimates (IRR) stratified by gender and age groups for industrial sectors significantly related to heatwaves in the warm season, Adelaide, South Australia, 2001–2010.

Classification	Agriculture, forestry and fishing				Electricity, gas and water			
	H/W	Non-H/W	IRR (95% CI)	*p*-value	H/W	Non-H/W	IRR (95% CI)	*p*-value
Gender								
Male	58	799	1.653 (1.198-2.281)	0.002	66	814	1.387 (1.165-1.652)	0.000
Female	13	260	0.936 (0.649-1.351)	0.725	1	72	0.279 (0.044-2.952)	0.173
Age group								
≤ 24	11	171	1.662 (0.719-3.843)	0.235	2	58	0.623 (0.177-2.194)	0.461
25–34	16	261	1.384 (0.785-2.439)	0.261	11	119	1.384 (0.785-2.439)	0.261
35–54	29	501	1.309 (0.922-1.857)	0.132	36	548	1.129 (0.882-1.446)	0.336
≥ 55	15	126	1.673 (1.049-2.667)	0.031	18	161	1.763 (1.161-2.676)	0.008

Abbreviations: H/W, heatwave; Non-H/W, non-heatwave. Shaded cells denote statistical significance at the $p < 0.05$ level.

and in terms of age, only workers aged ≥ 55 years showed a significant increase of 76.3% (95% CI 16.1–267.6%).

3.2. Types of work-related illnesses and injuries

As shown in Table 3, during heatwaves the three most common diagnoses for compensation claims were 'traumatic injuries', 'wounds, lacerations, and amputations', and 'musculoskeletal and connective tissue diseases'. Regression analyses showed that 'heat stress' increased by about 12-fold, 'occupational burns' (including electrical, chemical, heat, and friction burns) increased by 16.1% (95% CI 1.0–33.4%), and 'wounds, lacerations, amputations and internal organ damage' increased by 0.5% (95% CI 2.8–15.4%) during heatwaves. By contrast, claims due to 'traumatic joint/ligament and muscle/tendon injuries' decreased by 9.7% (95% CI 5.4–13.7%) during heatwaves.

3.3. Injury mechanisms

As shown in Table 4, the most common injury mechanisms resulting in claims during heatwaves were 'body stressing', 'hitting objects with a part of the body', and 'falls, trips and slips of a person'. Injury claims during heatwaves for 'being hit by moving objects', 'chemicals and other substances', and 'heat, electricity, and other environmental factors' increased by 9.7% (95% CI 0.2–20.2%), 20.1% (95% CI 5.0–37.3%) and 39.0% (95% CI 18.0–63.8%), respectively. By contrast, injury claims due to 'body stressing' and

Table 3
The incidence rate ratio (IRR) of workers' compensation claims by the type of injuries and illnesses during heatwave periods compared with non-heatwave periods in the warm season, Adelaide, South Australia, 2001–2010.

TOOCS code	Classification	H/W	Non-H/W	IRR (95% CI)	*p*-value
F201-F239	Traumatic joint/ligament and muscle/tendon injuries$^{\Delta-}$	2741	50,498	0.903 (0.863-0.946)	0.000
C129-C169	Wounds, lacerations, and amputations$^{\Delta+}$	1642	26,012	1.005 (1.028-1.154)	0.004
H401-H599	Musculoskeletal and connective tissue diseases	794	12,866	0.950 (0.850-1.063)	0.373
G301-G399, Q941-Q949, R951-R999	Other diseases and injuries	561	8161	1.119 (0.955-1.311)	0.165
I702-I719	Mental disorders$^{\Delta-}$	295	4714	0.945 (0.826-1.081)	0.412
B111-B119	Fractures	282	4645	0.965 (0.856-1.087)	0.556
L761-L779	Nervous system and sense organ diseases	211	3974	0.968 (0.828-1.131)	0.681
D171-D179	Burn$^{\Delta+}$	170	2439	1.161 (1.010-1.334)	0.035
K741-K759	Skin and subcutaneous tissue diseases	119	1807	1.012 (0.825-1.240)	0.912
J721-J739	Digestive system diseases	69	1115	0.946 (0.631-1.421)	0.791
A101-A109	Intracranial injuries	42	833	0.919 (0.754-1.120)	0.404
M781-M799	Respiratory system diseases	28	434	0.851 (0.630-1.148)	0.291
O821-O849	Infectious and parasitic diseases	21	283	0.915 (0.334-2.502)	0.862
N801-N819	Circulatory system diseases	14	221	0.919 (0.533-1.584)	0.762
E181-E189	Injury to nerves and spinal cord	8	115	0.897 (0.383-2.101)	0.802
P861-P879	Neoplasms (cancer)	4	56	1.151 (0.342-3.873)	0.820
G313	Heat stress$^{\Delta+}$	42	51	12.463 (6.673-23.275)	0.000

