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ORIGINAL ARTICLE

Extreme heat and occupational heat illnesses in South Australia, 2001–2010

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ABSTRACT

Objectives This study aims to examine the epidemiological characteristics of occupational heat illnesses in South Australia, to quantify the association between ambient temperature and occupational heat illnesses, and to investigate the impact of heatwaves on occupational heat illnesses.

Methods Workers' compensation claims data and weather data were obtained from SafeWork South Australia and the Bureau of Meteorology, respectively, for 2001–2010. Time series analysis with generalised estimation equation models and linear spline functions was used to quantify the temperature–heat illness claims association. A case-crossover design was applied to investigate the impact of heatwaves on occupational heat illnesses.

Results There were 306 heat illness claims during the study period, with an incidence rate of 4.5 per 100 000 employees. The overall risk of occupational heat illness was positively associated with maximum temperature (T_{max}), especially when T_{max} was over the threshold of 35.5°C. One degree increase of T_{max} was associated with a 12.7% (incidence rate ratio 1.127, 95% CI 1.067 to 1.190) increase of occupational heat illness claims. During heatwave periods, the risk of occupational heat illness was about 4–7 times higher than that of non-heatwave periods.

Conclusions There is a need to develop or refine current heat-related regulations and guidelines to minimise the risk of occupational heat illnesses in vulnerable workers in a warming climate.

What this paper adds

- Despite the growing heat stress challenge due to climate change, to date, there is very limited research to investigate the comprehensive characteristics of occupational heat illnesses.
- Relatively high occupational heat illness incidence rates were observed in 'mining' and 'electricity, gas and water' industries and among those employed as labourers and tradespersons in South Australia, 2001–2010.
- The overall risk of occupational heat illness was positively associated with daily maximum temperature (T_{max}), characterised by a significant increase when T_{max} was over 35.5°C.
- During heatwave periods in Adelaide, the risk of occupational heat illness was about 4–7 times higher than that of non-heatwave periods.

INTRODUCTION

Heat illness occurs as a direct consequence of thermoregulatory failure, ranging from minor heat cramps to life-threatening heat stroke. There are six fundamental factors influencing the thermal comfort of workers in the workplace, including ambient temperature, radiant temperature, air velocity, relative humidity, clothing insulation and work demands.[1] In the workplace, there are two types of external heat exposure sources: weather-related and process-generated heat. The predicted increase in the frequency and intensity of extremely hot weather in the context of climate change,[2] has significant implications for the occurrence of heat-related illnesses and injuries in the workplace.[3]

Compared with other occupational injuries, occupational heat illnesses are relatively uncommon due to a wide variety of reasons such as the 'healthy worker effect', under-reporting, misclassification, improved mechanisation level and air-conditioned workplaces.[4] Previous heat illness-related epidemiological data analyses mainly focus on military personnel,[5] athletes[6] or heat-related morbidity and mortality in the community.[4 7 8] The impact of climate change with the increased temperatures on workers' health and safety is a relatively research-neglected field,[3] and its importance has been addressed in the recently published Intergovernmental Panel on Climate Change Fifth Assessment Report.[9] Exposure to environmental heat may become a progressively more important occupational hazard in a warming climate. In 2011, the US Occupational Safety and Health Administration (OSHA) launched a nationwide heat illness prevention campaign to raise public awareness, and to teach employers and outdoor workers, about the risk of working in hot weather.[10]

Evidence shows that Australia would be one of the countries at moderate to high risk of occupational heat strain for outdoor workers if temperatures increase by 3°C.[11] Adelaide is the capital city of South Australia, situated on a plain between the Gulf St Vincent and the low-lying Mount Lofty Ranges. Its suburbs extend 20 km east to west and 90 km north to south. Adelaide has a Mediterranean climate, characterised by the influences of heat and aridity from the north, and moisture and coolness from the south and west. 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. According to weather projections for Adelaide, the average number of days with temperatures over 35°C will triple by 2070.[12] Several studies in Adelaide have found that heatwaves

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have resulted in excess mortality and morbidity in the community.[7 8] Moreover, the relationships between high ambient temperatures and work-related injuries were also found among some workers in Adelaide.[13] Nevertheless, to date, there is very limited research using long-term historical surveillance data to investigate the comprehensive characteristics of heat illnesses among occupationally exposed populations.[3]

The objectives of this study are to describe the characteristics of occupational heat illnesses in South Australia, to quantify the association between ambient temperature and occupational heat illnesses, to examine the impact of heatwaves on the occupational heat illnesses, and to provide implications for decision-makers and relevant stakeholders regarding the prevention of heat illnesses in the workplace.

