Extreme Heat and Workers' Health in South Australia: Association, perceptions, and adaptations in the workplace

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Thesis submitted for the degree of Doctor of Philosophy

October 2014

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Peer-reviewed Journals

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2. ***Xiang J***, Bi P, Pisaniello D, Hansen A, et al. Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010. *Occup Environ Med* (impact factor: 3.234). 2013, doi:10.1136/oemed-2013-101584.
3. ***Xiang J***, Bi P, Pisaniello D, Hansen A.The impact of heatwaves on workers' health and safety in Adelaide, South Australia, 2001-2010.*Environ Res* (impact factor: 3.951). 2014, 133: 90-95. doi: 10.1016/j.envres.2014.04.042.

Manuscript in draft

4. ***Xiang J***, Bi P, Pisaniello D, Hansen A. Extreme heat and occupational heat heat illness in South Australia, 2001-2010. (Submitted)
5. ***Xiang J***, Bi P, Pisaniello D, Hansen A. Workers' perceptions on workplace heat exposure in South Australia.
6. ***Xiang J***, Bi P, Pisaniello D, Hansen A. Workplace heat exposrue and OH&S: Perceptions from Australian occupational hygienists.

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1. ***Xiang J***, Bi P, Pisaniello D, Hansen A, et al. Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010 (*Oral presetation*).The 23rd International Conference on Epidemiology in Occupational Health (EPICOH), Utrecht, Netherlands, 2013.
2. ***Xiang J***, Bi P, Pisaniello D, Hansen A. Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010 (*Poster presentation*). The

Faculty of Health Science Postgraduate Research Conference, The University of Adelaide, SA, 2013.

3. ***Xiang J***, Bi P, Pisaniello D, Hansen A. Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010 (*Poster presentation*). The Australian National Climate Change Adaptation Research Facility (NCCARF) Conference, Sydney, Australia, 2013.

4. ***Xiang J***, Bi P, Pisaniello D, Hansen A. The impact of heatwaves on workers' health and safety in Adelaide, South Australia (*Poster presentation*). The 24th International Conference on Epidemiology in Occupational Health (EPICOH), Chicago, USA, 2014.

5. ***Xiang J***, Bi P, Pisaniello D, Hansen A. Climate change and workplace heat exposure: Perceptions from occupational hygienists. The Australian National Climate Change Adaptation Research Facility (NCCARF) Conference (*A synthesis talk and poster presentation*), Gold Coast, Australia, 2014.

6. ***Xiang J***, Bi P, Pisaniello D, Hansen A. Climate change and occupational heat stress: Perceptions from workers. The Australian National Climate Change Adaptation Research Facility (NCCARF) Conference (*Poster presentation*), Gold Coast, Australia, 2014.

7. ***Xiang J***, Bi P, Pisaniello D, Hansen A. Extreme heat and occupational heat illness in South Australia, 2001-2010. The Australian National Climate Change Adaptation Research Facility (NCCARF) Conference (*Poster presentation*), Gold Coast, Australia, 2014.

8. ***Xiang J***, Bi P, Pisaniello D, Hansen A. The impact of heatwaves on workers' health and safety in Adelaide, South Australia (*Poster presentation*). The Faculty of Health Science Postgraduate Research Conference, The University of Adelaide, SA, 2014.

AWARDS RECEIVED DURING PhD CANDIDATURE

- The University of Adelaide – China Scholarship Council Joint Postgraduate Scholarships Program, 2010-2014.
- Postgraduate Travelling Fellowship, funded by the Freemasons Foundation. Faculty of Health Sciences Research Committee, the University of Adelaide, 2013.
- Travel grant. The 23rd Scientific Committee on Epidemiology in Occupational Health (EPICOH) Conference Committee. Utrecht, Netherlands, 2013.
- Travel grant. The Australian National Climate Change Adaptation Research Facility (NCCARF) Annual Conference Committee. Sydney, Australia, 2013.
- Outstanding Service to the Adelaide Chinese Students & Scholars Association (ACSSA) Award. Education Office, Embassy of China in Australia, 2013.
- Travel grant. The 24th Scientific Committee on Epidemiology in Occupational Health (EPICOH) Conference Committee. Chicago, United States, 2014.

LIST OF ABBREVIATIONS

ABS	Australian Bureau of Statistics
ACGIH	American Conference of Governmental Industrial Hygienists
AIOH	Australian Institute of Occupational Hygienists
ASCO	Australian Standard Classification of Occupation
AT	Apparent Temperature
BOM	Bureau of Meteorology
CEN	European Committee for Standardization
CFMEU	Construction, Forestry, Mining and Energy Union
CI	Confidence Interval
FIFO	Fly-in/fly-out
GEE	Generalized Estimating Equation
H/W	Heatwave
ICD	International Classification of Diseases
IRR	Incidence Rate Ratio
ISO	International Organization for Standardization
NIOSH	National Institute for Occupational Safety and Health
OH&S	Occupational Health & Safety
OLS	Ordinary Least Square
OR	Odd Ratio
PPE	Personal Protective Equipment
SA	South Australia
SAWIC	South Australia WorkCover Industrial Classification
SWSA	SafeWork South Australia
TAFE	Technical and Further Education
TLV	Threshold Limit Value
T_{max}	Maximum Temperature
TOOCS	Type of Occurrence Classification System
UK	United Kingdom
USA	United States of America
USG	Urine Specific Gravity
UTCI	Universal Thermal Climate Index
WBGT	Wet Bulb Globe Temperature
WHS	Workers' health and safety

THESIS ABSTRACT

Background

Occupational heat exposure may lead to adverse health effects and contribute to work-related injury, illness or even death. With the predicted increase in the frequency and intensity of extremely hot weather in South Australia, workplace heat exposure is presenting a growing challenge to workers' health and safety. This thesis aims to examine the effects of workplace heat exposure on workers' health and safety in Adelaide, South Australia, to investigate perceptions of risks associated with workplace heat exposure, and to provide scientific evidence for the development of heat necessary heat prevention and adaptation strategies particularly in a warming climate.

Methods

This study can be broadly divided into two parts. The first part is the analyses of workers' compensation claim data and weather data, obtained from the SafeWork South Australia and the Bureau of Meteorology, respectively for 2001-2010. Time-series analysis approach was used to quantify the effects of heat exposure on workers' health and safety. Heat-related claims were identified according to the Type of Occurrence Classification System coding information and text-based diagnosis-related descriptions. Case-crossover analytic approach was undertaken to estimate the risk of occupational heat illnesses during heatwaves. The second part of this study comprises two cross-sectional questionnaire surveys to investigate how workers and occupational hygienists perceive the risk of workplace heat exposure and health impact.

Results

Analyses of workers' compensation claim data

Generally, there was a reversed U-shaped relationship between daily maximum temperature (T_{max}) and daily injury claims in Adelaide. With increasing T_{max} below certain threshold temperatures ranging from 31.8℃ to 38.9℃, significant temperature-injury claims associations were found in the following sub-groups: young workers aged ≤24 years; those working in some outdoor industries such as 'agriculture, forestry and fishing', 'construction', and 'electricity, gas and water'; or employed as labourers, production and transport workers, and tradespersons in small and medium sized businesses. When the temperature was extremely hot, almost all industries had a decrease in injury claims, except the 'electricity, gas and water' industry.

During heatwave (≥3 consecutive days with T_{max} ≥35℃) periods, outdoor male labourers and tradespersons aged ≥55 years in 'agriculture, forestry and fishing' and 'electricity, gas and water' industries were found to be at higher risk of work-related injuries. Occupational burns, lacerations, amputations, and heat illnesses were found to be significantly associated with extreme heat, together with injuries resulting from moving objects, chemical exposures, and environmental factors.

There were 306 heat-related injury claims reported during the 9-financial year period in South Australia, with an incidence rate of 4.5 per 100,000 workers. Relatively high heat illness incidence rates were observed in 'mining' and 'electricity, gas and water' industries, and those employed as labourers and tradespersons across the state during the study period. When T_{max} was above 35.5℃, a 1 ℃ increase of T_{max} was associated with a 12.7% increase in 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.

Workers and occupational hygienists' perceptions on heat exposure

Surveyed workers were moderately concerned about heat exposure. Young workers (≤24 years) were less concerned than older workers. Workers undertaking very physically demanding work, wearing personal protective equipment, or having had a previous heat illness/injury were found to be more concerned about heat exposure.

The majority (90%) of occupational hygienists and specialists surveyed showed great concerns over heat stress, but they did not show strong willingness to amend heat prevention recommendations to management or companies. From the occupational hygienists' point of view, Australian workplaces may not be well-prepared for the likelihood of increasing heat stress due to climate change.

Conclusions

Findings from this study will provide essential epidemiological evidence for policy makers and relevant stakeholders to develop regulations and guidelines locally and /or internationally to reduce the impacts of extreme heat on workers' health and safety, particularly in the susceptible subgroups identified. Industrial specific workplace hot weather alerts and response mechanisms need to be developed via multi-sectoral cooperation between stakeholders to improve vulnerable groups' risk perceptions and knowledge about harm minimisation strategies during extremely hot weather. In a warming climate, there is a need to develop specific and clear enforceable heat regulations to ensure the implementation and compliance of heat policies.

DECLARATION

I certify that this work is original and contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and brief, contains no material previously published or written by another person, except where due acknowledgement is made in the text. No part of the work will be used in a submission for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the join-award of the degree except where due reference has been made in the text.

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ACKNOWLEDGEMENT

First and foremost I would like to express my heartfelt gratitude to my supervisors Professor Peng Bi, Professor Dino L. Pisaniello, and Dr Alana Hansen, all of whom provided much appreciated continuous help, encouragement and guidance. I consider myself very lucky to have such a wonderful and supportive supervisory panel, and very fortunate to be part of our warm research team. I would also like to thank all members of the Thesis Writing Group, the other academic and professional staff, and fellow PhD students of the Discipline of Public Health for their support throughout the candidature.

Appreciation is extended to SafeWork SA for providing workers' compensation claims data, especially Mr. John Horrocks and Ms. Shelley Rowett's assistance in data delivery, collation and variable interpretation. Beyond that, I am also thankful to SafeWork SA for helping me to invite potential employers to participate in the heat stress questionnaire survey. I would also like to thank TAFE SA and the Australian Institute of Occupational Hygienists Inc. (AIOH) for their generous assistance in the distribution of questionnaires. All survey participants and employers getting involved in this research are greatly appreciated for their contributions.

My sincere thanks also go to Mr. Thomas Sullivan (DMAC, University of Adelaide), Mr. Graeme Tucker and Dr Monika Nitschke from SA Health, Dr. Sue Williams, Dr. Ying Zhang, and Dr. Murthy Mittinty for their helpful assistance in solving the many methodological problems encountered.

My PhD candidature was funded by the China Scholarship Council and the University of Adelaide through a joint postgraduate scholarship program.

Thanks are extended to my friends for providing support and friendship that I needed, and particularly to Mr. Andrew Bain, Ms Jennifer Cooper, Xue Qin, Sisi, Maoyi Xu, Ting Xia, Yanyan Kong, Shurong Han, Hui Li, Jimin Xiong, Tongzhe Bi, Yun Li, and Tao Zhang. Last but certainly not least, I wish to thank my hardworking parents and my two lovely younger sisters. Their love provided my inspiration and was my internal driving force throughout the journey.

Jianjun Xiang

INTRODUCTION

The relationship between high temperatures and population health has been well documented after a series of severe extreme heat events occurred in the past decades, particularly in Europe,[1] North America,[2-7] and Australia.[8-12] Epidemiological evidence suggests that extremely hot weather may contribute to excess morbidity and mortality,[5-9, 11-18] particularly among the elderly, patients with chronic diseases and those taking certain medications. Physically active workers are also vulnerable during extreme heat.[19-21] Short-term acute extreme heat exposure may disrupt core body temperature balance and result in heat-related illnesses.[22] Adverse long-term health effects of chronic workplace heat exposure have also been reported.[23-26] Moreover, working in hot environments can increase the risk of occupational injuries and accidents.[21, 27-29]

Heat exposure is a common physical hazard in the workplace. 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 heat. With the predicted increase in the frequency and intensity of extremely hot weather,[30-32] weather-related heat exposure is presenting an increasing challenge for occupational health and safety.[19-21, 33] In recent years, there has been a growing concern in the literature about the impact of heat-related events on workers' health and safety,[19-21] and its importance has been addressed in the 2007 Intergovernmental Panel on Climate Change assessment report[30] and reiterated in the recently released 2014 report.[34]

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.[35] In particular, for workers undertaking manual work outdoors or around heat sources, “dangerous days” (days when there is a 2.5℃ increase of body temperature in less than 2 hours) are predicted to increase to 15-27 days per year by 2070 compared to 1 day per year at present according to one Australian study.[36] The 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℃ in SA compared to 0.13℃ per decade nationally.[32] According to the weather projections for Adelaide, the capital of SA, the average number of days with temperatures over 35℃ and the frequency of heatwaves will triple by 2070.[32]

Although South Australians are likely acclimatized to extreme heat, several studies in Adelaide have found that heatwaves were associated with excess mortality and significant increases in hospital admissions and ambulance call-outs.[8, 11, 12, 17, 18] It is not known if findings from community-based studies extend directly to occupational health risks and outcomes. Indeed, heat vulnerability in the general population and heat vulnerability in the workforce are not mutually exclusive, as sensitive sub-groups in the community are also part of the working sector.[37] However, occupational heat exposure may be more hazardous than community exposure as the individual has less control over the work environment and activities, due to workplace disciplines, work nature and demands, and personal motivation. And few studies have specifically examined the potential differences in the impact of extreme heat on workers’ health as compared to that in general population.[37]

Workers are a relatively research-neglected and possible heat vulnerable sub-population according to the published literature.[19-21, 37] Exposure to environmental heat may be a significant but overlooked occupational hazard.[37] However, in Australia heat stress has not been listed to date as a national occupational health priority.[38 39] As the direct outcomes of heat exposure, the incidence and characteristics of occupational heat illnesses in Australia still remains unknown. Moreover, it should be noted that the potential impact of accidents and injuries due to heat exposure may represent a greater risk than heat-related illnesses itself.[20, 33, 40] In addition, cognitive and physical performance decrements can occur at heat exposure levels lower than those causing heat illnesses and injuries,[41] which may result in reduced hourly work capacity and economic productivity.[20, 42-46] Therefore, working in a hot environment is not only a matter of occupational health and safety, but also an area involving all levels of society economically: individual, family, community, regional, and national levels.[40, 47] In the past decades, studies about occupational health impacts of heat exposure mainly focused on workplace-generated heat exposure such as in foundries, mining and metal plants. Research related to estimating the effects of weather-related extreme heat exposure on workers' health and safety is relatively limited.

So far Australia has not released clear regulations specifying standards for maximum temperatures in the workplace,[19] leaving some employment sectors at high risk of heat-related illnesses and injuries.[46, 48] By contrast, two States (California[49] and Washington DC[50]) in the USA and some other countries such as China[51] have implemented specific strict heat regulations in recent years. Moreover, International Organization for Standardization (ISO) is also considering updating some heat standards in the context of climate change.[52] Therefore, intensified research on the potential impact of high ambient temperatures on workers' health and safety is increasingly essential for local heat prevention policy development, heat stress control, and evidence-based effective interventions. In addition, research on the characterization of work-related injuries occurring during high temperatures may fill a significant gap in injury research. It may also be helpful for the fulfilment of the Australian Work Health & Safety Strategy 2012-

2022 national targets and performance indicators: i.e. at least 20% reduction of worker fatalities due to injury and 30% reduction of serious injury claims.[38]

Heat-related illnesses and injuries are preventable. Current heat prevention strategies include engineering control, administrative control, personal protection, education and training, and regulations.[53, 54] Effective heat stress control and management needs comprehensive efforts, cooperation, and support from a wide variety of stakeholders such as employees, employers, decision makers, managers, and occupational hygienists, physicians, and nurses.[55, 56] An investigation of how people perceive the risk of workplace heat exposure may be helpful to identify potential heat prevention and adaptation barriers existing in the workplace, and to develop current heat policies to make them more practicable and operational. However, currently few studies have investigated the perceptions of workplace heat exposure in Australia.

The aim of this thesis was to fill the research gaps in knowledge about the health effects of occupational heat exposure, and provide valuable scientific evidence for policy-makers and occupational health and safety practitioners and officers to inform the development of heat-related regulations and guidelines for heat prevention and adaptation in a warming climate.

This thesis is formulated in four sections. Section I comprises two chapters, the first of which is a comprehensive literature review on the following four aspects: characteristics of health impacts of workplace heat exposure on selected susceptible occupations, heat vulnerability factors, perceptions of workplace heat exposure among different stakeholders, and current heat-related regulations in Australia and overseas. The first Chapter concludes with a discussion of published literature in occupational heat exposure and research gaps identified. The second Chapter of

Section I outlines the aims and objectives of this study, research questions, framework of this study and methodologies used.

Section II comprises four chapters, with the major aim of assessing the underlying impact of extreme heat exposure on the health and wellbeing of the Australian workers at the population level using workers' compensation claim data. Chapter 3 describes the epidemiological distribution characteristics of workers' compensation claims reported in South Australia during 2001-2010, and paves the way for the analysis of heat exposure and work-related illnesses and injuries. Chapter 4 investigates the characteristics of occupational heat illnesses, the incidence rates of occupational heat illnesses by industry and occupation, and the impacts of extreme heat on occupational heat illnesses. Chapter 5 mainly focuses on the quantitative association between ambient temperature and work-related injuries, while Chapter 6 seeks to estimate the effects of consecutive high temperature days (heatwave) on workers' health and safety, to identify who are most vulnerable to extreme heat, and to examine which types of work-related illnesses and injuries are associated with extreme heat exposure.