Abbreviations: H/W, heatwave; Non-H/W, non-heatwave. Shaded cells denote statistical significance at the $p<0.05$ level. Shaded cells denote statistical significance at the $p<0.05$ level when heatwaves defined as ≥ 3 consecutive days with $T_{max} \geq 35$ °C. $\Delta+/\Delta-$ represents IRR estimates are positively or negatively significant at the 0.05 level for heatwaves defined by the Australian Bureau of Meteorology for Adelaide as ≥ 5 consecutive days with $T_{max} \geq 35$ °C or ≥ 3 consecutive days with $T_{max} \geq 40$ °C, where detailed IRR estimates and *p* values were not listed in the table.

Table 4
The IRR of workers' compensation claims by the mechanism of injury during heatwave periods compared with non-heatwave periods in the warm season, Adelaide, South Australia, 2001–2010.

TOOCS code	Classification	H/W	Non-H/W	IRR (95% CI)	*p*-value
G41-G44	Body stressing$^{\Delta-}$	2517	45,673	0.909 (0.870-0.951)	0.000
G11-G13	Hitting objects with a part of the body$^{\Delta+}$	1312	20,883	1.052 (0.972-1.139)	0.211
G01-G03	Falls, trips and slips of a person$^{\Delta-}$	1013	17,941	0.907 (0.869-0.947)	0.000
G21-G29	Being hit by moving objects$^{\Delta+}$	945	14,885	1.097 (1.002-1.202)	0.045
G91-G99	Other and unspecified mechanisms of incident	327	5674	0.894 (0.747-1.071)	0.224
G81-G88	Mental stress	292	4625	0.949 (0.819-1.110)	0.487
G51-G59	Heat, electricity and other environmental factors$^{\Delta+}$	251	3035	1.390 (1.180-1.638)	0.000
G61-G69	Chemicals and other substances$^{\Delta+}$	233	3248	1.201 (1.050-1.373)	0.007
G31-G39	Sound and pressure	111	1686	1.181 (0.972-1.435)	0.094
G71-G72	Biological factors	42	574	1.009 (0.674-1.510)	0.966

Abbreviations: H/W, heatwave; Non-H/W, non-heatwave. Shaded cells denote statistical significance at the $p<0.05$ level when heatwaves defined as ≥ 3 consecutive days with $T_{max} \geq 35$ °C. $\Delta+/\Delta-$ represents IRR estimates are positively or negatively significant at the 0.05 level for heatwaves defined by the Australian Bureau of Meteorology for Adelaide as ≥ 5 consecutive days with $T_{max} \geq 35$ °C or ≥ 3 consecutive days with $T_{max} \geq 40$ °C, where detailed IRR estimates and *p* values were not listed in the table.

'falls, trips and slips' decreased by 9.1% (95% CI 4.9–13.0%) and 9.3% (95% CI 5.3–13.1%) during heatwaves, respectively.

3.4. Comparison of the two heatwave definitions

Using two heatwave definitions, similar results were observed in overall claims and the effects stratified by gender, age, outdoor industry, and occupation. The differences were found in indoor industries where significant decrease of claims in 'public, administration and defence' was observed only for the definition of ≥ 3 consecutive days over 35 °C, and claims in 'wholesale and retail trade' increased significantly only for the BOM definition (Table 1). In terms of injury diagnosis, only the BOM definition had a significant decrease of mental disorders claims (Table 3). The results of injury mechanism specific analysis between the two definitions were basically consistent, except 'hitting objects with a part of the body' increased significantly during heatwaves for the BOM heatwave definition (Table 4).