MATERIALS AND METHODS

Workers' compensation claim data

Under the South Australian WorkCover Scheme directed by the Workers Rehabilitation and Compensation Act 1986,[14] injured workers can lodge a compensation claim to WorkCover SA. All reported compensation cases are required to be aggregated to SafeWork SA (SWSA). SWSA is the government-run regulator responsible for the management of workers' compensation claim data, which have been used as a tool to monitor occupational illnesses and injuries since 1987. The Type of Occurrence Classification System (TOOCS) is developed as coding guidelines for recording details of workers' compensation claims reported to workers' compensation agencies.[15] The information needed for the allocation of appropriate codes is mainly sourced from the description given on the medical certificate or claim application form. Four classifications are designed in the TOOCS to assist in describing the type of injury or disease sustained by the worker, including the nature of injury (based on the International Classification of Diseases, ICD-9), bodily location, mechanism and agency of injury/disease.[15] Each case is allocated four codes according to the above four categories. Quarterly labour force information in South Australia (denominator data) was downloaded from the Australian Bureau of Statistics website for the calculation of claim incidence rates.[16]

In this study, workers' compensation claim data were obtained from SWSA for the period from 1 July 2001 to 30 June 2010. The data included all accepted compensation claims from both registered and self-employed employers during the 9-financial year period. Individual identifiable information was removed prior to receipt of the data. The study was approved by the Human Research Ethics Committee at the University of Adelaide (H-111-2011) and the SWSA data custodian.

Identification of compensation claims due to heat illnesses in workplaces

Workers' compensation claims due to heat illnesses in the workplace were identified through a three-step process (see online Supplementary figure S1). First, claims due to heat illnesses were identified using each of the following four codes: TOOCS nature classification G313 (heat stress/heat stroke), TOOCS mechanism classification G53 (exposure to environmental heat), TOOCS agency classification G7100 (weather and water) and TOOCS agency classification G7110 (sun). Second, identified claims were verified by reviewing diagnosis-related comments and workers' descriptions sourced from WorkCover South Australia. Finally, duplicate heat illness claims found using this search method were excluded.

Meteorological data

Historical weather data were obtained from the Australian Bureau of Meteorology. To quantify the association between temperature–occupational heat illness and the impact of heatwaves on occupational heat illnesses, the analyses were restricted to the metropolitan area of Adelaide. The Kent Town weather station near the central business district was selected to represent the weather conditions across the Adelaide metropolitan area.[7 8 13] In this study, daily maximum temperature (T_{max}) was selected as the heat exposure indicator. Heatwave was defined as three or more consecutive days with T_{max} ≥35°C, as reported in previous studies in South Australia.[7 8]

Statistical analyses

Descriptive analysis was used to describe the epidemiological distribution of occupational heat illnesses occurring during the study period in South Australia. The analyses of daily temperature–heat illness claims association and the impact of heatwaves on heat illness claims focused specifically on data relating to the Adelaide metropolitan area where, unlike the rest of the state, heat exposure (daily maximum temperature and the identification of heatwave periods) could be determined using local meteorological data.

Therefore, the association between daily heat illness claims and daily maximum temperatures in Adelaide was initially explored graphically using a LOWESS (locally weighted scatter plot smoothing) smoother performing a locally-weighted non-parametric regression.[8 13] The association of T_{max} with daily occupational heat illness claims in Adelaide was assessed using generalised estimating equation models (GEE) with negative binominal distribution, a log link function and a first order autocorrelation structure. Confounding factors were adjusted for, including day of the week, public holidays, calendar month and long-term trends (putting calendar year in the GEE model as a categorical variable). As a waiting period may exist before an injury claim is assessed and accepted for compensation, during the daily format time series analysis we used the date of injuries occurred in the workplace rather than a date accepted for compensation.