The theme of Section III is the perceptions of workplace heat exposure. Chapter 7 aims to investigate how workers perceive the risk of heat exposure and what prevention measures have been adopted in the workplace, and to identify potential heat prevention barriers existing in the workplace. Chapter 8 provides occupational hygienists' views on heat stress management and current preparedness for the likelihood of increasing hot weather.

Section IV comprises Chapter 9, concluding the thesis with a summary of the previous chapters highlighting the key findings, research strengths and limitations, the public health significance of this work, policy implications and suggestions for future research.

SECTION I

LITERATURE REVIEW AND STUDY DESIGN

Introduction

This first section of the thesis, comprising two chapters, provides a general background and outline to the relevant issues whist providing a basis for the main study.

Chapter 1 is a comprehensive literature review of recently published international and Australian studies and relevant regulations concerning workplace heat exposure and workers' health and safety. This chapter has been organized into six parts. Part 1.1 is a brief summary of the impact of heat exposure on workers' health and safety. Part 1.2 mainly presents a review of the characteristics of workplace heat exposure in selected relatively high risk occupations. Part 1.3 includes a review of the major heat vulnerability factors. Part 1.4 is a second literature review summarising published studies regarding workers' knowledge, attitudes, and behavioural changes towards heat exposure and relevant stakeholders' perceptions on the impact of a warming climate on workers' health and safety. Part 1.5 provides an overview of heat prevention methods and strategies, and includes a literature review (Part 1.5.3) of the heat-related regulations, policies and guidelines currently in place in Australia and overseas. Finally, research gaps in the international and Australian literature are identified, confirming there is a need to estimate the impact of extreme heat on workers' health and safety at a population level, understand heat perceptions of stakeholders, and develop heat prevention strategies that are relevant currently and in the future.

Chapter 2 gives a general outline of the study design complete with aims and objectives, research questions, the general framework of the study, the climatic and demographic characteristics of the study region, and a justification of the chosen study method such as time-series analysis with generalized estimating equations models and case-crossover analysis.

Chapter 1

Literature review

1.1 Effects of heat exposure on OH&S

Working in hot environment is a common physical hazard. Physiological impacts of heat exposures on human health have been well documented for decades.[22] The human body can maintain the internal heat balance through heat adjustment mechanisms including evaporation of sweat, conduction, convection and radiation. There are six fundamental factors influencing thermal comfort both environmentally and personally, including air temperature, radiant temperature, wind speed, relative humidity, work demands, and clothing insulation.[53, 54] The combined effect of external heat exposure and internal metabolic heat production can produce thermal stress on the body. The body's physiological response to that stress, such as sweating, increased heart rate and elevated temperature, can produce heat strain.[53, 54]

Without adequate heat dissipation, short-term acute extreme heat exposure can cause a rise in core body temperature and may result in direct heat illnesses, ranging from mild heat rash, heat cramps, heat exhaustion, to life-threating heat stroke. Adverse long-term health effects of chronic workplace heat exposure have also been reported such as cardiovascular diseases,[24] mental health problems,[57, 58] and chronic kidney diseases.[25, 26] In addition to work-related illnesses, working in hot environments can also increase the risk of occupational injuries and accidents.[20, 21, 27-29] Core temperature elevation and dehydration have had negative behavioural effects such as physical fatigue, irritability, lethargy, impaired judgment, vigilance decrement, loss of dexterity, coordination and concentration,[20, 59] and reduced visual acuity,[60] which may lead to a compromise of work efficiency, occupational safety, and productivity loss.[20, 42, 44, 61-63] Therefore, the adverse impact of extreme heat on occupational health and safety is an area which may have consequences for all levels of society: individual, family, community, regional, and national levels,[20, 40] as summarized in Figure 1.1.

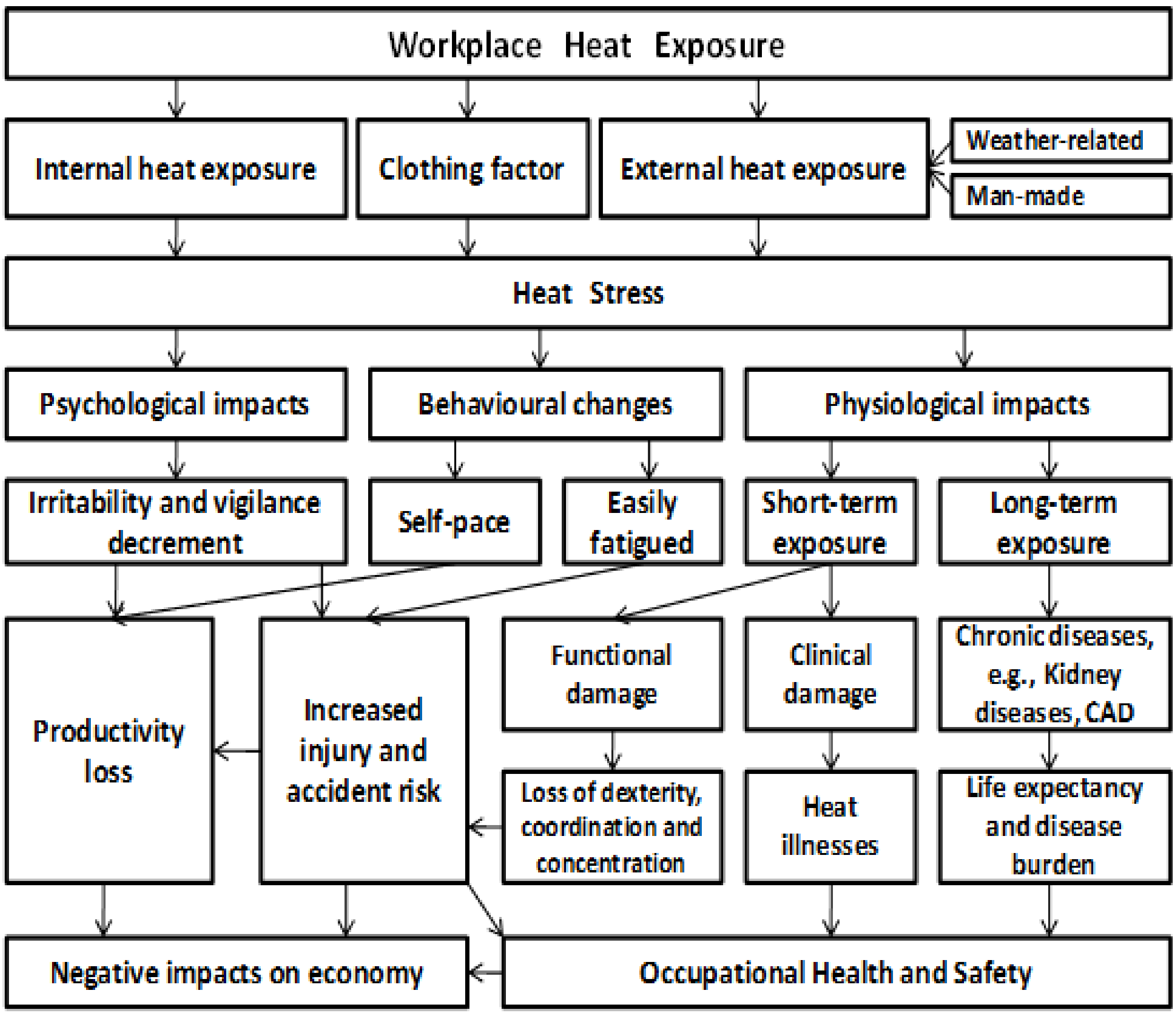

Figure 1.1 Conceptual framework of the relationship between workplace heat exposure and its impact (adapted from Schutle et al[21])

1.2 Health impacts of workplace heat exposure on selected susceptible occupations: an epidemiological review

A literature review was conducted to summarize the body of literature concerning the health impacts of workplace heat exposure. As concerns over the environmental heat-related impacts of climate change on population health have been raised since the late 1990s,[64] relevant literature in English for the period of January 1997 to January 2014 was retrieved utilizing the searching strategy of random combinations of the first keywords [tiab] AND the second keywords [tiab]. The term 'tiab' is the abbreviation of 'title or abstract'. All academic articles containing search keywords in the title or abstract would be retrieved. The keywords used for the searching strategy of random combinations of the first keywords [tiab] AND the second keywords [tiab] included "climate change, heat stress, heatwaves, heat exposure, extreme heat" and "workplace, work-related injury, workers, occupational health and safety". Literature databases used for this review ranged from PubMed (biomedical sciences), Scopus, ScienceDirect, and Google Scholar. Only original research articles published in English in peer reviewed journals were included, whereas review articles, editorials, letters, conference abstracts, and government reports were excluded.

Figure 1.2 shows the process of selection of articles for inclusion in this subheading. Out of 289 identified articles, 64 were finally included in the review, with 13 articles (20%) being surveillance data analyses (ecological studies), 41 articles (64%) being cross-sectional studies, 6 articles (9%) being epidemiological experiments, and 4 articles (6%) being cohort studies, as presented in Table 1.1 and 1.2 respectively.

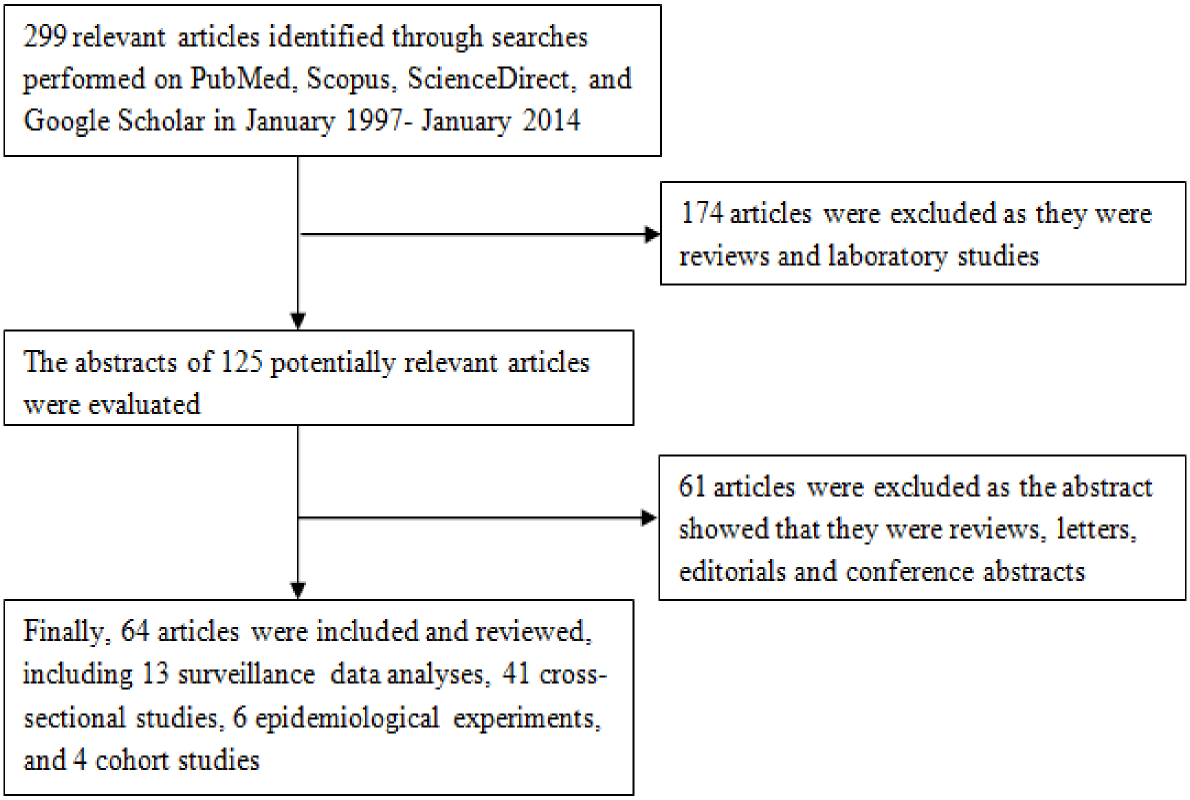

Figure 1.2 Process of selection of articles for reviewing health impacts of workplace heat exposure

1.2.1 Overview of published epidemiological studies on workplace heat exposure

As shown in Table 1.1, all 13 surveillance data analysis articles (ecological studies) were studies from high income countries with over half from the USA, 3 from Australia, and 1 each from Germany and Italy. In terms of data sources, about 50% of studies were based on government surveillance data, and the remaining 50% were based on hospital or workplace daily records. Only 3 studies explored the relationship between temperatures and work-related illnesses and/or injuries, using Poisson regression analysis. Others simply described the distribution of heat-related illnesses over time periods.

As shown in Table 1.2, of the 51 studies (cross-sectional, experimental, and cohort studies), there were 24 (47%) articles for outdoor workplaces, 21 (41%) for indoor workplaces, and 6 (12%) for mixed workplaces. Approximately 25(49%) studies involved process generated heat. In terms of region, most studies were carried out in the tropical zones, with 21 (41%) studies from South and Southeast Asia, 12 (24%) from America, 8 (16%) from the Middle East, 7 (14%) from Australia, and 3 (6%) from Europe. A range of heat indices were used with 25 (49%) studies using Wet Bulb Globe Temperature (WBGT), 8 (16%) using subjective heat stress and 7 (14%) using air temperature. Thirty four (79%) of the studies indicated that participants were suffering from heat strain, with outdoor workplaces (90%) being much higher than indoor workplaces (65%). In terms of gender, 45% of studies focused on male workers only. In contrast, one study from India targeted only female workers. In addition, only 3 studies utilized qualitative research methods.

Overall, in terms of occupation classification, 20% of the 64 identified articles focused on manufacturing workers in steel and foundry industries, followed by miners (18%), mixed manual workers (16%), construction workers (13%), farmers (13%), and armed forces personnel (5%). In a majority of those studies, survey data were collected using self-administered[57, 65-67] or interviewer-administered questionnaires.[62, 68]

1.2.2 Characteristics of heat exposure in selected relatively high risk occupations

The characteristics of workplace heat exposure may vary in different occupations. The impacts of heat exposure can be particularly harsh on outdoor workers such as those in the agriculture, construction, mining and manufacturing industries as well as the armed forced personnel and fire-fighters as discussed in detail below.

Table 1.1 Summary of findings from surveillance data analysis articles on workplace heat exposure published during January 1997-January 2014

Data sources	Country	Data period	Target workers	Heat indices	Statistical analysis	Relationship between temp and occupational injuries/illnesses
The Australian Institute of Health and Welfare [57]	Australia	2003-2004	Athletes	Not used	Descriptive analysis	Not analysed
Hospital discharge data, New South Wales, Australia [69]	Australia	2001-2004	Athletes	Not used	Descriptive analysis	Not analysed
The medical centre of deep underground metal mine in Australia [70]	Australia	1997-1998	Miners	Dry bulb temp and WBGT[1]	Descriptive analysis, U test	Not analysed
Hard coal mines in the Ruhr district, Germany [71]	Germany	1995-1999	Miners	Basic effective temp	Multivariate linear regression	U-shaped curve
Admission records of 5 hospitals, Central Italy [27]	Italy	1998-2003	All workers	Apparent temp	Poisson regression	Reversed U-shaped curve
The Washington State Department of Labour and Industries' State Fund, USA [72]	USA	1995-2005	All workers	Not used	Descriptive analysis	Not analysed
The Agricultural Safety and Health Bureau of the North Carolina Department of Labour, USA [73]	USA	1992-2006	Farmers	Not used	Descriptive analysis	Not analysed
The US Bureau of Labour Statistics (BLS) Census of Fatal Occupational Injuries (CFOI) [74]	USA	2003-2008	Farmers	Not used	Descriptive analysis	Not analysed
An aluminium smelting plant, USA [28]	USA	1997-1999	Foundry workers	Dry bulb temp	Poisson regression	U-shaped curve
The US National Institute for Occupational Safety and Health Website [75]	USA	1983-2001	Miners	Not used	Descriptive analysis, U-test, z-test	Not analysed
Total Army Injury and Health Outcomes Database, the US Army Research Institute[76]	USA	1980-2002	Soldiers	Not used	Poisson regression	Not analysed
The Centre for Accession Research, US Army Accession Command [77]	USA	2005-2006	Soldiers	Not used	Multiple logistic regression	Not analysed
The Maricopa County Department of Public Health, Arizona, USA [78]	USA	2002-2009	All workers	Not used	Multiple logistic regression	Positive

[1]WBGT denotes wet bulb globe temperature.