4. Discussion

Our previous study has examined the association between daily high temperature and injury claims (Xiang et al., 2014). In this paper, we investigated the impact of heatwaves (consecutive extreme heat exposure) on work-related illnesses and injuries in a temperate Australian city, using workers' compensation claims data. To our knowledge, this is the first study of its kind in Australia. Our results suggest that overall there was no significant increase in compensation claims in Adelaide during heatwaves. However, a 6.2% increase in claims was observed for outdoor industry workers during heatwaves.

To date many cross-sectional field surveys have been conducted internationally assessing outdoor workplace heat exposure during hot days in summer (Maeda et al., 2006; Mathee et al., 2010; Crowe et al., 2013; Fleischer et al., 2013), with the majority showing that heat stress levels exceed the recommended criteria of American Conference of Governmental Industrial Hygienists (National Institute for Occupational Safety and Health (NIOSH), 1986). Outdoor workers, in particular those undertaking highly intensive and physical activities are at high risk of heat-related illnesses and injuries during extremely hot weather if preventive measures are not adequately adopted in the workplace. This is particularly the case in some middle-low income countries (Kjellstrom et al., 2009b). Factors that may contribute to potential injury risk in hot environments include loss of concentration and coordination, sweaty palms, fogged-up safety glasses, and accidental contact with hot surfaces.

The identification of high risk groups is essential for heat stress management and targeted intervention programmes. In this study, the identified vulnerable groups in the workplace in South Australia during heatwaves were male labourers and tradespersons ≥ 55 years of age in 'agriculture, forestry and fishing' and 'electricity, gas and water' industries. Although construction workers are often considered to be at high risk of injury during heatwaves, this was not detected in our findings. Evidence shows that construction workers in Japan are not physically challenged by heat stress if effective prevention measures are taken on building sites (Morioka et al., 2006). According to the heat stress management policy of Construction, Forestry, Mining and Energy Union (CFMEU) South Australia Branch, 'if temperature is over 35 °C work in exposed areas ceases; if temperature is over 37 °C all work ceases unless working in air conditioned area' (Australian Construction, Forestry, Mining and Energy Union, 2013). That may explain, at least in part, our observation.

For outdoor workers in 'electricity, gas and water', ceasing work or working in an air-conditioned area may be impractical as the nature of work may involve ensuring the continuous supply of utilities during periods of extreme heat. Indeed, pipe failure rates and electric power outage rates in the summer can be considerably higher than that in other seasons (Simonoff et al., 2005; Gabel et al., 2009), indicating a potential increased work load for workers in this industry.

Our results suggest that workers in 'agriculture, forestry and fishing' had a significant increase of injury claims during heatwaves. This may be attributed to the physically demanding work outdoors or a lack of effective occupational health strategies. Recently, there has been increased recognition of heat hazards to agricultural workers due to noticeably high heat-related death rates in the industry (Jackson and Rosenberg, 2010). Studies have reported a high prevalence of heat stress related symptoms among US migrant farm workers (33%) (Fleischer et al., 2013), Japanese forestry workers (32%) (Maeda et al., 2006), Costa Rican sugarcane workers (Crowe et al., 2013), and South African horticultural workers (Mathee et al., 2010). These findings highlight the importance of heat strategies for agricultural workers, especially for seasonal migrant workers who have less knowledge of the local extreme heat impact and their legal OHS rights (Fleischer et al., 2013). In addition to field equipment to monitor heat stress conditions (Jackson and Rosenberg, 2010), enforceable legal regulations may be needed to ensure the implementation of heat stress control and prevention standards such as California Code of Regulations, Titel 8, Section 3395 (2014)), particularly in industries with a large proportion of temporally employed non-union workforces.