Given that the relationship between temperature and health outcomes is usually non-linear, a piecewise linear spline function with one knot (the junction between two splines) was utilised to quantify the effect of ambient temperature on heat illness claims below and above a threshold temperature.[17] The threshold temperature was estimated by using the hockey-stick model.[8 13] Results for the negative binominal regression models are expressed as incidence rate ratios (IRR) with 95% CIs, and interpreted as percent change in heat illness claims per degree increase of T_{max} below or above threshold temperatures.

The case-crossover design was applied to investigate the impact of heatwaves on occupational heat illnesses in Adelaide. The key feature of the design is that each case serves as its own matched control. It is suitable to the study of transient effects of exposure (eg, heatwave) on acute events (eg, occupational heat illnesses) with relatively small sample size.[18] An effect estimate is calculated by dividing the number of cases exposed during the hazard period (heatwave) by the number exposed during the control period (non-heatwave). In this study, both unidirectional (retrospective) and bidirectional (combination of retrospective and prospective) control samplings were used.[18 19] For the retrospective sampling, the same weekdays 1–3 weeks before the occurrence of heat illness were selected as the control periods.[19] For bidirectional sampling, the same weekdays 1–3 weeks before

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and after the occurrence of heat illness were defined as the control periods.[19] Choosing the same weekdays as control periods avoids the day-of-the-week effect. The effects of heatwaves on heat illness claims were estimated using conditional logistic regression.

All analyses were performed with Stata V.12.0 (StataCorp LP, College Station, Texas, USA). The 0.05 level of statistical significance was adopted for each test. A spatial analysis of heat-related claims by postcode was undertaken using Epi Info 7 (US Centre for Disease Control and Prevention).

RESULTS

Characteristics of occupational heat illness claims in South Australia

The distribution characteristics of occupational heat illness claims and all claims are summarised in table 1. There were 306 compensation claims due to occupational heat exposure from 1 July 2001 to 30 June 2010 in South Australia, representing 0.1% of all 318 932 claims reported during the study period. Of the 306 heat illness claims, 69% (211) occurred in the Adelaide metropolitan area as defined as postcode (see online Supplementary figure S2). The proportion of heat illness claims occurring in the metropolitan area was significantly less than that of all claims (Pearson $\chi^2=10.255$, $p=0.001$). Among the total number of identified occupational heat illnesses, 142 (46.4%) compensation claims were diagnosed as 'heat stress/heat stroke', and 133 (43.5%) were diagnosed as 'other unspecified diseases or injuries' due to effects of weather, exposure, air pressure and other external factors (see online Supplemental figure S1). In terms of injury mechanism, 256 (83.7%) compensation claims were caused by 'exposure to environmental heat', followed by 'exposure to non-ionising radiation' (9.8%) and 'car accident' (1.6%). When classified by breakdown agency, 144 (47.1%) compensation claims were attributed to 'weather and water' and 51 (16.7%) resulted from 'sun'. Of the 144 weather and water-related compensation claims, 89 (61.8%) were diagnosed as 'heat stress/heat stroke'.

Approximately 81% (248) of heat illness claimants were men. The proportion of male heat illness claimants was significantly higher than that in all claims (68.3%) (Pearson $\chi^2=22.229$, $p<0.001$). The average age of heat illness claimants was 39.4 years and the median age was 39 years. Accordingly, the average and median ages for all claims were 38.6 and 39 years, respectively. Approximately 86.9% of heat illness claims occurred in the warm season, from October to March for South Australia, with 64.3% occurring in the summer months. By contrast, the percentage of all compensation claims reported in the warm season was 49.7%. About 65% of heat illness claims occurred during the hottest part of the day, between 10:00 and 18:00. Similar to all compensation claims, about half of all heat illness claims were from large businesses.