Table 1.2 Summary of epidemiological studies of workplace heat exposure published during January 1997-January 2014

Target workers	Country	Sample size	Gender	Study design	Indoors or outdoors	Heat stress indices
All workers [57]	Thailand	40,913	Both	Cohort	Both	Subjective symptoms
All workers [25]	Thailand	37,816	Both	Cohort	Both	Subjective symptoms
All workers [79]	Thailand	58,495	Both	Cohort	Both	-
All workers [80]	Nepal	120	Both	Cross-sectional	Both	WBGT, HI[3], Humidex
Airport ground servicers [81]	Saudi Arabia	-	-	Cross-sectional	Outdoor	WBGT
Construction workers [66]	Japan	319	Male	Cross-sectional	Outdoor	WBGT
Construction workers [82]	UAE[1]	150	Male	Cross-sectional	Outdoor	TWL[2]
Construction workers [83]	India	11	Female	Cross-sectional	Outdoor	WBGT
Construction workers [84]	Thailand	108	Both	Cross-sectional	Outdoor	WBGT
Construction workers [85]	UAE[1]	22	Male	Cross-sectional	Outdoor	TWL[2], dry bulb temp
Construction workers [86]	Japan	12	Male	Cross-sectional	Outdoor	WBGT
Construction workers [87]	UAE[1]	44	Male	Cross-sectional	Outdoor	-
Construction workers [88]	Iran	60	Not indicated	Cross-sectional	Outdoor	TWL, USG[4]
Cooks [89]	Japan	12	Male	Cross-sectional	Indoor	WBGT
Cooks [90]	Japan	809	Both	Cross-sectional	Indoor	WBGT
Cooks [91]	Japan	16	Male	Cross-sectional	Indoor	WBGT
Farmers [92]	USA	300	Both	Cross-sectional	Outdoor	Subjective symptoms
Farmers [93]	USA	405	Both	Cross-sectional	Outdoor	Subjective symptoms
Farmers [94]	Costa Rica	42	Male	Cross-sectional	Outdoor	Dry bulb temp
Farmers [95]	Costa Rica	105	Male	Cross-sectional	Outdoor	WBGT
Farmers [96]	India	26	Male	Cross-sectional	Outdoor	WBGT
Farmers [97]	Costa Rica	17	Not indicated	Cross-sectional	Outdoor	Subjective symptoms
Fire fighters [98]	Canada	37	Both	Experimental	Outdoor	Dry bulb temp
Fire fighters [99]	Canada	40	Both	Experimental	Outdoor	Dry bulb temp
Fire fighters [58]	USA	16	Male	Experimental	Outdoor	Dry bulb temp
Fire fighters [100]	Australia	15	Male	Experimental	Outdoor	Core and skin temp

Forestry workers [101]	Japan	125	Both	Cross-sectional	Outdoor	Subjective symptoms
Manufacturing workers [102]	UAE[1]	275	Not indicated	Cross-sectional	Indoor	WBGT
Foundry workers [103]	USA	31	Not indicated	Cross-sectional	Indoor	WBGT
Aluminium smelter [104]	USA	61	Both	Cross-sectional	Indoor	Core temp, heat rate, USG[4]
Manufacturing workers [105]	India	-	-	Cross-sectional	Indoor	WBGT
Manufacturing workers [106]	India	-	-	Cross-sectional	Indoor	WBGT
Manufacturing workers [24]	Bulgaria	102	Male	Cohort	Indoor	WBGT
Manufacturing workers [107]	India	-	-	Cross-sectional	Indoor	WBGT
Manufacturing workers [108]	India	242	Not indicated	Cross-sectional	Indoor	Subjective symptoms
Mine rescue workers [109]	USA	-	-	Cross-sectional	Indoor	WBGT
Mine rescue workers [110]	Germany	52	Male	Cross-sectional	Indoor	Basic effective temp
Miners [111]	Germany	38	Male	Cross-sectional	Indoor	Basic effective temp
Miners [112]	Australia	362	Not indicated	Cross-sectional	Indoor	WBGT, TWL[2]
Miners [113]	Australia	39	Male	Cross-sectional	Indoor	WBGT, TWL[2]
Miners [114]	Australia	36	Male	Cross-sectional	Indoor	WBGT, TWL[2]
Miners [115]	Australia	45	Male	Cross-sectional	Indoor	WBGT, TWL[2]
Mixed manual workers [116]	South Africa	151	Both	Cross-sectional	Outdoor	Subjective symptoms
Mixed manual workers [62]	Thailand	21	Both	Cross-sectional	Both	WBGT
Mixed manual workers [117]	UAE[1]	186	Male	Cross-sectional	Both	USG[4]
Mixed manual workers [118]	Australia	29	Male	Cross-sectional	Outdoor	Dry bulb temp
Garbage collectors [119]	Japan	10	Male	Cross-sectional	Outdoor	Dry bulb temp, heart rate
Soldiers [120]	Australia	64	Male	Experimental	Outdoor	WBGT
Steel workers [121]	Israel	3507	Both	Cross-sectional	Indoor	Dry bulb temp
Steel workers [122]	Taiwan, ROC	55	Male	Cross-sectional	Indoor	WBGT
Steel workers [123]	Brazil	8	Male	Experimental	Indoor	WBGT

[1]UAE: United Arab Emirates; [2]TWL: thermal work limit; [3]HI: heat index; [4]USG: urine specific gravity.

1.2.2.1 Agricultural workers

Agriculture is one of the industries at highest risk of heat-related illness and injury.[21, 63, 124] Farmers are often exposed to outdoor heat extremes for long periods, and often there is a lack of occupational health and safety programs to protect them. In the USA, agricultural industries have the third highest rate of heat-related deaths among all industries, with the mortality rate approximately 20 times greater than for all civilian workers.[74] In terms of heat-related morbidity, farmers have been shown to be four times more likely than non-agricultural workers to suffer from heat-related illnesses in the USA.[125]

Currently, published literature assessing farmers' heat stress status is limited. Mirabelli identified that 161 heat-related fatalities occurred from 1977 to 2001 in North Carolina by reviewing medical records, and found that 45% occurred among farmers.[126] In another study by the same author, it was found that approximately 94% of farmers reported working in extreme heat, among which 40% experienced heat stress related symptoms.[92] At the time no regulations and prevention measures were available for preventing heat exposure. A study of 124 Japanese forestry workers showed that 32.3% had reported symptoms of heat illness.[101] Additionally, agricultural workers in some low-middle income countries may be at relatively higher risk of heat exposure, due to the low levels of mechanized farming and motivation by payment based on work output.[94]

1.2.2.2 Construction workers

In the building industry, several contributing factors increase the risk of heat-related illness and injury. These include the constant use of machinery and powered tools, working on elevated surfaces, heavy workload, simple accommodation conditions near work sites, being temporarily employed by a sub-contractor on a daily payment basis, and constant and direct exposure to sunlight.[63, 127] From 2003 to 2008, the US Census of Fatal Occupational Injuries recorded 196 heat-related mortalities, and construction workers occupied the greatest proportion (36%).[74] A self-administered questionnaire among 115 Japanese male construction workers in summer demonstrated that in terms of heat-related subjective symptoms, up to 63.7% of workers reported 'feeling thirst' at work, followed by 42.2% reporting it was 'easy to get fatigued', 41.2% reported 'waking up early due to hot conditions', 31.9% reported 'impatience', 13.2% 'headache', and 11.8% 'dizziness'.[66] Those symptoms are consistent with the hypothesis that heat exposure may increase the risk of occupational accidents and injuries. In Taiwan[63] and Thailand,[84] temporarily self-employed construction workers reported suffering from severe heat strain because of physically demanding work and hot living conditions in dormitories near construction sites.

However, if preventive measures are sufficient on building sites, workers could reduce heat-related symptoms. A cross-sectional study has been conducted among 12 male workers in a Japanese hydroelectric power plant building site with WBGT often exceeding the recommended exposure limit values on a typical hot day in summer.[86] However, there was no significant change in subjective symptoms, serum electrolytes, blood pressures and heart rates before and after work, because preventive measures had been taken. These included temporary tents for rest, electric fans for ventilation, and automatic machines for cool drinks. However, there should be caution in the interpretation of the results because of the small sample size and the fine weather conditions during the two day investigation period. Apart from common preventive measures, self-pacing (self-adjustment of work rate) can also be an effective way of reducing the risk of heat-related illness and injury as reported in a study of construction workers in the United Arab Emirates.[85]

1.2.2.3 Miners

Hot working conditions in mines are very common and vary according to the type of mining. For open-cut mines, heat exposure is similar to other outdoor workplaces. However, by far the most problems of heat stress have been reported from underground mines as additional heat from virgin rock and mines increase with depth. Furthermore, air auto-compression for ventilation adds about 6℃ dry bulb temperature per 1000m of vertical depth.[113] High humidity from water required for dust control also contributes markedly to the thermal load. The incidence of heat illness in underground mines has been reported to be higher for metal mining than for coal mining as underground metal mines are usually much deeper than coal mines in the USA.[75] One study of miners in Australia showed that the incidence rate ratio of heat exhaustion for deep mines below 1200 m compared with above 1200 m was 3.17.[70]

According to the 1983-2001 data from the US National Institute for Occupational Safety and Health, most heat illness cases in mines occurred during dayshift hours rather than night shift hours.[75] This is to be expected for surface mining given the higher air temperatures during the day. But for underground mining, there is lack of convincing reasons for more heat illnesses during dayshift hours even after considering the greater proportion of dayshift workers than nightshift workers, because there is no significant change in temperatures in underground mines between day and night due to thermal damping effects.[70] Brake and Bates[114] suggested that the normal diurnal variation of body internal temperature, which is relatively lower at night, may contribute to the lower risk of heat illness on night shift. The effects of seasonal change on underground temperatures decrease with the increase of mining depth. Hence, heat illnesses may occur throughout the year and with less incidence rate in non-warm seasons. As expected, most heat illnesses have been reported in summer seasons.[70, 75] Therefore, surface temperature forecasts can also be useful for warning miners and management about the risk of heat illnesses.

In some low-middle income countries miners with heat illness symptoms may still keep working in extremely hot environments due to relatively low perceptions of prevention strategies, lack of protective measures, and income incentives, which may result in the occurrence of life-threatening heat strokes. In South African deep underground gold mines, for instance, heat stroke has been a serious occupational hazard since before the 1970s. In recent years due to acclimatization and prevention measures, the incidence rate of heat stroke has been declining significantly.[68] The occurrence of heat stroke is reportedly relatively rare currently but still remains unresolved.

In high income countries heat stroke cases are seldom reported in mining industries. In an Australian deep underground mine with about 2 000 miners, no heat stroke cases had been reported to the 24-hour on-site medical clinic during over 10 million work shifts in the period 1966-1997.[114] Similarly, there were no cases of heat strokes reported in 1983-2001 in the USA mining industry.[75] Several reasons may contribute to the few occurrences of heat stroke cases in high income countries. Firstly, this may be attributed to a flexible management approach and the resistance of miners to continue strenuous labour in severe thermal conditions. Secondly, most miners are presumably well-trained about the effects of working in heat. Thirdly, in high income countries miners suffering heat-related illnesses generally report their conditions actively and cease mining.[70] Finally, adverse health effects may be averted because of self-pacing.[111] Miller et al even suggest that self-pacing should be encouraged as a protective behaviour without productivity compromise in the mining industry,[82] as nowadays many tasks in mining are highly mechanized and a reduction of work load may not necessarily result in productivity loss.

1.2.2.4 Armed forces personnel

Most epidemiological studies on military personnel have focused on specific military bases for relatively short periods and with relatively small populations.[77] At present, heat-related morbidity and mortality analyses of military personnel data are based on consulting military hospital records.[76, 128, 129] Over time there has been a downward trend of heat illness hospitalization rates due to preventive measures in the USA Army.[76] The total number of hospitalizations for heat illness reduced by 60% in the 22-year period of 1980-2002.[76] However, heat stroke rates have markedly increased eightfold.[76] The possibility is that preventive measures might allow compromised soldiers to avoid minor heat illnesses and continue to exercise until more severe heat stroke occurs.

Overall, almost 60%-70% of heat illness cases in the USA military during the period of 1980-2002 were reportedly due to heat exhaustion and 13%-18% for heat stroke.[76] The percentage of mild heat illnesses is small as individuals may recover rapidly in the field without being hospitalized. Infantry soldiers had the greatest risk of heat illness in the USA in the period 1980-2002,[76] whereas soldiers in administrative and support jobs had the lowest risk. In addition, ethnicity, gender, fitness level, and geographical origin are related to heat illness occurrence in military populations. Caucasians are more vulnerable to heat illness than African Americans and Hispanic Americans.[76] Soldiers from northern USA are more susceptible to heat illness that those from southern USA, and female soldiers are at greater risk of heat illness than male soldiers.[76] In Australia, there has been no such report due to data availability.

1.2.2.5 Fire-fighters and other emergency workers

Fire-fighters are required to wear fire-fighting protective clothing and self-contained breathing apparatus regardless of environmental temperatures. This personal protective equipment can reduce the effect of heat dissipation and increase the risk of heat stress. Recently, based on simulated trials among 70 volunteers recruited from the Toronto Fire Service, the replacement of the duty uniform long pants and shirt, with shorts and T-shirt has been recommended by McLellan and Selkirk[98, 99] who claim it could significantly reduce heat strain and extend at least 10-15% heat exposure time. However, it raises concerns about whether the replacement of long pants with shorts may put fire-fighters at greater risk of injury. Evidence from the New York City Fire Department proved that not only were the burn incidence and severity not affected when wearing shorts instead of long pants, but also the days lost due to heat illnesses were significantly reduced.[130]

In a simulated fire-fighting drill among 16 male fire-fighters from a Fire Service Institute in the USA, higher blood lactate levels, longer recovery time, and significantly increased heart rate and core temperature were observed after performing tasks in a live fire environment than after performing the same tasks in a non-fire environment.[58] In the same study it was shown that psychological impacts of emergency conditions are also a problem for fire-fighters. A dramatic increase of anxiety level immediately following firefighting activities was found.[58] Elevated anxiety status may impact on cognitive performance, resulting in inappropriate decisions that might increase of risk of injury. Interestingly, the relationship between perceptions of heat illness and heat strain varies by thermal conditions. In non-hot conditions, the correlation coefficient between perceptions of heat illness and heat strain was moderately positive, however, there was little relationship in hot conditions. If perceived risk of heat illness is underestimated, fire-fighters may put themselves at greater risk. But there is a probability that the results may be prone to information bias if participants were unwilling to report their real feelings because of peer pressure.[58]

In addition, evidence has shown that outdoor workers in "electricity, gas and water" are at high risk of heat strain[131, 132] and occupational burns.[133] Due to the nature of work, sometimes workers in this industry have to work even during extremely hot weather to ensure the continuous supply of electricity, gas, and water. Moreover, pipe failure rates in Australia and electric power outage rates in the USA in summer were reportedly about 200% and 85% respectively higher than that in other seasons,[134, 135] indicating a potential increased work load in summer for outdoor utility maintenance workers in this industry. However, there is no research to examine the impact of extreme heat on heat-related illnesses and injuries recorded in this industry at a population level, using occupational health and safety surveillance data.

1.2.2.6 Manufacturing workers

Manufacturing workers in non-air conditioned indoor workplaces are also at risk of heat-related illness despite little or no direct sunlight radiation. The levels of heat stress can be very high in workplaces surrounding hot machines, furnaces, ovens, and molten metal. Even in winter, the temperatures near furnaces in a steel plant have ranged from 35.5 to 46.5℃ when the outdoor temperature was only 14-18℃.[122] Summer hot days may worsen the extent of heat stress for individuals working around heat generating sources. Hence, many epidemiological studies have focused on the impacts of workplace-generated heat on factory workers in steel plants,[28, 123] foundries,[24] automobile industries,[107] and glass manufacturing units.[106]

Excessive industrial heat exposure is associated with dyslipidemia,[24] cardiovascular and digestive diseases.[136] However, a cohort study in a French stainless steel producing plant showed that cardiovascular disease mortality was 10% lower for the workers exposed to heat than for a control group that was not exposed.[137] The negative relationship between heat exposure and mortality may result from the 'healthy worker effect' due to the stringent selection criteria when recruiting workers.

1.3 Personal vulnerability factors of workplace heat exposure

The likelihood and severity of heat strain experienced by an individual worker for a given level of heat stress depends on the physiological capacity to respond to heat exposure. Personal risk factors of heat strain are those elements that may reduce an individual's heat tolerance. A previous history of heat illnesses is a critical factor for heat tolerance.[54] Other risk factors include age, gender, lifestyle, acclimatization, medical conditions, and ethnicity, as summarized below.

1.3.1 Age

Previous literature has shown that physiologically, middle-aged men and women are more heat intolerant than younger individuals in general according to a heat tolerance test.[138] However, in the workplace, epidemiological studies have found that younger workers seem to be more likely to suffer from heat-related injuries and accidents.[28, 72] The greater risk of experiencing heat-related illnesses for younger workers is likely due to undertaking more strenuous tasks, lack of safety training and working skills, relatively lower awareness of the risk of heat exposure, and presumably compromised self-pacing or /and work breaks because of peer or supervisor pressure.[139-141]

By contrast, many community-based studies have shown that elderly people are more vulnerable to extreme heat,[142-145] which may be attributable to the ageing-related thermoregulatory dysfunctions, and a higher prevalence of pre-existing heat aggravated chronic diseases.[14] Currently, few studies have particularly investigated which age groups of workers are more vulnerable to extreme heat at a population level. In 2004, Fogleman et al. found that older workers had a slightly higher injury rate than younger workers in an US aluminium smelting plant when the temperature exceeded 38℃, whereas younger workers showed consistently higher injury rates than older workers in all other thermal categories below 38℃.[28] Older male workers were also found to be at higher risk of heat-related deaths in the US agricultural workers.[78] Further research is needed regarding age-related variations in the vulnerability to heat-related injury/accident during extreme heat when developing new heat prevention policies or guidelines.

1.3.2 Gender

Women have a lower sweat rate than men, which is disadvantageous in hot-dry environments, but advantageous in hot-wet environments.[146, 147] Menstrual cycle effects on heat tolerance are minimal.[146, 147] One qualitative study conducted in South Africa has shown that women felt they could not cope with hot weather as well as men, especially when they had to undertake labour intensive work,[116] although the distinctions tended to disappear if cardiovascular fitness level, aerobic capacity, surface area-to-mass ratio, and the extent of acclimation were standardized.[53] When undertaking work of an emergency nature, women were found to be at greater risk of suffering from heat-related illnesses and injuries than their male counterparts.[148] More evidence is required to develop consensus views regarding gender differences for heat exposure.[149]

In terms of heat-related mortality in the general population, several studies have shown that women were found to be at higher risk in the general population during heatwaves.[143, 149-151] On the contrary, in the workplace male workers have found to be at higher risk of heat-related deaths than female workers,[73] as male workers are more likely to undertake outdoor physically demanding work with an inherently high risk of heat-related illnesses and injuries. In the period between 1992–2006, 68 crop workers died from heat stroke in the USA, and nearly all of the deaths were males.[73] Further industry/occupation specific research may be needed to clarify which gender is more vulnerable to extreme heat in the workplace, to identify whether it is necessary to develop special adaptation guidelines and practice.