It has been reported that compared with older workers, young workers are more vulnerable to occupational injuries due to undertaking more strenuous tasks and lack of safety training and skills (US for Disease Control and Prevention, 2003; Xiang et al., 2014). However, in this study middle-aged and older workers (≥ 55 years of age) were found to be more prone to illnesses/injuries in certain outdoor industries during heatwaves. Older male workers were also found at higher risk of heat-related deaths in the U.S. agricultural workers (Petitti et al., 2013). Previous literature on heat tolerance suggests that middle-aged and older men and women are more work-heat-intolerant and more likely suffer from physiological heat strain than younger individuals (Blatteis, 2011). They may also have ageing-induced dysfunctional thermoregulatory mechanisms, and a higher prevalence of pre-existing illnesses (Astrom et al., 2011). Therefore, age-related variations in the vulnerability to heat-related injury/accident should be taken into account when developing new heat prevention policies/regulations and service guidelines.

We also studied the impact of heatwaves on claims due to heat stress, and found that heat illnesses increased by approximately 12 fold compared with non-heatwave periods. Heat illnesses are relatively uncommon when compared with other injuries, and to date heat stress is not listed as an occupational health priority in Australia (Safe Work Australia, 2012–2022). The number of heat stress related claims was very small, perhaps due to under-reporting and misclassification (Safe Work Australia, 2005-2006); however its potential impact on heat-induced injuries and heat-aggravated diseases should not be neglected.

Mechanism-specific analyses show that workers being hit by moving objects increased by 9.7% during heatwaves. Core temperature elevation and dehydration can result in fatigue, lethargy, vigilance decrement, and loss of concentration which may account for these injuries. The significant increase of injuries due to 'contact with chemicals' during heatwaves may be due to workers reducing the use of personal protective equipment (PPE) under conditions of extreme heat (Park et al., 2009), or the increased absorption rate of liquid chemicals through the skin in higher ambient temperatures (Cherrie et al., 2004). This highlights the importance of continued education in the use of PPE during heatwaves among those exposed to chemical substances (Park et al., 2009). By contrast, the decrease of 'falls, trips and slips' may be attributable to effective heat intervention policies in South Australia (Australian Construction, Forestry, Mining and Energy Union, 2013).

There are several limitations to this study. First, work-related illnesses and injuries during heatwaves may be underestimated due to the underreporting of compensation claims (Safe Work Australia, 2005-2006), or because of the number of workers on summer vacations when heatwaves occur. The validity of effect estimates may be improved if using daily injury claim rates; however denominator data for Adelaide are not available. In addition, the relatively small number of daily injury claims in some categories requires cautious interpretation of results. Second, we did not consider interaction effects between heatwaves and subgroup variables as our focus was on investigating the impact of heatwaves on injury claims within subgroups rather than comparing associations across subgroups. Different industries may have variations in the age or/and gender profiles of employees which may account for some age or/and gender effects observed. However, this could not be accounted for methodologically as some individual characteristics and related confounders are time-fixed and do not change on a daily basis (Bhaskaran et al., 2013; Xiang et al., 2014). Third, evidence has shown that a small change in heatwave definition may appreciably affect the heat health outcome estimates (Tong et al., 2010). In this study, we used two heatwave definitions, which produced similar but slightly different outcomes. A community-based study has found that a stricter heatwave definition may be not able to fully capture the real impact of extreme heat on health outcomes (Tian et al., 2013). It is especially true for the workplace as more preventive measures (e.g. the cessation of work) will be taken during a more severe heatwave. In addition, a stricter heatwave definition means smaller sample size, which may reduce statistical power. Further research is needed to develop regional appropriate heatwave definitions for the purpose of either workplace health impact assessment or heatwave warning. Finally, we did not take specific characteristics such as duration, intensity, timing, and lag effects into account when analysing the heatwave effects.

In summary, outdoor male labourers and tradespersons aged ≥ 55 years in 'agriculture, forestry and fishing' and 'electricity, gas and water' industries are at higher risk of injury during heatwaves in Adelaide. Occupational burns, lacerations, amputations, and heat illnesses are examples of health outcomes we found to be significantly associated with extreme heat, together with injuries resulting from moving objects, chemical exposures, and environmental factors. This study may provide valuable implications for policy makers and relevant stakeholders to develop regulations and guidelines locally or/and internationally to reduce the impacts of extreme heat events on WHS, particularly in susceptible subgroups.

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