The expenditure for heat illness claims ranged from $0 to $487 055, with a total cost of $1 795 641 during the study period (table 1). The average expenditure for each heat illness claim was $5868, which was about half of the average expenditure for all claims. Seventy-nine claims (25.8%) due to heat illnesses resulted in time lost from work. Days lost due to heat illnesses ranged from 0 to 827 days, with an average of 9 days. One heat-related death occurred during the study period.

As shown in table 2, the distribution by industrial sectors was similar between heat illness claims and all claims. However, characteristics of incidence rates between the two were different. Overall, the heat illness claim rate was 4.5 per 100 000 employees. Specifically, the mining industry had the highest heat illness claim rate (18.9 per 100 000 employees), followed by 'electricity, gas and water' (9.2 per 100 000 employees), public administration and defence (8.8 per 100 000 employees) and community services (7.3 per 100 000 employees). For all claims, the manufacturing industry had the highest claim rate (10.2%).

As shown in table 3, the distribution characteristics of percentage and claim rate by occupation were consistent for both occupational heat illness claims and all compensation claims. Tradespersons (who typically operate a wide variety of complex precision machinery or work in a plant to complete several stages in the fabrication and maintenance of products) had the highest occupational heat illness claim rate (12.3 per 100 000 employees), followed by labourers (8.6 per 100 000 employees) and intermediate production and transport workers (7.8 per 100 000 employees).

Association between temperature and heat illness claims in Adelaide

An analysis of claims restricted to the Adelaide metropolitan area was conducted. As shown in figure 1, there was no significant increase in daily occupational heat illness claims (IRR

Table 1 Characteristics of heat illness compensation claims and all compensation claims reported in South Australia, 2001–2010

Classification	Heat illness compensation claims	All compensation claims
Total	N=306	N=318 932
Male (n/(%))	248 (81.0)	218 544 (68.5)
Age group (n/(%))		
≤24	51 (16.7)	54 736 (17.2)
25–34	66 (21.6)	70 283 (22.0)
35–54	144 (47.1)	156 791 (49.2)
≥55	45 (14.7)	37 122 (11.6)
New workers* (n/(%))	52 (17.0)	61 624 (19.3)
First language (n/(%))		
English	302 (98.7)	312 219 (97.9)
Other	4 (1.3)	6713 (2.1)
Injury location (n/(%))		
Adelaide	211 (69.0)	244 614 (76.7)
Rest of South Australia	95 (31.0)	74 318 (23.3)
Seasons (n/(%))		
Warm (October–March)	266 (86.9)	158 373 (49.7)
Cool (April–September)	40 (13.1)	160 559 (50.3)
Employer size† (n/(%))		
Large (>200)	163 (53.3)	161 683 (50.7)
Medium (20–200)	105 (34.3)	100 562 (31.5)
Small (<20)	38 (12.4)	56 687 (17.8)
Employer type (n/(%))		
Registered	244 (79.7)	254 668 (79.9)
Self-employed	62 (20.3)	64 264 (20.1)
Compensated claims	n=262	n=292 912
Average cost per claim ($AU)	5868	12 520
Median cost ($AU)	436	423
Time loss claims	n=79	n=97 468
Average days lost per claim	9	32
Median days lost	0	0
Death (n/(‰))	1 (3.3)	186 (0.5)

*New workers are defined by the duration between injury date and start date with employer of less than 1 year or a worker is under or equal to 18 years old.
†The employer size is grouped by the number of employees as follows: small (1–20), medium (21–200) and large (≥201).[20]
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Table 2 The number, percentage and claim rate of all and heat illness compensation claims by South Australia WorkCover Industrial Classification System (SAWICS) in South Australia, 2001–2010