1.3.3 The use of certain medications, drugs, and alcohol during extremely hot periods

Certain medications have been reported to be one of the possible causes of extra morbidity and mortality in the general population during heatwave periods.[152] The use of many prescription drugs and some over-the-counter medications require cautions when working in hot environments. Certain drugs can affect human body thermoregulation in different mechanisms: altered thermoregulatory mechanisms, drug administration-related fever, fever from the pharmacologic action of the drug, idiosyncratic reactions, and hypersensitivity reactions.[153] There are not only possible adverse effects of a single drug but also the interactions between multiple medications. Limited research has been conducted to investigate the prevalence of medications usage among workers particularly those working in hot environments. According to the statistics from Washington State, at least 22% of the 480 heat-related workers' compensation claims reported during the period of 1995-2005 involved medication use.[72]

As a central nervous system depressant, alcohol not only affects perception and judgment in high doses, but also reduces thermoregulatory responses in low doses including vasomotor and sweating reflexes, leaving working people more susceptible to heat-related illnesses and injuries.[154] The proportion of workers drinking alcohol may vary by regions and culture. Among Japanese construction workers, the prevalence of every day drinkers and heavy drinkers was 28.7% and 20%, respectively.[66] By contrast, the percentage of regular drinkers was about 5.0% in a Thai workplace according to a national cohort survey.[79] In Australia, according to the 2001 National Drug Strategy Household Survey, approximately 8% of the workforce drank at least weekly at short-term risky or high risk levels.[155] Nevertheless, it is necessary to incorporate the knowledge about the combined risks of alcohol consumption and heat exposure into heat stress education or training programs. The NIOSH and the US Department of Labour[156] also recommend that the information about individual use of alcohol and certain drugs should be included in pre-placement and periodic health assessments for workers exposed to heat in the workplace.

1.3.4 Acclimatization level

Heat acclimatization is a series of physiological changes allowing workers to withstand heat stress with a reduction in heat strain by the increased effectiveness and efficiency of heat dissipation.[157, 158] The time it takes for employees to adjust to the heat varies. It is estimated that most individuals adjust gradually to higher occupational heat levels in 4 to 14 days.[159] One study demonstrated that the majority of heat stress complaints were from new workers who were not acclimatized or limited to those who engaged in heavy work outdoor.[108]

Worker acclimatization is a requirement for heat prevention and is not compromised by rest breaks in air-conditioned settings.[54] However, it is very important to note that employees coming back from extended leave, new employees, or temporary contract labour from a cooler climatic region will not be acclimatized and also at high risk of heat-related illnesses and injuries[53] such as seasonal workers in Australia.[160] The effects of heat acclimatization can be decreased or nullified by sleep loss, infection, dehydration, and salt depletion.[55]

1.3.5 Pre-existing diseases

In the general population, pre-existing chronic diseases such as cardiovascular diseases have been found to be an important contributing risk factor resulting in excess mortality and significant increases in hospital admissions and ambulance call-outs during heatwaves.[143, 161] According to the Thai national cohort study investigating the association between heat stress and occupational injury,[79] 3.6% of the 58,495 workers had existing illnesses, which may be to some extent underestimated as about 70% of participants were less than 35 years of age. However, whether the presence of pre-existing diseases was a risk factor for heat-related illnesses and injuries in the workplace was not been analysed in the study. Currently, relevant epidemiological evidence is limited on this topic and more work is needed in this area.

1.3.6 Hydration state

Remaining well-hydrated is one of the most effective interventions to protect workers' health and safety when working in hot environments. The breakdown of human body water balance has been shown to elevate core temperature, adversely affect physical performance and coordination, and impair cognitive function.[162] As a result, dehydration may potentially result in an increased risk of injuries and accidents. Bates et al. have observed a consistent pattern of poor hydration status in workers employed in a range of industries in Australia and in the Middle East in the past decade.[85, 112, 113, 117] A study conducted among outdoor workers at aboveground mines in the Pilbara region of Western Australia in 2007, has shown that over 70% of the 710 workers' urine samples indicated that the workers were poorly hydrated, with 16% of the samples reaching a state of clinical dehydration.[112] Although results from other Australian studies varied,[113, 163] in almost all groups the mean hydration status assessed by urine specific gravity was inadequate, leaving a large proportion of workers being compromised in their ability to work safely in the heat.[164] A similar situation was found among construction workers in the United Arab Emirates[85, 117] and Iran.[88] The hydration status in some low-middle income countries may be worse, especially in the agriculture industry. In some Central American countries such as Nicaragua, up to 80% of sugarcane workers had signs of dehydration, with about 33% having severe dehydration.[165] A similar situation had been found in Costa Rican workers.[94, 97]

Education is a vital component to help workers maintain their hydration state. Some organizations such as the NIOSH have made recommendations regarding fluid intake and hydration, e.g. drink small amounts of water frequently, approximately 1 cup (250ml) every 15-20 minutes.[166] However, the recommended amounts may be either too much or too little,[164] as water deficits or dehydration levels vary greatly for individuals and between groups, depending on the environment, protective clothing, and work intensity.

1.4 Awareness and knowledge of workplace heat exposure

Literature review was also conducted with the aim of summarizing the current views and perceptions on heat exposure from different stakeholders. As mentioned previously, there is a growing concern on the effects of heat exposure on workers' health and safety in recent years,[19-

[21, 33, 37, 40, 167, 168] which is mainly driven by a changing climate. A better understanding of how people perceive the risk of heat exposure may provide implications for heat stress management. However, so far limited studies have investigated the perceptions of workplace heat exposure. For the literature review, the keywords used for the searching strategy of the first keywords [tiab] AND the second keywords [tiab] included “heat stress, workplace heat exposure, occupational heat exposure, heat illness” and “perceptions, attitudes, knowledge”. Only original research articles published in English in peer reviewed journals were included, whereas review articles, editorials, letters, conference abstracts, and government reports were excluded.

In total 8 papers investigating perceptions of workplace heat exposure were identified (Table 1.3). All applied cross-sectional study design, with half of them targeting farmers. The majority (6/8) of studies were qualitative studies involving interviews or focus group discussions. The data of two quantitative questionnaire survey studies were analysed using descriptive analysis and multivariate logistic regression.[169, 170]

1.4.1 Perceptions of heat among physical workers

Compared with the growing concerns on the impact of extreme heat on workers’ health and safety in academia, current awareness about the occupational health and safety in hot environment remains low in the workplace, according to interviews conducted among Indian industrial workers,[108] South African outdoor manual workers,[116] and Costa Rican sugarcane workers.[97] In the Mexican Immigration to California: Safety and Acculturation (MICASA) Study, more than 92% of 474 hired farmworkers were not at all or a little concerned about the risk of heat illness at work in 2008-2010.[169] This may be partly the reason why the US OSHA launched the Heat Illness Prevention Campaign in 2011 to raise awareness of heat exposure in the workplace.[171]

An Australian study showed that for outdoor workers, exposure to high temperatures during the hot summer months was regarded as 'routine'.[43] Similarly in southern India, heat exposure was considered as a 'common and general' occupational hazard.[108] This may indirectly reflect that workers in Australia and India were either well acclimatized to heat or had low heat risk awareness. To date few studies have investigated the factors affecting individuals' heat perceptions. In the MICASA Study, is has been found that females and individuals undertaking certain specific types of jobs or with longer duration of outdoor work experience in agriculture were more concerned about heat illnesses.[172]

In terms of knowledge about heat exposure, the majority of surveyed workers in the USA and South Africa knew the symptoms and severe outcomes of excessive heat exposure.[116, 169, 172] Inaccurate or incorrect answers were mainly in response to questions about heat acclimatization and medication use,[172] and the potential impact of climate change on occupational health and safety.[116] A minority of outdoor physical workers in South Africa thought that hot weather did not affect their health and safety.[116] Similarly in India, a study found most of the workers in the sectors of heavy truck and vehicle manufacturing were not aware of the consequences of heat stress.[108]

Evidence has shown that more concerns about heat stress do not necessarily result in more heat knowledge. In the MICASA Study, female farm workers were more concerned about the risk of heat exposure than male farmers; however, the latter had a significantly higher heat knowledge score.[169] In addition, workers' actual behaviours against heat in the workplace were not necessarily consistent with the level of heat knowledge. For example, the female Latino farm workers in the USA deliberately wore dark and tight clothes to induce sweating to lose weight;[173] Some male farm workers drank cool beers at work to help quench thirst, and some workers selected highly caffeinated energy drinks to increase alertness and productivity, although they realized that it may increase this risk of heat illness.[173] Therefore, it is important to understand the mutual interactions between heat awareness, knowledge, and behaviours to assure the effectiveness of heat prevention programs.

1.4.2 Awareness of workplace management personnel and relevant stakeholders

In South Africa, a study showed the majority of workplace supervisors agreed that physical work in the sun was strenuous and that hot environments made it difficult for workers to perform optimally.[116] Moreover, many supervisors agreed that there was a need to take measures to protect workers against heat exposure. By contrast, a study in India found that workplace management, who were normally exempt from direct sun exposure, had limited awareness of the need for preventive measures against heat stress, despite widespread reported thermal discomfort by workers.[108] Therefore, it is necessary to investigate the views of heat exposure among all levels of people in the workplace including employees, employers and managers, as well as related stakeholders.

Table 1.3 Review of studies on perceptions and behavioural responses of workplace heat exposure in January 1997- January 2014

Reference	Participant	Country	Study design	Sample size	Study period	Data collection	Statistical method
Mathee et al [116]	Grave diggers, street sweepers, construction workers, and horticultural workers	South Africa	Cross-sectional study	151 focus group discussions, 17 interviews	March 2009	Focus group discussions and interviews using semi-structured interview schedule	Grounded theory approach, and thematic analysis
Balakrishnan et al [108]	Workers in 10 different industrial units	India	Cross-sectional study	242	-	Interviewer-administered questionnaire	Thematic analysis
Crowe et al [97]	Sugarcane workers	Costa Rica	Cross-sectional study	22	Nov 2008 – Mar 2009	Direct observations and exploratory interviews	Thematic analysis
Singh et al [43]	Union and industry representatives, governmental officials	Australia	Cross-sectional study	20	Summer of 2010	Semi-structured telephone interview	Thematic analysis
Shendell et al [170]	Athletes	USA	Cross-sectional study	1,138	Feb-Mar 2008	Online questionnaire survey	Descriptive analysis
Flocks et al [174]	Female farmworkers in pregnancy	USA	Cross-sectional study	35	Spring of 2012	Focus group, semi-structured interview	Thematic analysis
Lam et al [173]	Farmworkers	USA	Cross-sectional study	35	-	Focus group	Thematic analysis
Stoecklin et al [169]	Farmworkers	USA	Cross-sectional study	474	Nov 2008-Feb 2010	Questionnaire survey	Descriptive analysis, multivariate logistic regression

1.5 Workplace heat exposure prevention

Heat-related illnesses and deaths are largely preventable. Heat stress management and control may have multiple benefits in terms of better health, improved productivity, and improved sense of comfort and social well-being, as well as reducing health costs.[107] Work-related injuries are often the result of a concurrence of many workplace hazards, and no injuries are likely to be due solely to heat exposure alone.[46] However, the control of heat stress may reduce the probability of workplace injuries. Heat stress management strategies mainly include administrative control, engineering control, training and education, and heat-related regulations.[54]

1.5.1 Administrative management

Administrative controls are a useful way to minimize heat-related illnesses and deaths in workplaces. First, work times may able to be rearranged to reduce heat exposure. Strenuous outdoor activities may able to be rescheduled to cooler times of the day,[175] and routine maintenance and repair work in hot areas should be scheduled for the cooler seasons of the year.[55] Second, cooling systems and facilities could be provided in the workplace where possible. Workers should have free access to cool water and shaded or air-conditioned rest areas and should be advised to drink small amounts frequently before they get thirsty. For instance, in Japan[86] and United Arab Emirates,[85] tents, electric fans, cool drinking water and ice making machines are available in some workplaces plus appropriate shift-work schedules. Thus, the effects of hot working environments on the health of the workers have not been remarkable.

Further administrative controls include acclimatizing workers to hot work environments. This is could be a low-cost and highly effective way of improving safety and delaying the development of heat strain.[53] Other administrative controls may include reducing the physical demands of work, and providing recovery areas. Emergency procedures should be in place to facilitate immediate first aid and transport to medical care.[55] Additionally, heat tolerance screening can identify potential risk factors such as individuals taking particular medication; sufferers of underlying medical conditions that may compromise thermoregulatory functions; excessive alcohol intake; unsatisfactory levels of basic fitness; body mass index; and high blood pressure.[33] This can be an effective way to prevent heat stress and strain.

1.5.2 Heat training and education

Health education for employers, on-site managers and employees is an important approach to reduce workers' thermal stress.[113] Prevention of heat illnesses among workers requires educating employers, managers and workers on the adverse effects of working in hot environments and showing them the most effect adaptive approaches.[73] Such occupational health and safety education and training programs may include: the hazards of heat stress; recognition of predisposing factors, danger signs and symptoms; creating awareness of first-aid procedures for, and the potential health effects of, heat stroke; understanding the prevention strategies that the employer must have in place and implementing appropriate heat stress management measures.[55] In seasonal farmers in the USA, the high proportion of heat-related mortality among foreign-born workers suggests that an effective health education approach should be considered for the culturally and linguistically diverse (CALD) groups among workers such as using images and their own languages.[73] The occupational health and safety for seasonal workers during extreme hot days is also a challenge in Australia, and so far there has been very little work conducted in this area. Obviously more research needs to be done in this area, together with government organisations and employers.

1.5.3 Heat indices, policies and regulations for working in hot environments

A review of current literature of heat prevention regulations and policies was conducted to gain a broad understanding of current heat stress policies and provide necessary evidence for the development of heat prevention guidelines and regulations applicable to the workplaces. A comprehensive search of the local and international heat stress, standards, heat indices, guidelines, and regulations was therefore conducted.

The search strategy was the random combination of the first keywords "heat stress, extreme heat, high temperature, and hot weather" and the second keywords "standard, regulation, exposure limit, policy, and guidelines". The following databases were searched: PubMed, Scopus, ScienceDirect, Google Scholar, and 'grey literature' including national and international organizations' official websites in relation to occupational health and safety. A manual search for relevant references in articles was also conducted. Contents involving heat prevention in the complex occupational health and safety regulations/laws were identified by searching the keywords "heat, temperature, weather, and work environment". All superseded heat regulations, codes, and standards were excluded. Documents not in English were translated by using Google Translator.

1.5.3.1 Heat indices

Findings from the literature review revealed that since 1905 many attempts have been made to measure the integrated heat stress level in the workplace and/or to estimate the corresponding heat strain.[176] A heat stress index is a composite measure used for the assessment of heat stress, taking environmental and/or personal factors into account. Due to the complexity of interaction of heat stress determining variables which exist in the real working environment, it may not be feasible to create a universal heat stress index accounting for each variable. Differences in physical demanding level of tasks, health status, tolerance to heat, heat sources, interference of thermolytic mechanisms, level of intermittent work, and the ambient environment may all influence levels of risk. As a result, to date more than 40 heat indices have been created,[176] which provide a scientific basis for the establishment of safety criteria and limits for those working in hot environments.

Heat indices can be divided into three categories: rational indices, based on calculations involving the heat balance equation; empirical indices, based on measurements of objective and subjective heat strain; and direct indices, based on measurements of environmental variables.[176] Among all heat indices, the WBGT index is now the most widely used heat stress index for workplace applications and adopted by many international organizations, although it still has several limitations.[177] It is regarded as an exploratory method to determine heat stress through the calculation of radiative, dry bulb, and wet bulb values. The simplicity of WBGT makes it an easy field assessment tool as it requires minimal equipment and training. This index has two variations: including radiative or solar heat loads. Typically these have been used indoors or outdoors:

Indoors: $WBGT=0.7t_{nw}+0.3t_g$

Outdoors: $WBGT=0.7t_{nw}+0.2t_g+0.1t_a$

Where t_{nw}= natural web bulb temperature; t_g = globe temperature; t_a = air temperature (dry bulb temperature)

Most recently in 2012, Lemke and Kjellstorm suggested a new heat stress index UTCI (Universal Thermal Climate Index) with the aim to assess the trends of occupational heat exposure at population level, using ordinary meteorological surveillance data.[178]

Some of the authoritative governing bodies that have developed heat stress guidelines and/or indices include the International Organization for Standardization (ISO),[52] the European Committee for Standardization (CEN), the US National Institute for Occupational Safety and Health (NIOSH),[179] and the American Conference of Governmental Industrial Hygienists (ACGIH).[180] 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.

1.5.3.2 Heat-related regulations in Australia

The management of heat exposure in the Australian workplaces has long been a perplexing dilemma due to the lack of clear regulations.[53] As summarized in Table 1.4, legal requirements relating to heat stress in Australia are fairly ambiguous. To date, the federal government has not released its national regulations specifying explicit standards for maximum temperatures in the workplace.[19] Moreover, no State or Territory has specific legal requirements for heat stress control and prevention, whereas guidelines and educational materials relating to heat stress are available on each state's Safe Work or/and Department of Health websites. Recently, the Construction, Forestry, Mining and Energy Union (CFMEU) South Australia Branch launched a campaign about working in extremely hot weather.[181] It suggests that "If temperature is less than 35°C work continues normally but take actions to minimize heat stress as temperature rises in exposed areas"; "If temperature is over 35°C work in exposed areas ceases"; and "If temperature is over 37°C all work ceases unless working in air conditioned area."

Australia is one of the observing countries involved in the production of ISO heat standards.[52] Heat stress standards and guidelines developed by the Australian Institute of Occupational Hygienists (AIOH) were basically adopted from the US TLVs,[180] which have been updated in 2013 for use in the Australian environment.[54] Table 1.4 summarizes regulations and codes for Australia.

Overseas heat-related regulations and guidelines are summarized in Appendix A.

Table 1.4 Australian legal regulations and codes for occupational heat stress

Jurisdiction	Legislation	Scope	Requirements relating to management of heat stress
National [182]	Model Work Health and Safety Regulations 2014	All workplaces	Part 3.2 General workplace management, Division 2 General working environment (page 101): "A person conducting a business or undertaking at a workplace must ensure, so far as is reasonably practicable, the following: …(f) workers carrying out work in extremes of heat or cold are able to carry out work without risk to health and safety"
National [183]	Model Work Health and Safety Act 2011	All workplaces	None required
National [184]	Model Code of Practice - Construction Work	Construction	Part 7 General workplace management arrangements (page 61): "Consider rescheduling work in the open in very hot weather conditions, or ensure subcontractors are adequately managing risk of heat stress; Providing access to adequate, cool, clean water; Providing access to appropriate PPE"; Page 65, "A readily accessible and plentiful supply of drinking water must be available to all workers on the site."
National [185]	Model Code of Practice - Managing the Work Environment and Facilities	All workplaces	Part 2.8 Heat and cold (page 14): "Work should be carried out in an environment where a temperature range is comfortable for workers and suits the work they carry out…"; "If it is not possible to eliminate exposure to extreme heat, the risk of heat strain and heat exhaustion must be minimised so far as is reasonably practicable. For example: „increase air movement using fans, install air-conditioners..."; "An adequate supply of clean drinking water must be provided free of charge for workers at all times."
South Australia [186]	Work Health and Safety Act 2012	All workplaces	None required
South Australia [187]	Mines and Works Inspection Regulations 2013	Mining	None required

South Australia [188]	Work Health and Safety Regulations 2012	All workplaces and mining	Chapter 3, Part 2 General workplace management, Division 2 General working environment: "A person conducting a business or undertaking at a workplace must ensure, so far as is reasonably practicable, the following: …(f) workers carrying out work in extremes of heat or cold are able to carry out work without risk to health and safety"; Chapter 10 Mines, part 2, division 3 (page 116): "the mine operator of a mine must ... (b) if risks associated with extreme heat exist in an underground mine—implement control measures (including monitoring) to manage heat stress in places in the mine where—(i) persons work or travel; and (ii) the wet bulb temperature exceeds 27°C."
Australian Capital Territory [189]	Work Health and Safety Act 2011	All workplaces	None required
Australian Capital Territory [190]	Work Health and Safety Regulation 2011	All workplaces	Part 3.2 General workplace management, Division 3.2.2 General working environment (page 29): "A person conducting a business or undertaking at a workplace must ensure, so far as is reasonably practicable, the following: …(f) workers carrying out work in extremes of heat or cold are able to carry out work without risk to health and safety"
Australian Capital Territory [191]	Work Health and Safety (Construction Work Code of Practice)	Construction	Part 7.1 The work environment (page 33): "workers exposed to extremes of heat or cold are able to carry out work without risk to their health and safety…"; Page 35: "Outdoor workers should be provided with protection in adverse weather conditions, for example sunshades, sheds, caravans, tents and windbreaks."
Australian Capital Territory [192]	Work Health and Safety (Managing the Work Environment and Facilities) Code of Practice 2011	All workplaces	Part 2.8 Heat and cold (page 15): "Work should be carried out in an environment where a temperature range is comfortable for workers and suits the work they carry out…"; "If it is not possible to eliminate exposure to extreme heat, the risk of heat strain and heat exhaustion must be minimised so far as is reasonably practicable. For example: „increase air movement using fans, install air-conditioners..."; "An adequate supply of clean drinking water must be provided free of charge for workers at all times."
New South Wales [193]	Work Health and Safety Act 2011	All workplaces	None required

New South Wales [194]	Work Health and Safety Regulation 2011	All workplaces	Part 3.2 General workplace management, Division 2 General working environment: "A person conducting a business or undertaking at a workplace must ensure, so far as is reasonably practicable, the following: …(f) workers carrying out work in extremes of heat or cold are able to carry out work without risk to health and safety"
New South Wales [195]	Managing the work environment and facilities: Code of practice	All workplaces	Part 2.8 Heat and cold (page 14): "Work should be carried out in an environment where a temperature range is comfortable for workers and suits the work they carry out…"; "If it is not possible to eliminate exposure to extreme heat, the risk of heat strain and heat exhaustion must be minimised so far as is reasonably practicable. For example: „increase air movement using fans, install air-conditioners..."; "An adequate supply of clean drinking water must be provided free of charge for workers at all times."
Northern Territory [196]	Model Work Health and Safety (WHS) Act	All workplaces	None required
Northern Territory [197]	Model Work Health and Safety (WHS) Regulations	All workplaces	Part 3.2 General workplace management, Division 2 General working environment: "A person conducting a business or undertaking at a workplace must ensure, so far as is reasonably practicable, the following: …(f) workers carrying out work in extremes of heat or cold are able to carry out work without risk to health and safety"
Northern Territory [198]	Transitional Arrangements for Construction Work	Construction	None required
Queensland [199]	Work Health and Safety Act 2011	All workplaces	None required
Queensland [200]	Managing the Work Environment and Facilities Code of Practice 2011	All workplaces	Part 2.8 Heat and cold (page 14): "Work should be carried out in an environment where a temperature range is comfortable for workers and suits the work they carry out…"; "If it is not possible to eliminate exposure to extreme heat, the risk of heat strain and heat exhaustion must be minimised so far as is reasonably practicable. For example: „increase air movement using fans, install air-conditioners..."; "An adequate supply of clean drinking water must be provided free of charge for workers at all times."

Queensland [201]	Foundry Code of Practice 2004	Foundry	Part 3.1 "Working in heat: altering the work environment, administrative controls …"
Queensland [202]	Hazardous Manual Tasks Code of Practice 2011	All workplaces	Part 4.8 Changing the work environment (page 30): "For workers in hot and humid conditions, reduce temperature and humidity during manual tasks where possible by relocating work away from sources of heat, providing fans or air-conditioning, using screens, awnings and clothing to shield workers from radiant heat sources such as ovens, furnaces and the sun..."
Queensland [203]	Forest Harvesting Code of Practice 2007	Forestry	Part B workplace health and safety, 14 heat stress (page 37): "To avoid heat stress: the golden rule for workers in hot conditions who may be feeling weak or faint is to stop work immediately and cool down..."
Queensland [204]	Children and Young Workers Code of Practice 2006	All workplaces	None required
Queensland [205]	Managing the risk of falls at workplaces	All workplaces	Part 2.3 How to control the risk: "When assessing the risks arising from each fall hazard, the following matters should be considered, such as …extreme heat…"
Queensland [206]	Traffic Management for Construction or Maintenance Work Code of Practice 2008	Construction	Part 8.3 Sun and heat (page 17): "Every workplace should carry out its own assessment of sun exposure, identify tasks that place workers at risk, and control workers' sun exposure."; "Some examples of controlling exposure to sun and heat are: wearing personal protection, taking precautions and setting time limits spent working in the sun during summer's highest risk time – between 9 am and 3 pm, reorganising work schedules so that outdoor tasks are done early in the morning or late in the day..."
Victoria [207]	Occupational Health and Safety Act 2004	All workplaces	None required
Victoria [208]	Occupational Health and Safety Regulations 2007	All workplaces	None required

Victoria [209]	Mines Act 1958	Mining	None required
Victoria [210]	Working Safely With Trees 2001 (recommended practices for the amenity tree industry)	Tree industry	Part 3.1 Heat and cold (page 36): "Inform and train workers to recognise symptoms of heat-related illness and to understand the need to drink coo, non-alcoholic fluids; allow workers time to acclimatise to working in heat. This takes several days; make sure workers take frequent rest breaks in hot or humid conditions; provide shade where possible, at least for break periods; Cease work if conditions become unsafe to continue…"
Victoria [211]	Health and Safety in Shearing	Shearing	Part 10 Work in heat and cold (page 34): " changing working hours to avoid working during the hottest part of the day; allowing for acclimatisation to heat by workers; decreasing the workload in very hot conditions…"
Victoria [212]	Guidance Note: Working in heat (Advice about how to prevent heat illness from working outdoors in hot weather or where heat is generated as part of work)	All workplaces	"increasing air movement using fans; installing shade cloth to reduce radiant heat from the sun; removing heated air or steam from hot processes using local exhaust ventilation; locating hot processes away from people; insulating hot processes or plant; isolating employees from the hot process by locating them in air conditioned control rooms…"
Victoria [213]	Foundries-Compliance Code 2008 (guidance)	Foundry	pp7-8, "an acclimatisation process; pacing of work to suit the conditions; scheduling of hot work in cooler parts of the day or isolating it by distance from other workers; rotation of hot tasks between employees to minimise exposure time; employees are trained, educated and continuously monitored for sighs of excessive heat exposure and heat stroke…"
West Australia [214]	Occupational Safety and Health Act 1984	All workplaces	None required
West Australia [215]	Occupational Safety and Health Regulations 1996	All workplaces	Part 3.15: "Employer must ensure — that work practices are arranged so that employees are protected from extremes of heat and cold."

Tasmania [216]	Construction Industry (Long Service) Act 1997	Construction	None required
Tasmania [217]	Work Health and Safety Act 2012	All workplaces	None required
Tasmania [218]	Mines Work Health and Safety (Supplementary Requirements) Act 2012	Mining	None required
Tasmania [219]	Construction Work: Code of Practice	Construction	Part 7.1 The work environment (page 35): "If it is not reasonably practicable to eliminate exposure to heat and cold, risks can be minimised with a range of control measures. Examples of control measures in a hot work environment may include installing shade structures, task rotation, rest breaks, or isolating workers from heat. Workers must have access to adequate, cool, clean water."
Tasmania [220]	Managing the Work Environment and Facilities	All workplaces	Part 2.8 Heat and cold (page 14): "Work should be carried out in an environment where a temperature range is comfortable for workers and suits the work they carry out…"; "If it is not possible to eliminate exposure to extreme heat, the risk of heat strain and heat exhaustion must be minimised so far as is reasonably practicable. For example: „increase air movement using fans, install air-conditioners..."; "An adequate supply of clean drinking water must be provided free of charge for workers at all times."
Tasmania [221]	Work Health and Safety Regulations 2012	All workplaces	Division 2-general work environment: "A person conducting a business or undertaking at a workplace must ensure, so far as is reasonably practicable, the following: …(f) workers carrying out work in extremes of heat or cold are able to carry out work without risk to health and safety"

1.6 Discussion

If the predictions about future temperature increases prove reliable, weather-related extreme heat exposure will be placing many types of indoor and outdoor workers at increasingly high risk of heat-related illnesses and injuries.[19-21, 30] For acclimatised manual workers, a few degrees rise in temperature can make dangerous days increase to 15-26 days per year in 2070 compared to 1 day per year at present in Australia.[36] Outdoor workers, in particular those undertaking highly intensive and physical activity such as construction and road maintenance under the sun are susceptible to heat stress during heatwaves when preventive measures are not adequately adopted.[66, 83, 86, 87, 92, 94, 96, 97] Physical and strenuous activity generating internal body heat load associated with increasing metabolic rate, together with significant radiant heat load from direct sunlight, may further worsen heat stress. Indoor workers, especially those working around furnaces, ovens, smelters and boilers, are at a higher heat stress risk on hot days.[58, 98, 99, 121, 122] Despite indoor workers not being exposed to direct solar radiation, they can be exposed to heat and humidity generated from work processes or equipment. Their working environment can also become very hot when a cooling system is not available or ventilation is insufficient during hot days.[122]

The review of the health impacts of workplace heat exposure has examined 64 epidemiological studies published between January 1997 and January 2014. Due to the availability of occupational health and safety data, all published papers based on surveillance data have been from high income countries. Although the underreporting of work-related injuries may challenge the data quality and affect the reliability of results, these findings provide a good overview of the characteristics of occupational health and safety in hot condition. However, roughly three quarters of the articles simply described the distribution of heat-related illness or injuries by industrial sectors, occupations, seasons, and months, suggesting most of heat-related illnesses and injuries occurred in summer months and hottest parts of the day.[72] There is lack of further data analyses exploring the quantitative association between temperatures and heat/work-related injuries.

In general, the association between temperature and morbidity & mortality has been characterized as U, V, or J-shaped relationship.[11, 13, 15, 16, 18, 222] Some attempts have been made to identify threshold temperatures,[18, 223, 224] above which health outcomes increase significantly. It provides useful evidence-based implications for the establishment of extreme heat early warning systems.[225] However, in the workplace preventive measures may be adopted and workers may be able to stop work or self-pace if the workplace temperature is extremely high.[226] This can result in a decline in the number of work-related injuries at the certain temperature point, which is described as reversed U-shaped curve.[27, 139, 226] However, if denominator information is available for calculating work-related injury rates, the relationship still appears to be U-shaped curve.[64, 111] The relationship patterns between temperatures and work-related injuries may vary by industries, gender, and age group. For example, young workers aged less than 30-years-old showed consistently higher injury rates than other age groups in all thermal categories,[111] which may be related to the practice of assigning young workers with more physically demanding work, in addition to their lack of experience for self-pacing.

More epidemiological analyses based on occupational injury surveillance data are needed to quantify the extent to which high-risk manual workers are affected by workplace heat exposure and to identify risk factors for workplace heat prevention and adaptation,[37] especially for low-middle income countries in tropical regions.[20] This is achievable if there is a routine occupational injury surveillance system, which may provide epidemiology-based evidence for the decision of heat alert temperatures in the workplace. There are several points worth noting when analysing the temperature-occupational injury relationship, including the selection of appropriate regression models, the adjustment of confounding factors, and the handling of non-linear relationship.[222, 227, 228] Among these reviewed articles, only three papers used Poisson regression suitable for count data.[27, 28, 76] However, none reported checking whether the distribution of work-related injuries was over-dispersed or not, in which case negative binominal regression is more appropriate.[229] Consideration should also be given to the selection of functions when using GEE (generalized estimating equation) models. In terms of confounding factors, amongst the reviewed articles only Morabito[27] took public holidays, weekends, and time-lag effects into account, whereas the long-term variation trend and day of week were not adjusted. As to the problem of non-linearity, piecewise linear regression or linear spline functions have been adopted in some studies by dividing temperature ranges into several pieces.[27, 28]

Usually, the number of reported direct heat illness is very small. In Australia, statistics show there were only 485 work-related illnesses and injuries due to exposure to environmental heat in the 11-year period of 1997-2007.[230] Similarly, 480 heat-related illnesses were identified during the 11-year period of 1995-2005 in Washington State, USA.[72] If just based on the reported statistical figures, it is not surprising that heat stress is not listed as occupational health priority. However, it should be noted that heat-related illnesses may be underreported largely due to following reasons. Firstly, many high income countries utilize workers' compensation claims to measure occupational health and safety performance. However, the compensation based data do not provide any information for groups not covered by workers' compensation schemes, such as some self-employed workers. Secondly, some workers with minor injuries may not apply for compensation claims. Most heat illnesses are mild and individuals recover rapidly through simple treatment or rest on site without hospitalization. Thirdly, because heat exposure can exacerbate existing medical conditions, illness or death due to heat exposure may be preceded by other diseases and reported as other diseases other than heat illness. Additionally, the criteria used to determine heat illness and death vary largely, resulting in misclassification. Overall, it should be realized that a huge potential risk of heat-related injury and accident may be disguised by the underestimated number of heat-related illness and death.

In contrast to surveillance data analyses, most cross-sectional field surveys aiming to investigate heat stress status and workers' physiological responses to heat are from low-middle income countries, especially in tropical regions.[62, 83, 94, 97, 106-108, 116] It is consistent with the regional maps proposed by Hyatt,[35] predicting regions at high risk of occupational heat exposure. With global climate change trends, extreme workplace heat exposure situations may extend to large areas of the world apart from Australia, South Asia, Southern Africa, Central America, and southern USA. A majority of the studies show that workplace heat stress exceeds the heat stress criteria of the American Conference of Governmental Industrial Hygienists and is presenting a threat to manual workers' health and safety. Usually, physiological responses and subjective symptoms of industrial workers exposed to heat include elevated blood pressure and urine gravity, increased recovery heart rates and body temperature, and increased fatigue symptoms.[58, 71, 86, 98, 112, 115, 117, 122] However, if effective prevention measures are taken in the workplace, risk of heat-related illness and injury can be significantly reduced.[66, 85, 121, 123]

Workers' self-pacing has been found to reduce heat strain in construction and mining industries in Australia,[114, 115] Germany,[111] and the United Arab Emirates.[82] Currently, there is no consensus about whether self-pacing should be encouraged in the workplace. Positive self-adjustment of work pace to a safe level could be considered as a flexible management approach to maintain productivity without compromising workers' safety in hot environments.[82] This can be subject to the conditions that the task has no urgent character and does not involve work output based payment incentives that workers should be well trained in their job, and that self-pacing may be associated with close supervisory surveillance.[231] On the contrary, if self-pacing is workers' passive physiological or/and psychological reactions to thermally stressful conditions by slowing work pace, it may be inefficient either in terms of productivity or in terms of heat strain reduction. Evidence from field studies in Australia has suggested that few workers will voluntarily work at a pace that requires an average heart rate over 110 bpm for any length of time,[114] a level consistent with WHO recommendation.[232]

In addition, there are few studies to investigate how decision-makers, occupational hygienists, employers, supervisors, unions, workers and relevant stakeholders perceive the role of self-pacing for reducing the risk of heat-related illnesses and injuries in the workplace. This can be important for the formulation of heat-related policies, guidelines and regulations and more studies in this area should be encouraged.