Industry (SAWICS)	Heat illness compensation claims n	Per cent	Incidence rate*	All compensation claims n	Per cent	Claim rate†
Agriculture, forestry and fishing	13	4.3	3.5	9770	3.1	2.7
Communication	1	0.3	0.8	205	0.1	0.2
Community services	97	31.7	7.3	87 291	27.4	6.6
Construction	33	10.8	6.8	22 036	6.9	4.6
Electricity, gas and water	7	2.3	9.2	2420	0.8	3.2
Finance, property and business services	7	2.3	7.6	12 129	3.8	1.3
Manufacturing	50	16.3	6.0	85 037	26.7	10.2
Mining	13	4.3	18.9	3463	1.1	5.0
Public administration and defence	36	11.8	8.8	10 681	3.4	2.6
Recreational, personal and other services	10	3.3	1.2	16 569	5.2	2.1
Transport and storage	20	6.5	6.6	16 338	5.1	5.4
Wholesale and retail trade	16	5.2	1.6	50 211	15.7	4.9
Non-classifiable	3	1.0	–	2782	0.9	–
Total	306	100.0	4.5	318 932	100.0	4.7

*Incidence rate: per 100 000 employees.
†Claim rate: per 100 employees.

0.990, 95% CI 0.975 to 1.006) in Adelaide with the increase of T_{max} below a threshold of 35.5°C (95% CI 34.4°C to 36.7°C, $p<0.001$), which was estimated using a hockey stick model. However, when T_{max} was above 35.5°C, 1°C increase of T_{max} was associated with 12.7% (IRR 1.127, 95% CI 1.067 to 1.190) increase of occupational heat illness claims in Adelaide.

Impact of heatwaves on heat illness claims in Adelaide

A total of 21 heatwaves were recorded during the study period in Adelaide, with a maximum of four heatwaves in one calendar year (2009). The duration of individual heatwaves ranged from 3 to 15 days, with a mean of 4.9 days. Of the 211 heat illness claims that occurred in the Adelaide metropolitan area, 92 (43.6%) occurred during 103 heatwave days. Results of a case-crossover analysis yielded differences according to the control period used. Using unidirectional design with three control periods before the case period, the risk of occupational heat illness during heatwaves was about seven times that during non-heatwaves (OR=6.78, 95% CI 4.03 to 11.38). Case-crossover models with one or two control referent periods before the case period when heat illness occurred produced similar results (OR=4.50, 95% CI 2.27 to 8.93; OR=5.34, 95% CI 3.07 to 9.28, respectively). For bidirectional sampling, ORs for 1–3 weeks before and after the occurrence of occupational heat illness, were 6.12, 5.91 and 5.94, respectively (table 4).

DISCUSSION

With predictions of increasing temperatures,[2 12] the baseline occupational heat illness incidence data from this study in South Australia may be used for a comparative risk assessment in the future. Although the number of occupational heat illnesses may be underestimated due to misdiagnosis, under-reporting and misclassification,[4] it can still provide an overview of the magnitude of the heat illness problem in the workplace. The results may also aid relevant stakeholders in policymaking, and in developing occupational health and safety education, and promotion campaigns, for extreme heat.

Incidence of occupational heat illness

A total of 306 injury claims due to occupational heat illnesses were identified during 2001–2010 in South Australia. This compares with 480 cases reported in Washington State, USA, during

Table 3 The number, percentage and claim rate of heat illness compensation claims and all claims by occupation in South Australia, 2001–2010

Occupation	Heat illness compensation claims n	Per cent	Incidence rate*	All compensation claims n	Per cent	Claim rate†
Advanced clerical and service workers	1	0.3	0.4	3162	1.0	1.4
Associate professionals	23	7.5	2.8	28 899	9.1	3.5
Elementary clerical, sales and service workers	30	9.8	4.8	24 245	7.6	3.9
Intermediate clerical and service workers	18	5.9	1.6	33 123	10.4	2.9
Intermediate production and transport workers	48	15.7	7.8	60 355	18.9	9.8
Labourers and related workers	60	19.6	8.6	71 687	22.5	10.3
Manager and administrators	2	0.7	0.3	5336	1.7	0.9
Professionals	17	5.6	1.5	23 800	7.5	2.0
Tradesperson and related workers	106	34.6	12.3	64 759	20.3	7.5
Other	1	0.3	–	759	0.2	–
Total	306	100.0	4.5	318 932	100.0	4.7

*Incidence rate: per 100 000 employees.
†Claim rate: per 100 employees.