1.7 Summary and research gaps

With the predicted increasing frequency and intensity of extremely hot weather due to climate change,[30-32] workplace heat exposure is presenting an increasing challenge to employers and employees.[19-21, 30] Manual workers who are exposed to extreme heat or work in hot environments may be at risk of heat stress, especially for workers in low-middle income countries in tropical regions.[233, 234] Those workers include farmers, construction workers, fire-fighters, miners, soldiers, and manufacturing workers working around process-generated heat.[56, 64] If effective prevention measures are taken in the workplace, the negative effects from extreme heat on the occupational health and safety for workers may be reduced.[66, 85, 121, 123] There is lack of research exploring the quantitative association between temperatures and heat/work-related injuries in Australia despite the hot climate. The potential impacts of workplace heat exposure are to some extent underestimated due to the underreporting of heat illnesses and the lack of awareness that heat exposure can increase the risk of work-related injuries.

There are significant gaps in knowledge in this area. These may include: (1) a lack of epidemiological evidence of the extent to which Australian workers are affected by or adapted to weather-related extreme heat; (2) a lack of the knowledge about which types of work-related illnesses/injuries are associated with heat exposure; (3) a lack of the incidence and epidemiological characteristics of occupational heat illnesses; (4) a lack of relevant investigations about perceptions of weather-related extreme heat exposure in workplaces in Australia; and (5) a lack of threshold temperature based specific heat regulations. The knowledge gaps summarized here represent important areas for future research regarding extreme heat and workers' health and safety. Other possible future research directions are discussed in Chapter 9.

Chapter 2

Study design and methodology

2.1 Introduction

This chapter describes the geographical and demographic characteristics of the study region, and outlines the overall research aims and objectives of the thesis. The research questions are listed and the framework of the study is explained together with an overview of study design and justification of methodologies used in data analysis.

2.2 The study region

South Australia (SA) had a population of 1.60 million with a labour force of 784,328 in 2011.[235] The industries which play an important part of SA's economy include meat, wheat, wine, wool, machinery, mining, fishing, vehicle manufacturing, and petroleum products. Adelaide (latitude 34º55' S and longitude 138º35' E) is the capital city of South Australia (Figure 2.1), with a population of 1.23 million and a labour force of 576,823 in 2011.[236] According to the Australian Bureau of Statistics, the most common occupations in Adelaide included 'professionals'(21.6%), 'clerical and administrative workers'(15.4%), 'technicians and trades workers'(14.0%), 'managers'(11.1%), 'community and personal service workers'(10.7%), 'sale workers' (9.9%), 'labourers' (9.9%), and 'machinery operators and drivers' (5.8%).[236]

Characterized 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. According to weather projections for Adelaide, the average number of days with temperatures over 35°C will triple by 2070.[32] Thus, high ambient temperatures may have and will continue to pose a growing challenge for occupational health and safety.

Figure 2.1 Location of metropolitan Adelaide, Adelaide, South Australia (adapted from Google map)

2.3 Aims and objectives of the study

The aim of the study was to identify the effects of workplace heat exposure on workers' health and safety in Adelaide, South Australia, to investigate how workers and occupational hygienists perceive the risk of workplace heat exposure, and to provide scientific evidence for the development of heat prevention and adaptation strategies in a warming climate.

The objectives of the study are:

- To explore the association between daily ambient temperatures and work-related injuries by analysing workers' compensation claims data and weather data in Adelaide;
- To identify which categories of workers are most vulnerable to extreme heat;
- To investigate workers' perceptions, knowledge, and heat adaptation barriers towards extreme heat exposure in the workplace; and
- To understand the perceptions of occupational hygienists towards extreme heat exposure in the workplace;
- To provide recommendations and suggestions for the development of heat adaptation and prevention strategies.

2.4 Research questions

The research questions to be addressed in this thesis include:

- To what extent workers are impacted by weather-related heat exposure in Adelaide, South Australia?
    - What is the association between ambient temperature and work-related illnesses and injuries?
    - Which groups of workers are at higher risk of illnesses and injuries during heatwaves?

- Which types of illnesses and injuries are most prevalent during heatwaves?

- What are the risk perceptions of workers and relevant stakeholders? What are the existing barriers for prevention and adaptation?
- What new intervention and adaptation strategies can be developed to reduce the risk of work-related illnesses or injuries when working in hot environments?

2.5 Framework of the study

To address the research questions, this study can broadly be divided into two parts, as shown in Figure 2.2. Part I assesses the impact of extreme heat on workers' health and safety, using workers' compensation claim data and weather information, obtained respectively from the SafeWork South Australia and the Bureau of Meteorology for the period of 2001-2010. In Chapter 3, the epidemiological distribution characteristics of injury claims reported in SA during the study period is first described. Despite previous evidence showing that heat stress was an occupational hazard in South Australia,[46] the incidence rate and the epidemiological distribution characteristics of occupational heat illnesses in SA remains unknown. These issues are addressed in Chapter 4. To evaluate the extent to which heat exposure may increase the risk of work-related injuries, the analyses were restricted to the Adelaide metropolitan areas, and the association of age, gender, business size, industry, occupation, and daily maximum temperature was assessed (Chapter 5). Furthermore, the impact of consecutive extreme heat exposure (heatwaves) on workers' health and safety was examined, and the illnesses and injuries significantly associated with extreme heat are identified (Chapter 6).

Part II is a questionnaire survey, to investigate perceptions of workers (Chapter 7), occupational hygienists and relevant stakeholders (Chapter 8) about workplace heat exposure in the context of a warming climate.

Findings of this study may provide scientific evidence to help relevant stakeholders develop preventive strategies targeted on vulnerable subgroups and prioritize work-related illnesses and injuries associated with heat exposure. A diagrammatic representation of the overall framework of the study is shown in Figure 2.2.

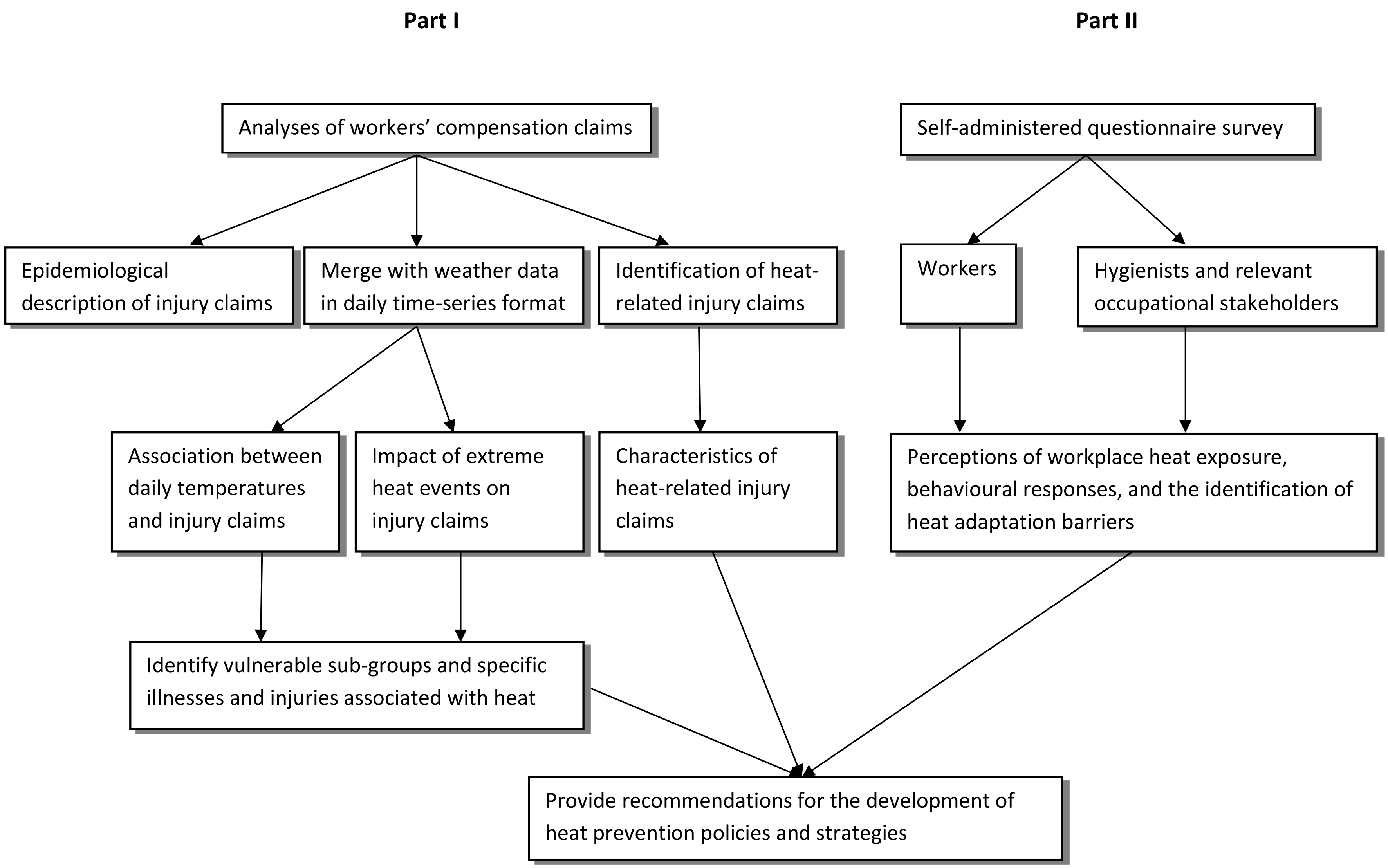

Figure 2.2 Flowchart outlining the framework of the study

2.6 Methodology used in the study

2.6.1 Analysis of occupational surveillance data

2.6.1.1 Data collection

Under the South Australian WorkCover Scheme directed by the Workers Rehabilitation and Compensation Act 1986,[237] 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).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.[238]

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-10), bodily location, mechanism, and agency of injury/disease.[238] Each case is allocated 4 codes according to the above four categories. Workers' compensation claim data are a good occupational surveillance data resource currently available for measuring the trend of workers' health and safety at population level.

De-identified workers' compensation claims data for the period of 1st July 2001 to 30th June 2010 were obtained from SafeWork South Australia. The data included all accepted compensation claims from both registered and self-employed employers during the 9-financial year periods (1 July to 30 June next year). Individual identifiable information was removed prior to receipt of the data. A confidentiality agreement (Appendix C) was signed between the SWSA and the University of Adelaide to ensure the dataset was only used for research purposes. 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 (i.e. time lost from work and total medical expenditure).

To assess the impact of extreme heat on workers' health and safety, climatic data (daily maximum and minimum temperatures and relatively humidity) in Adelaide over the study period were obtained from the Bureau of Meteorology, Kent Town station, centrally situated in metropolitan Adelaide.

Ethics approval for the analysis of workers' compensation claims data was obtained from the Human Research Ethics Committee at the University of Adelaide (H-111-2011) (Appendix B1-2).

2.6.1.2 Data analysis

Summary frequency statistics were used to describe the epidemiological distribution characteristics of workers' injury claims and occupational heat illness claims. Time series design was chosen for the analyses of heat-injury claims association, which has been widely used in environmental epidemiology in recent years.[222, 227] A 'time-series' design refers to a sequence of data points recorded at regular time intervals. The main unit of analysis is represented by aggregated or grouped observations, not the individual person. Therefore, individual related confounding factors such as age, gender, smoking status, and body mass index do not apply to this method, because the distribution of these factors do not change from day to day at population level and cannot be associated with fluctuations in environmental exposures.[227] The main feature of the analytical methods is the temporal decomposition of the outcome and exposure series, where the variability is partitioned into contributions related to different timescales.[222, 227, 239] Time series is a valid method to investigate whether some of the short-term variation in the health outcomes can be explained by the changes in the main exposure.[227] In this study, time series design is used to investigate whether day-to-day changes in the number of injury claims can be explained, at least in part, by heat exposure (daily temperature or consecutive days with high temperatures).

After determining the time series study design for the analysis of the workers' compensation claim data, it is important to select a best-fit model to estimate the outcome-exposure association.[222] In this study, the generalized estimating equations (GEE) model was selected, based on the following two considerations. First, the time series format temperature-injury claim dataset in essence can be treated as a longitudinal study, with the assumption that daily injury claims were repetitively collected among different years of the study period. Second, injury claims may be correlated within each year. Failure to incorporate correlation of responses can lead to incorrect estimation of regression model parameters.[240] The GEE approach was created by Liang and Zeger in 1986 for use in analysing longitudinal or repeated measures research designs,[241, 242] and hence is suited to this application. Another strength of GEE is its appropriateness for the analysis of data that the dependent variable is not normally distributed and correlated within sub-groups,[240] compared with the Ordinary Least Squares (OLS) regression models. Therefore, GEE has been widely used in the heat-health outcomes studies.[18, 243-248]

Correctly fitting a GEE model is important for the estimates of the heat-injury association, which is sensitive to the choice of link functions, the distribution and the correlation structure of the dependent variables.[222, 240] For count data (e.g. daily injury claims), generally the most appropriate link function is the logarithm of the mean which make the GEE techniques part of the log-linear models.[240] Regression coefficients represent the expected change in the log of the mean of the dependent variable for each change in a covariate.[240] Regarding the distribution of the dependent variable (daily injury claims), negative binominal regression accounting for over-dispersion was selected.[229, 240] The last step is the specification of a working correlation structure. Incorrect specification of the correlation structure can affect the efficiency of the estimates, although GEE models are robust to misspecification of the correlation structure.[240] In this study, first order autocorrelation structure was selected, as in other similar heat-health studies.[244, 245, 247]

The relationship between temperature and health outcomes is usually non-linear, being described as U, V, or J-shaped.[11, 13, 15, 16, 18, 27, 139, 222] Thus, a simple log-linear function is not adequate to capture the real relationship between temperature and work-related injury risk. Based on the assumption of more than one segment in the relationship between daily injury claims and temperatures, a hockey-stick model was selected to determine the cut point in the curve at which the change in slope occurs.[12] Parameters are determined using informative initial estimates of the slope and threshold temperatures in iterative non-linear regression models. Calculated threshold temperatures should approximate visual estimates and have a statistical significance level of 0.05.

The threshold model can be defined as:[12]

$$E(Y) = \beta_0 \qquad \text{for } T_{max} < x_0 \quad [1]$$

and

$$E(Y) = \beta_0 + \beta_1 (T_{max} - x_0) \qquad \text{for } T_{max} \geq x_0 \quad [2]$$

Where E(Y) is the expected value of the outcome variable, β_0 is the baseline number of daily admissions, x_0 is the threshold temperature value to be determined, β_1 is the slope of the segment of the regression line prior to the change point; β_0 is the slope after the change point. If a nonzero slope is expected in Equation 1, the model becomes:

$$E(Y) = \beta_0 + \beta_1 (T_{max}) \qquad \text{for } T_{max} < x_0 [3]$$

and

$$E(Y) = \beta_0 + \beta_1(x_0) + \beta_2 (T_{max} - x_0) \text{ for } T_{max} \geq x_0 \ [4]$$

The Stata command ‘nl hockey’ was used to estimate the threshold temperatures.[12, 139]

Additionally, case-crossover design was chosen to evaluate to the extent to which extreme heat (heatwave) may increase the risk of occupational heat illnesses, given that the number of injury claims due to environmental heat is likely to be very small according to the findings of previous literature.[72] The case-crossover design is suited to the study of transient effects of exposure (e.g. heatwave) on acute events (e.g. occupational heat illnesses).[249] The key feature of the design is that each case serves as its own matched control. Therefore, this design can automatically control for individual related confounders such as age, gender and occupation.[250] 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). Conditional logistic regression analysis is typically used to calculate risk estimates.[251, 252]

2.6.2 Questionnaire survey

There are two cross-sectional self-administered questionnaire surveys in this study. The first questionnaire survey aims to investigate worker's perceptions of workplace heat exposure in the context of climate change, and to identify existing heat prevention and adaptation barriers in the workplace. Target workers were determined according to the findings of occupational surveillance data analyses and previous literature. With the support of SafeWork South Australia (Appendix D), employers who were interested in participating in the research helped the distribution of questionnaires and reply-paid envelopes to workers and TAFE students meeting the inclusion criteria.

Another questionnaire survey was conducted during the 2012 Australian Institute of Occupational Hygienists Conference period, the aim of which was to investigate how professional hygienists and relevant occupational stakeholders perceive the risk of workplace heat exposure. Descriptive analysis was used to summarize the percentage distribution of perceptions by different strata e.g. age, gender, occupation, and industry. Bivariate and multivariate logistic regression analysis was used to explore factors relating to the perceptions of heat exposure.

Ethics approval for the two questionnaire surveys was obtained from the Human Research Ethics Committee at the University of Adelaide (H-200-2011) (Appendix H).