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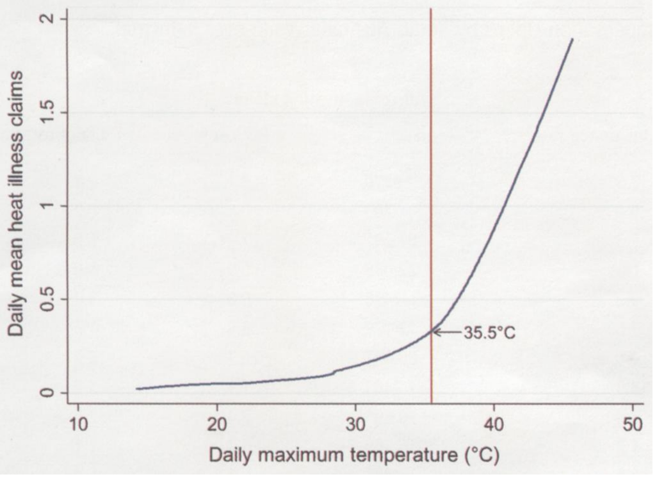

Figure 1 The association between daily maximum temperature and daily mean occupational heat illness claims in Adelaide, South Australia, 2001–2010.

1995–2005,[21] 259 cases in Quebec, Canada, during 1998–2010[22] and 105 cases in Florida, USA, during 2005–2009.[23] However, the incidence rate of occupational heat illnesses in South Australia (4.5 per 100 000 employees) was higher than that in Washington State (3.1 per 100 000 employees) and Florida (3.5 per 100 000 employees). Moreover, as mentioned, the occupational heat illness incidence rate may be underestimated because of under-reporting of heat illness in the workplace.[4] This could be due to some workers believing it is too minor or too inconvenient to claim, or the workers could be worried about future employment.[24] The occupational heat illness incidence rate in this study was far lower than recorded heat illness claims among the military personnel[5] and athletes[6] in other studies, as these groups are sometimes required to perform strenuous exercise during extremely hot weather.

In Australia, heat stress has not been listed in the six national 2012–2022 occupational health priorities,[25] which could be due to its relatively low incidence when compared with other occupational injuries.[26] The results in this study showed that average cost and average days lost per heat illness claim were both much less than the average levels for all claims, which is consistent with the findings of Bonauto *et al*'s[21] USA study. That a heat-related fatality occurred during the study period indicates the potential severity of heat-illnesses and that early detection, diagnosis and treatment of mild forms of heat illnesses are vital to prevent life-threatening heat stroke. Additionally, the substantial indirect impacts of workplace heat exposure cannot be neglected, as extreme heat may increase the risk of work-related injuries, reduce work efficiency,[27] and result in loss of work time.[28] This is particularly so for low-middle income countries where adequate protective measures may be lacking.[27]

Table 4 The ORs of occupational heat illness claims during heatwave periods compared with non-heatwave periods in different control groups in Adelaide, South Australia, 2001–2010

Control	OR	95% CI
Before case period (days)		
7	4.50	2.27 to 8.93
7 and 14	5.34	3.07 to 9.28
7, 14 and 21	6.78	4.03 to 11.38
Before and after case period (days)		
7	6.12	3.35 to 10.91
7 and 14	5.91	3.66 to 9.53
7, 14 and 21	5.94	3.89 to 9.08