SECTION II

HEAT EXPOSURE AND WORK-RELATED INJURY

Introduction

This Section comprises 4 chapters, utilizing workers' compensation claim data and weather data to investigate the effects of heat exposure on workers' health and safety at the population level. Chapter 3 describes the epidemiological distribution characteristics of workers' compensation claims reported during the study period in South Australia (SA), to provide some background information and implications for the following three chapters.

Chapter 4 is intended to estimate the incidence rates of occupational heat illnesses in SA, to describe its distribution characteristics, to quantify the association between ambient temperatures and occupational heat illnesses using time-series analysis, and to investigate to what extent heatwaves may increase the risk of occupational heat illnesses using case-crossover design.

In Chapter 5, time-series analyses with GEE models are used to explore the association between daily maximum temperatures and daily injury claims by age group, gender, industry, occupation, and business size. Using the same analysis methods as Chapter 5, Chapter 6 investigates the impacts of several consecutive days' of high temperatures (i.e. heatwave) on injury claims, to identify the high risk sub-groups, and to examine which types of work-related illnesses and injuries are associated with heat exposure.

Chapter 3

Epidemiological characteristics of work-related injury claims in South Australia, 2001-2010

3.1 Introduction

Analysis of reliable occupational surveillance data provides a useful way to monitor workers' health and safety and evaluate the effectiveness of workplace interventions and guide policies. Workers' compensation claim data are currently the most widely used source of information for reporting work-related injuries in Australia. This chapter is intended to provide an overview of the epidemiological characteristics of workers' compensation claims reported in South Australia during the study period, and to provide some background information and implications for the following three chapters.

3.2 Materials and methods

As mentioned in Chapter 2, de-identified workers' compensation claims data for South Australia for the period of 1st July 2001 to 30th June 2010 were obtained from SafeWork SA (SWSA). Descriptive analyses were performed to summarize the distribution of claims data by age, gender, occupation (Australian Standard Classification of Occupation, ASCO),[253] industry (South Australia WorkCover Industrial Classification, SAWIC),[254] season, month, injury time, and the nature and mechanism of injury claims. Percentiles were used for highly skewed variables such as days lost from work and medical costs. Claims in the Adelaide metropolitan area were identified by location postcode.[255] For the calculation of claim rates, quarterly labour force information was downloaded from the Australian Bureau of Statistics website.[256] The formula used to calculating a claim rate was:

$$Claim\ rate = \frac{New\ compensation\ claims\ occurring\ during\ the\ study\ period}{Labour\ force\ at\ risk\ during\ the\ same\ study\ period}$$

The denominators used in calculating each financial year's claim rate were calculated as the mean of the sum of the quarterly labour forces. A spatial analysis of claims by postcode was undertaken using Epi Info 7 (US Centre for Disease Control and Prevention).

3.3 Results

There were 318 932 notified workers' compensation claims during the 9-financial year period of 2001-2010 in South Australia, with an overall claim rate of 4.7 per 100 employees. The majority (76.7%) of claims occurred in the Adelaide metropolitan areas (Figure 3.1). The least occurred in the far north-west of the state and the lower north-east.

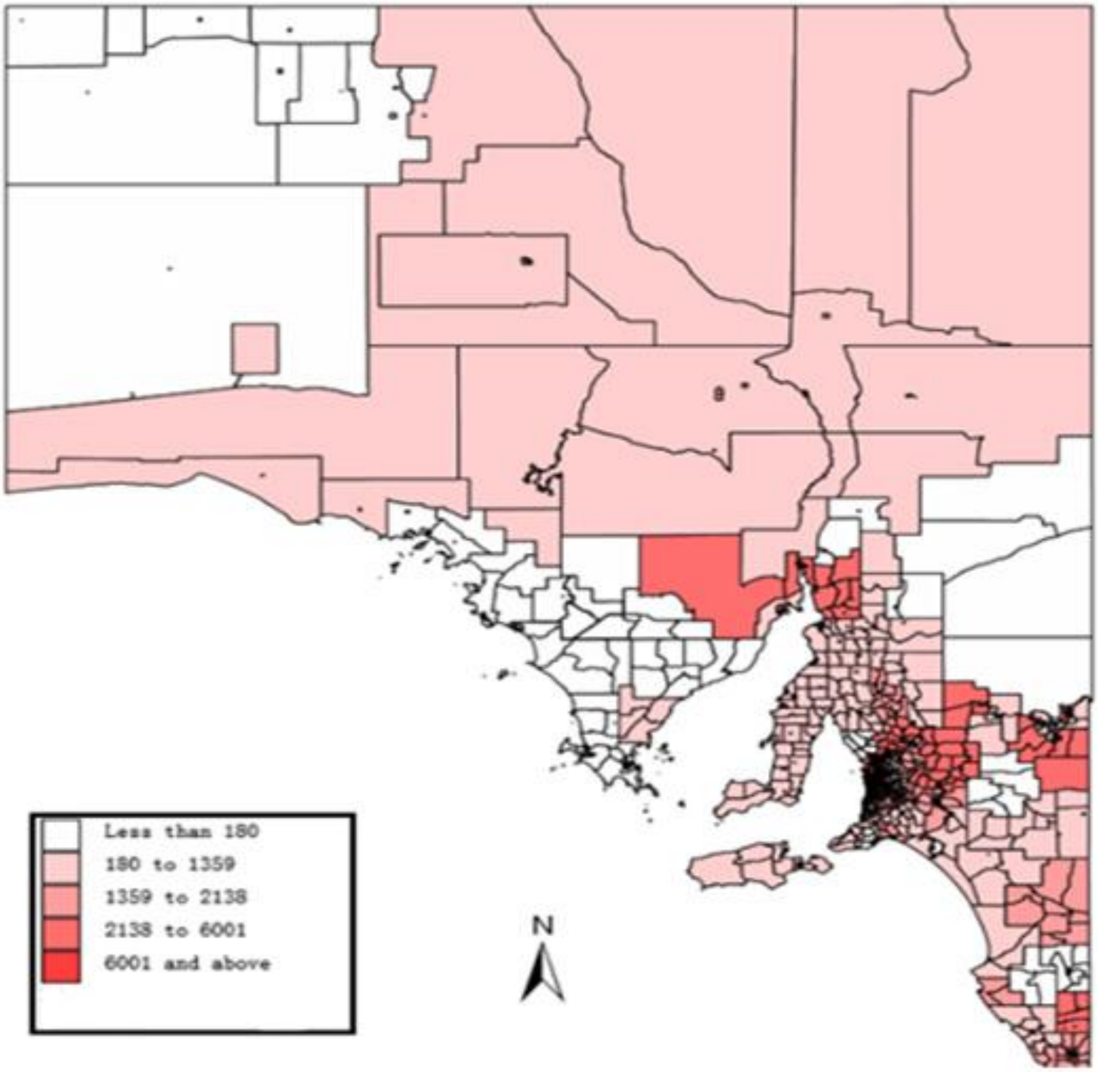

Figure 3.1 Spatial distribution of workers' compensation claims in South Australia, 2001-2010 by postcode

3.3.1 Age and gender

As shown in Table 3.1 and Figure 3.2, claim counts and claim rates across the state for both genders during the study period demonstrated a gradually downward trend from 2001 to 2010. The number of claims lodged by male workers (218 554) was about twice that of female workers (100 343). Moreover, male workers' claim rate was significantly higher than that of female workers (χ^2=620 000, p<0.001).

Table 3.1 The number of claims, percentages and claim rates by gender, South Australia, 2001-2010

Financial Year [a]	Male			Female			Total		
	Claims	Percentage	Claim rate[b]	Claims	Percentage	Claim rate[b]	Claims	Percentage	Claim rate[b]
2001/02	28,548	13.1	7.6	12,132	12.1	4.0	40,680	12.8	5.9
2002/03	27,347	12.5	7.1	11,935	11.9	3.8	39,282	12.3	5.6
2003/04	27,594	12.6	7.0	12,029	12.0	3.7	39,624	12.4	5.5
2004/05	26,664	12.2	6.6	11,978	11.9	3.7	38,642	12.1	5.3
2005/06	24,632	11.3	6.0	11,348	11.3	3.3	35,982	11.3	4.8
2006/07	23,344	10.7	5.7	10,728	10.7	3.1	34,086	10.7	4.5
2007/08	21,575	9.8	5.1	10,150	10.1	2.8	31,735	9.9	4.1
2008/09	19,273	8.8	4.5	9,815	9.8	2.7	29,099	9.1	3.7
2009/10	19,567	9.0	4.5	10,228	10.2	2.8	29,802	9.4	3.7
Total	218,544	100.0	6.0	100,343	100.0	3.3	318,932	100.0	4.7

[a] Financial year: from the 1st July through to the following 30th June;

[b] Claim rate: per 100 employees.

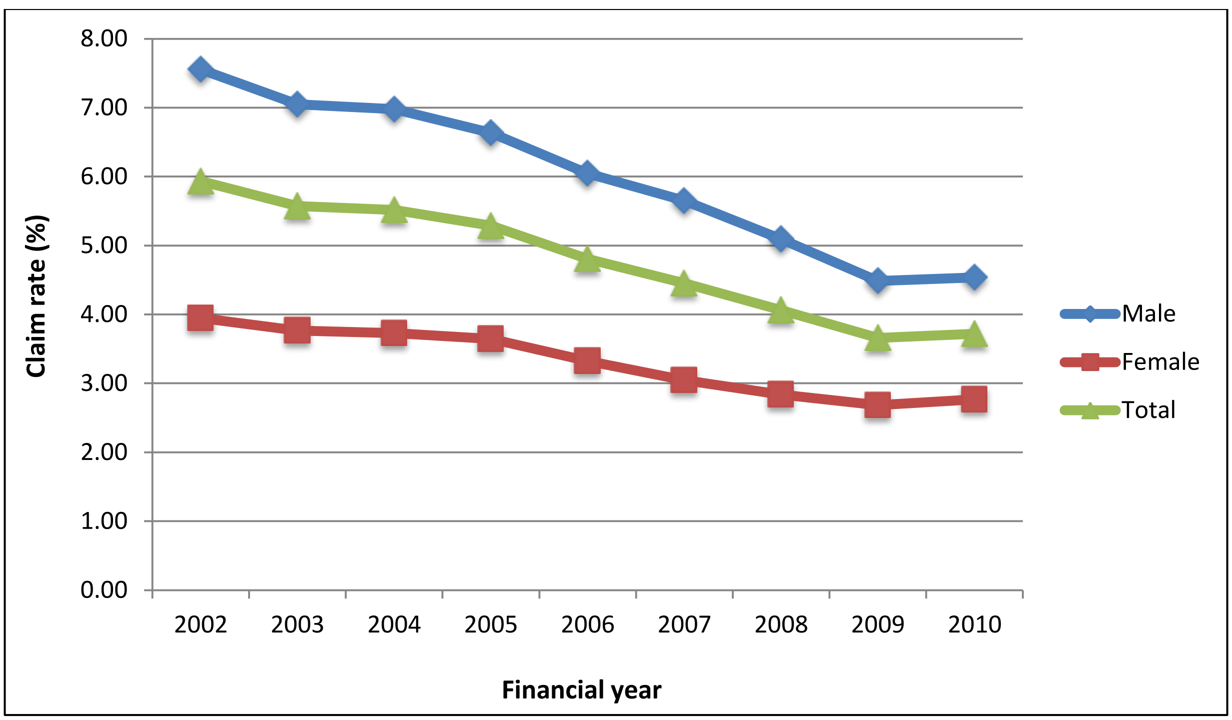

Figure 3.2 Claim rates by gender, South Australia, 2001-2010

As shown in Table 3.2, 99.2% of reported claims were distributed in the working age groups of 15-64 years. Young workers (aged 15-24 years)[140] represented about 17.1% of all claims. The distribution pattern of the proportion of claims in different age groups between males and females was similar, and increased gradually with the increase of age, peaking at 35-44 years for males and 45-54 years for females. Claim rates for male workers decreased gradually as age increased. By contrast, for female workers claim rates increased gradually between 15-54 years and then declined in the over 55 years age bracket.

Table 3.2 Claims, percentages, and claim rates by age group and gender, South Australia, 2001-2010

Age range	Male			Female			Total		
	Claims	Percentage	Claim rate[b]	Claims	Percentage	Claim rate[b]	Claims	Percentage	Claim rate[b]
<15[a]	98	0.1	-	81	0.1	-	180	0.1	-
15-24	40,171	18.4	6.6	14,374	14.3	2.5	54,556	17.1	4.6
25-34	52,519	24.0	6.7	17,751	17.7	2.9	70,283	22.0	5.0
35-44	55,879	25.6	6.5	25,641	25.6	3.5	81,525	25.6	5.1
45-54	45,088	20.6	5.5	30,170	30.1	4.1	75,266	23.6	4.8
55-64	22,967	10.5	4.7	11,907	11.9	3.3	34,881	10.9	4.1
65+	1,822	0.8	1.9	419	0.4	0.9	2,241	0.7	1.6
Total	218,544	100.0	6.0	100,343	100.0	3.3	318,932	100.0	4.7

[a] <15: The denominator (labour force information) for <15 age group is not available;

[b] Claim rate: per 100 employees.

3.3.2 Season, month, and injury time

No significant differences were found in the number of claims between the four seasons during the study period (ANOVA, F=0.985, p=0.412). Nevertheless, claims reported in summer were the least among the four seasons (Table 3.3). The percentages of claims by month had significant differences (ANOVA, F=2.801, p=0.003), ranging from the highest percentage (9.0%) in March to the lowest (7.1%) in December when workers often take their annual leave (Table 3.4).

Table 3.3 Claims by season, South Australia, 2001-2010

Season	Claims	Percentage (%)
Summer (December-February)	74,710	23.4
Autumn (March-May)	81,394	25.5
Winter (June-August)	81,489	25.6
Spring (September-November)	81,294	25.5
Total	318,887	100.0

Table 3.4 Claims by month, South Australia, 2001-2010

Month	Claims	Percentage (%)
January	23,972	7.5
February	28,197	8.8
March	28,600	9.0
April	24,757	7.8
May	28,053	8.8
June	25,657	8.0
July	27,469	8.6
August	28,376	8.9
September	26,247	8.2
October	26,846	8.4
November	28,210	8.9
December	22,548	7.1
Total	318,932	100.0

As shown in Figure 3.3, the distribution of claims by time of day showed that injuries were at a low level between 1am-6am and began to increase at 7am. The first peak appeared between 10am-12pm. The second peak was observed at 3pm, and thereafter decreased gradually.

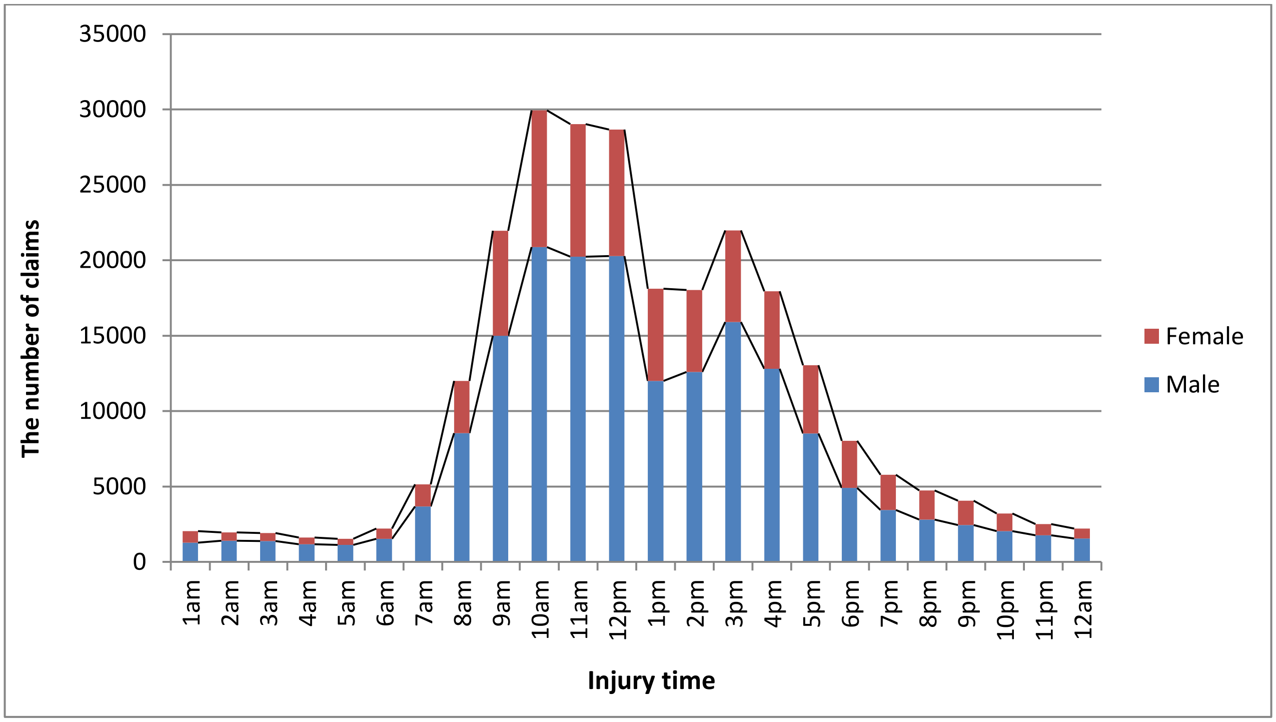

Figure 3.3 Distribution of claims by injury time and gender, South Australia, 2001-2010

3.3.3 Industry

As shown in Table 3.5, approximately two-thirds of work-related compensation claims during the study period involved three industrial sectors: 'community services (e.g. health, school education, museum, library, and meteorology services)' (27.4%), 'manufacturing' (26.7%), and 'wholesale and retail trade' (15.8%). The 'manufacturing industry' had the highest claim rate, followed by 'community services', 'transport and storage', 'mining', 'wholesale and retail trade', 'construction', and 'electricity, gas and water' during the study period.