Risk factors of occupational heat illness

The majority (81%) of heat illness claims occurred in male workers, which is consistent with the findings of other similar studies.[21 22] However, although studies have shown women to be less heat tolerant than men,[29 30] male and females workers should both be targeted in the preventive measurements. The results also showed that about half of heat illnesses occurred in the 35–54-year age group. This is similar to previously published literature, which suggested that middle-aged and older workers were more work-heat-intolerant and suffer more physiological strain than young individuals when working in hot environments.[31] This could be due to ageing-induced degraded thermoregulation functions, relatively high prevalence of some heat-triggered chronic diseases, the use of certain medications or pertinent morphological factors.[32] However, young workers are found at high risk of work-related injuries when the weather is not unduly hot,[13] as they are likely to undertake more strenuous tasks and have a lack of heat prevention skills when compared with older workers.[33] Therefore, preventive measures for occupational heat illnesses should be targeted to all age groups. Nevertheless, age-related variations in heat vulnerability during mild days and extremely hot days should be taken into account. In terms of the category of industry and occupation, results of this study suggested that tradespersons, labourers and transport workers in 'mining' and 'electricity, gas and water' industries had relatively higher occupational heat illness claim rates. Outdoor workers, in particular those undertaking highly intensive and physical activity under the sun, are susceptible to heat stress during extremely hot weather when preventive measures are not adequately adopted.[4] This could be due to the fact that physical and strenuous activity generate internal body heat and an increased metabolic rate. This, together with significant radiant heat load from direct sunlight, may increase the risk of heat stress.

The results showed that the majority (87%) of heat illness claims occurred in the warm season from October to March for South Australia (in particular during summer months) and the hottest part of the day. This is consistent with other similar studies elsewhere.[21 34] The findings in this study showed that approximately 65% of heat illness claims occurred between 10:00 and 18:00, which is similar to overall injury claims. Therefore, the distribution pattern of heat illness by the hour of injury may coincide with normal work shifts and the hottest times of the day.

Ambient temperature and occupational heat illness

The association between temperature and heat illness claims was quantified after controlling for confounding factors such as day of the week, public holidays and long-term trends. The estimated 35.5°C threshold above which claims increase is consistent with the current Extreme Heat Guideline of the Construction, Forestry, Mining and Energy Union (CFMEU) South Australia Branch.[35] This provides valid implications for the establishment of a workplace heat alert system, which may include threshold temperature detection, weather forecasting, prediction of the possible health outcomes, an effective and timely response plan and an ongoing evaluation of the system.[36] The selection of trigger temperatures for workplace heat alert levels is very important for the activation of action responses. It

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needs to take into account the sensitivity, reliability and validity issues. It is not known if temperature-based thresholds for the general population can be directly applied to the workplaces. However, evidence has suggested that occupational heat illnesses may occur at a lower temperature than non-occupational heat illnesses.[23] It should also be noted that different regions may need different threshold temperatures due to the differences in climatic characteristics, heat acclimatisation level, work environments and public health infrastructure.

In addition to the temperature–heat illness claim relationship, the effects of heatwaves on heat illness claims in Adelaide were examined by using a case-crossover approach. The results showed that the risk of heat illness in the workplace during heatwaves was between 4 and 7 times higher than that during non-heatwave periods, indicating there is a need to: comprehensively review current heat-related policies and regulations, taking into account the impact of heatwaves and consecutive days of extreme heat on worker' health and safety; identify who are the high-risk subgroups; and investigate the heat prevention and adaptation barriers existing in the workplace.

Occupational heat illness prevention

Occupational heat illness is largely preventable. Current strategies to reduce the effects of heat stress include policy and regulation implementation, engineering controls, administrative controls, education and training and personal adaptation, which have been well described in previous publications.[1] Some of the authoritative governing bodies that have developed heat stress guidelines and/or indices include the International Organization for Standardization (ISO), the European Committee for Standardization (CEN), the US National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH).[37] In addition to the internationally accepted technical standards, many countries have formulated their own standards, according to local climatic characteristics, level of economic development and industrial structure.

The management of heat exposure in Australian workplaces has long been a perplexing dilemma due to the lack of clear regulations. Heat stress technical standards and guidelines developed by the Australian Institute of Occupational Hygienists (AIOH) were basically adopted from the US ACGIH threshold limit values, which were updated in 2013 for use in the Australian environment.[1] As in the USA, legal requirements relating to heat stress in Australia are fairly ambiguous, and there are no mandatory regulations and guidelines specifying standards for maximum/threshold temperatures in the workplace.[38] Ambiguous and unspecific heat regulations cannot ensure the compliance and effective implementation of heat control and prevention measures,[39] leaving some industrial sectors at high risk of heat stress in hot weather.[4 13] Moreover, no State or Territory has specific legal requirements for heat stress control and prevention in Australia, whereas guidelines and educational materials relating to heat stress are available on each state's SafeWork or/and Department of Health websites.

Regarding suggestions for heat stress control and management, in the short to medium term, these may include the establishment of workplace heat alert systems, real-time health surveillance for workers undertaking emergency tasks,[40] the flexible combination of a self-regulated and mandatory heat management pattern,[41] specific and clear enforceable heat regulations and a heat awareness campaign and promotion.[10] For the long-term, changes to building and urban design to mitigate the impacts of increasing global temperatures, the improvement of work conditions and measures to reduce greenhouse gas emission need to be considered.[41] Multidisciplinary collaboration between institutions from various sectors and administrative levels is essential for the successful control and management of heat stress. Involved institutions may include SafeWork Departments, the Bureau of Meteorology, State Emergency Service, Health Departments, trade associations, unions and professional bodies and training institutions. It is also important to decide who are the overall responsible lead bodies coordinating cooperation, interventions, joint activities and resource allocation.[36]

To prepare for the challenge of increasing weather-related heat stress, the following two issues should be further addressed. First, it is important to understand how workers and relevant stakeholders perceive the risk of heat exposure in the context of global warming, as their perceptions and views are important for the formulation, development and implementation of heat policies and regulations. Studies of the 'high occupational temperature health and productivity suppression' programme (HOTHAPS) suggest that workplaces in participating countries are not well prepared for climate change-related rising temperatures.[30 42] To address lack of awareness of the dangers of working in hot weather, the US Occupational Safety and Health Administration recently launched a nationwide campaign.[10] Second, more evidence is needed to assess the current mainstream heat policies and regulations to make them fit for the future warming climate. The system of International Standards is currently reconsidering its current heat-related standards to meet future requirements.[43]

LIMITATIONS

There are several limitations in this study. First, the heat illness incidence may be underestimated or misclassified due to underreporting or poorly described workers' compensation claims data. Second, when quantifying the temperature–heat illness relationship, maximum dry air temperature was selected as the heat exposure indicator rather than composite heat indices that take account of the combined effects of temperature, relative humidity, wind speed and solar radiation (ie, wet-bulb globe temperature). However, evidence shows that different heat indices have similar predictive abilities.[44] Moreover, Adelaide is known as the driest capital city in Australia, and humidity is relatively consistent and is generally not considered to be a major concern. Third, the quantitative effects of heatwaves on occupational heat illnesses may be overestimated, as healthcare providers may more readily recognise and diagnose heat illnesses during hot days in summer.[21] Fourth, the relatively small number of occupational heat illnesses (306 over the 10-year period) dictates cautious interpretation of results. Fifth, workers are more likely to take holidays over summer, which may result in fewer occupational heat illnesses due to a decreased workforce. Additionally, heat-related injury claims identified using the classification of 'weather and water' may include claims not relating to heat. Nevertheless, the impact would be limited, as the number of heat-related claims due to weather and water was very small. Furthermore, we did not investigate the impacts of some personal risk factors such as medical conditions, use of certain medications, and levels of fitness and acclimatisation on the occurrence of heat illness, due to unavailability of data. Finally, only one weather station was selected to provide the daily temperature of the Adelaide metropolitan area, which may introduce a misclassification of exposure; however, the Bureau of Meteorology advises that the station should be representative of the whole city.

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CONCLUSIONS

Relatively high-heat illness incidence rates were observed in 'mining' and 'electricity, gas and water' industries and among those employed as labourers and tradespersons in South Australia, during the study period. The overall risk of heat illness was positively associated with T_{max}, characterised with a significant increase when T_{max} exceeded 35.5°C. During heatwave periods in Adelaide, the risk of heat illness was about 4–7 times higher than that of non-heatwave periods. This highlights the need to consider regulations and guidelines to minimise the risk of heat-related health outcomes in workers, particularly in the light of predictions of heatwaves increasing in frequency and intensity in the future.

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