The percentage pattern by industry for total time-lost and medical costs was similar to that for total claims. The industrial sectors recording the highest number of days of time lost due to injury were 'communication' (17), 'agriculture, fishing and forestry' (10), 'community services' (7), and 'public administration and defence' (6), which roughly coincided with the highest median medical costs.

In terms of deaths, about two-thirds of work-related deaths occurred in the following four industries during the period 2001-2010: 'community services' (38), 'transport and storage' (35), 'construction' (22), and 'manufacturing' (21). By contrast, there were no work-related deaths reported from 'electricity, gas and water' and 'communication' industries.

3.3.4 Occupation

The top three occupations having the highest percentage of total claims were 'labourers and related workers', 'intermediate production and transport workers', and 'tradespersons and related workers' respectively, as shown in Table 3.6. This was also the case for total days of time lost, medical costs, and claim rates. Advanced clerical and service workers' had the highest median medical costs, followed by 'professionals', 'managers & administrators', 'intermediate clerical and service workers', and 'associate professionals'. The occupations recording the highest number of days of time lost were 'intermediate production and transport worker' (6), 'professionals' (6), 'associate professionals' (5), and 'advanced clerical and service workers' (4). About one-third of work-related deaths occurred in intermediate production & transport workers, followed by labourers' (11.7%), tradespersons and related workers (16.1%), and 'professionals' (10.2%).

3.3.5 Nature of injury

As shown in Table 3.7, claims due to 'traumatic joint/ligament and muscle/tendon injury' accounted for 42.0% of total claims, 41.1% of total time lost and 41.9% of medical costs. 'Digestive system diseases' resulted in the highest median number of days of time lost (10) and medical costs ($5,643), although the percentages for total claims, time-loss, and medical costs for digestive system diseases were as low as 1.0%, 0.8%, and 0.7% respectively. Claims due to 'mental disorders' represented 3.8% of total claims, with the second highest median time-lost days (5) and medical costs ($5,248). 'Circulatory system diseases' were the most common causes of work-related deaths, representing about 26.3% of total deaths, followed by intracranial injuries (7.0%), and fractures (6.5%).

3.3.6 Mechanism of injury

As shown in Table 3.8, injury claims due to 'body stressing'(injuries or diseases resulting from stress placed on muscles, tendons, ligaments and bones)[238] accounted for 38.0% of all claims during the study period. About half of total time-loss days and medical costs resulted from body stressing. Among all injury mechanisms, 'mental stress' had the highest median time-loss days (5) and the second highest median medical costs ($5,445). Although 'sound and pressure' related claims only represented 1.5% of total claims, resulting in 1.1% of total time-lost and 1.1% of total medical expenditure, they resulted in the highest median medical costs ($6,316). Claims due to "heat, electricity and other environmental factors" accounted for 2.6% of all claims. About 0.6% of total time lost and 0.8% of medical costs were attributable to "heat, electricity and other environmental factors" which ranked in the lowest third for median medical costs. Eight workers died from "heat, electricity and other environmental factors", representing about 4.3% of total deaths during the study period.

Table 3.5 The number of claims, percentage, time-loss days, medical costs, and deaths by industry, South Australia, 2001-2010

SAWIC [a] Industrial Classification	Claims: n (%)	Claim rate[b]	Total time-loss days: n (%)	Time-loss days: median (25-75th percentile)	Total medical costs ($): n (%)	Medical costs($): median (25-75th percentile)	Death: n (%)
Community services	87,525 (27.4)	6.6	3,147,472 (30.6)	0 (0-7)	1,148,644,412 (28.8)	576 (144-3,533)	38 (20.4)
Manufacturing	85,131 (26.7)	10.2	2,062,355 (20.0)	0 (0-1)	946,990,274 (23.7)	400 (135-2,356)	21 (11.3)
Wholesale and retail trade	50,271 (15.8)	4.9	1,402,715 (13.6)	0 (0-0)	503,170,268 (12.6)	332 (116-1,821)	14 (7.5)
Construction	22,062 (6.9)	4.6	945,978 (9.2)	0 (0-0)	369,179,594 (9.2)	382 (119-3,480)	22 (11.8)
Recreational, personal and other services	16,648 (5.2)	2.1	643,476 (6.2)	0 (0-1)	198,163,959 (5.0)	350 (115-2,493)	7 (3.8)
Transport and storage	16,388 (5.1)	5.4	701,837 (6.8)	0 (0-3.5)	292,929,550 (7.3)	528 (168-4,013)	35 (18.8)
Finance, property and business services	12,163 (3.8)	1.3	591,880 (5.7)	0 (0-2)	199,840,951 (5.0)	520 (134-4,326)	14 (7.5)
Agriculture, fishing and forestry	9,800 (3.1)	2.7	482,379 (4.7)	0 (0-10)	162,178,359 (4.1)	465 (113-4,325)	18 (9.7)
Public administration and defence	10,700 (3.4)	2.6	153,111 (1.5)	0 (1-6)	77,522,584 (1.9)	964 (279-4,101)	4 (2.2)
Mining	3,496 (1.1)	5.0	101,176 (1.0)	0 (0-1)	62,489,395 (1.6)	621 (139-5,916)	7 (3.8)
Electricity, gas and water	2,408 (0.8)	3.2	12,927 (0.1)	0 (0-0)	13,244,011 (0.3)	399 (120-1,892)	0 (0.0)
Communication	213 (0.1)	0.2	17,466 (0.2)	0 (0-17)	6,406,118 (0.2)	813 (145-11,787)	0 (0.0)
Non-classified	2,127 (0.7)	-	36,121 (0.4)	0 (0-0)	12,561,232 (0.3)	0 (0-0)	6 (3.2)
Total	318,932 (100)	4.7	10,298,893 (100)	0 (0-3)	3,993,320,712 (100)	443 (132-2,943)	186 (100.0)

[a] SAWIC: South Australia WorkCover Industrial Classification (SAWIC);

[b] Claim rate: per 100 employees.

Table 3.6 The number of claims, percentage, time-loss days, medical costs, and deaths by occupation, South Australia, 2001-2010

Occupation classification [a]	Claims: n (%)	Claim rate [b]	Total time-loss days: n (%)	Time-loss days: median (25-75th percentile)	Total medical costs ($): n (%)	Medical costs($): median (25-75th percentile)	Death: n (%)
Labourers and related workers	71,687 (22.5)	10.2	2,709,247 (26.3)	0 (0-3)	972,672,890 (24.4)	427 (133-2937)	33 (17.7)
Tradespersons and related workers	64,759 (20.3)	7.5	1,514,787 (14.7)	0 (0-0)	614,851,376 (15.4)	303 (114-1,826)	30 (16.1)
Intermediate production and transport workers	60,355 (18.9)	9.8	2,105,044 (20.4)	0 (0-2)	894,755,781 (22.4)	489 (155-3314)	61 (32.8)
Intermediate clerical and service workers	33,123 (10.4)	2.9	1,296,555 (12.6)	0 (0-6)	440,998,252 (11.0)	577 (143-3,800)	4 (2.2)
Associate professionals	28,899 (9.1)	3.5	841,871 (8.2)	0 (0-5)	345,736,611 (8.7)	577 (151-3,626)	0 (0.0)
Elementary clerical, sales and service workers	24,245 (7.6)	3.9	747,667 (7.3)	0 (0-3)	251,754,238 (6.3)	443 (137-2,704)	7 (3.8)
Professionals	23,800 (7.5)	2.0	769,609 (7.5)	0 (0-6)	328,804,269 (8.2)	748 (166-4,387)	19 (10.2)
Managers & administrators	5,336 (1.7)	0.9	218,173 (2.1)	0 (0-2)	106,029,683 (2.7)	706 (154-5,655)	14 (7.5)
Advanced clerical and service workers	3,162 (1.0)	1.4	86,126 (0.8)	0 (0-4)	34,220,974 (0.9)	909 (206-5,100)	0 (0.0)
None-classified	3,566 (1.1)	-	9,814 (0.1)	0 (0-0)	3,496,637 (0.1)	0 (0-0)	1 (0.5)
Total	318,932 (100)	4.7	10,298,893 (100)	0 (0-3)	3,993,320,712 (100)	443 (132-2,943)	186 (100.0)

[a] Occupation classification: Australian Standard Classification of Occupation;

[b] Claim rate: per 100 employees.

Table 3.7 The number of claims, percentage, time-loss days, medical costs, and deaths by nature of injury or illness, South Australia, 2001-2010

Diagnosis of injury	Claims: n (%)	Total time-loss days: n (%)	Time-loss days: median (25-75th percentile)	Total medical costs ($): n (%)	Medical costs($): median (25-75th percentile)	Death: n (%)
Traumatic joint/ligament and muscle/tendon injury	134,027 (42.0)	4,234,184 (41.1)	0 (0-4)	1,672,460,964 (41.9)	621 (196-3,177)	1 (0.5)
Wounds, lacerations, amputations and internal organ damage	69,406 (21.8)	504,467 (4.9)	0 (0-0)	229,457,297 (5.7)	182 (77-426)	11 (5.9)
Musculoskeletal and connective tissue diseases	34,713 (10.9)	2,684,300 (26.1)	0 (0-27)	949,695,770 (23.8)	1,908 (432-14,742)	2 (1.1)
Fractures	12,986 (4.1)	773,162 (7.5)	1 (0-33)	298,308,098 (7.5)	2,387 (410-11,547)	12 (6.5)
Mental disorders	12,061 (3.8)	1,249,934 (12.1)	5 (0-88)	433,448,192 (10.9)	5,284 (792-30,887)	6 (3.2)
Nervous system and sense organ diseases	11,177 (3.5)	339,317 (3.3)	0 (0-0)	161,073,465 (4.0)	1,885 (203-12,169)	0 (0.0)
Burn	6,839 (2.1)	48,394 (0.5)	0 (0-0)	27,955,494 (0.7)	183 (76-516)	4 (2.2)
Skin and subcutaneous tissue diseases	5,153 (1.6)	68,455 (0.7)	0 (0-0)	25,247,342 (0.6)	231 (86-1,020)	0 (0.0)
Digestive system diseases	3,055 (1.0)	78,391 (0.8)	10 (0-25)	29,665,895 (0.7)	5,643 (2,945-9,206)	1 (0.5)
Intracranial injuries	2,209 (0.7)	65,454 (0.6)	0 (0-1)	32,915,981 (0.8)	345 (80-1,108)	13 (7.0)
Respiratory system diseases	1,012 (0.3)	37,891 (0.4)	0 (0-6)	13,063,102 (0.3)	1,197 (283-6,025)	2 (1.1)
Circulatory system diseases	606 (0.2)	45,864 (0.4)	0 (0-29)	26,165,823 (0.7)	2,535 (223-19,339)	49 (26.3)
Infectious and parasitic diseases	762 (0.2)	15,513 (0.2)	0 (0-5)	4,578,673 (0.1)	437 (58-1,420)	1 (0.5)
Injury to nerves and spinal cord	387 (0.1)	27,027 (0.3)	0 (0-22)	15,175,460 (0.4)	2,918 (497-9,718)	0 (0.0)
Neoplasms (cancer)	134 (0.0)	1,960 (0.0)	0 (0-2)	1,405,007 (0.0)	1,431 (269-5,808)	5 (2.7)
Other illnesses and injuries	24,405 (7.7)	124,580 (1.2)	0 (0-0)	72,704,149 (1.8)	487 (69-2,016)	79 (42.5)
Total	318,932 (100)	10,298,893 (100)	0 (0-3)	3,993,320,712 (100)	443 (132-2,943)	186 (100.0)

Table 3.8 The number of claims, percentage, time-loss days, medical costs, and deaths by mechanism of injury or illness, South Australia, 2001-2010

Mechanism of injury	Claims: n (%)	Total time-loss days: n (%)	Time-loss days: median (25-75th percentile)	Total medical costs ($): n (%)	Medical costs($): median (25-75th percentile)	Death: n (%)
Body stressing	121,116 (38.0)	5,149,180 (50.0)	0 (0-8)	1,932,453,254 (48.4)	869 (246-5,301)	10 (5.4)
Hitting objects with a part of the body	56,209 (17.6)	949,594 (9.2)	0 (0-0)	394,195,463 (9.9)	221 (90-793)	28 (15.1)
Falls, trips and slips of a person	49,206 (15.4)	1,811,904 (17.6)	0 (0-6)	694,036,557 (17.4)	600 (169-3,921)	12 (6.5)
Being hit by moving objects	39,980 (12.5)	266,035 (2.6)	0 (0-0)	112,726,945 (2.8)	182 (82-429)	1 (0.5)
Mental stress	11,834 (3.7)	1,232,576 (12.0)	5 (0-89)	431,901,923 (10.8)	5,445 (833-31,432)	21 (11.3)
Chemicals and other substances	8,819 (2.8)	92,867 (0.9)	0 (0-0)	36,805,515 (0.9)	144 (53-534)	8 (4.3)
Heat, electricity and other environmental factors	8,268 (2.6)	56,684 (0.6)	0 (0-0)	32,360,824 (0.8)	172 (72-478)	8 (4.3)
Sound and pressure	4,697 (1.5)	6,223 (0.1)	0 (0-0)	45,551,224 (1.1)	6,316 (790-15,364)	0 (0.0)
Biological factors	1,548 (0.5)	20,141 (0.2)	0 (0-2)	6,490,307 (0.2)	169 (45-727)	1 (0.5)
Other and unspecified mechanisms	13,716 (4.3)	713,689 (7.0)	0 (0-7)	306,798,698 (7.7)	794 (150-6,057)	95 (51.5)
Total	318,932 (100)	10,298,893 (100)	0 (0-3)	3,993,320,712 (100)	443 (132-2,943)	186 (100.0)

3.3.7 Other distribution characteristics

Claims lodged by new workers (the duration of work less than one year or those aged ≤18 years)[257] accounted for 19.3% of total claims. The vast majority (97.9%) of claimants reported that English was their first language. Approximately three-quarters of workers sustaining work-related injuries or illnesses were born in Australia (75.9%), followed by UK (7.7%) and New Zealand (1.2%). During the study period, over half (50.7%) of claims were reported by large businesses (≥201 employees).[258] The percentages for medium (21-200 employees) and small (1-20 employees)[258] businesses were 31.5% and 15.8% respectively.

3.4 Discussion

This chapter has depicted a picture of the distribution characteristics of workers' compensation claims in South Australia in the period 2001-2010. Both the number of claims and claim rates demonstrated a gradual downward trend over the study period due to the increasing improved occupational health and safety interventions, which is consistent with the results of WorkCover South Australia' statistical reviews[259] and in alignment with the designated goals of the National OH&S Strategy 2002-2012.[39]

3.4.1 Gender

In this study, it was found that male workers' claim rates were obviously higher than that of female workers in all age groups. This may be due to the over-representation of males in high-risk industries. According to the Australian Bureau of Statistics (ABS), in 2012 male workers represented around 70% of the labour force in 'agriculture, fishing and forestry', 75% in manufacturing, 82% in mining, 88% in construction, and 82% in transport and storage in South

Australia.[256] Another reason resulting in gender differences on claim rates may be that female workers may be less likely to apply for workers' compensation for their work-related injury than male workers.[260] According to the Work-Related Injuries Survey (WRIS) conducted by the ABS for the period of 2005-2006,[260] 44% of female workers who sustained injuries that resulted in some time lost from work did not apply for a compensation claim compared to 36% of male workers. Regarding the specific reasons for not applying for workers' compensation, equal percentages of male and female workers cited "minor injury / not necessary" (38%) and "inconvenient / too much effort" (18%). However, a much greater percentage of male (20%) than female (10%) workers thought they were "not covered / not eligible". By contrast, female workers (20%) were more concerned that making a compensation claim would have a "negative impact on employment" than male workers (10%).[260]

3.4.2 Age

The results in the present study showed that claim rates of male workers decreased as age increased. Higher non-fatal injury rates among young workers have also been observed in other countries,[140, 261] although young workers can be less likely to make injury claims than older workers according to the ABS WRIS survey.[260] Young workers' vulnerability to injury in the workplace has generally been attributed to lack of occupational risk awareness, training, and relevant work skills, together with peer pressure.[140] According to the ABS, young workers represented about 17.0% of the labour force in South Australia,[262] accounting for 17.2% of all reported injury claims in this study. Young workers' health and safety has been listed as one of the occupational research priorities according to the recently released Australian Work Health and Safety Strategy 2012-2022 by SafeWork Australia.[38, 263]

3.4.3 Season, industry, and occupation

In this study, relatively less claims occurred in December and January compared with other months. This may be due to public holidays and that people are more likely to take annual leave during the summer months.

'Manufacturing', 'community services', 'transport and storage', and 'mining' were the four industries with the highest claim rates in South Australia. 'Community services', 'transport and storage', and 'construction' had the greatest number of work-related deaths. 'Public administration and defence' had the highest median medical costs. All of these industries were on the list of national priority industries for prevention activities.[38] Labourers, tradespersons, intermediate clerical and service workers were the top three occupations with the highest percentages of total claims, time-loss days, medical costs, and deaths. However, advanced clerical and service workers, professionals, and managers and administrators had the highest median medical costs for injury claims, possibly indirectly reflecting the high salaries associated with these occupations.[264]

3.4.4 Heat-related claims

According to the latest Type of Occurrence Classification System (TOOCS) version,[265] which has incorporated the International Classification of Diseases (ICD10) to code the type of occupational diseases and injuries, heat-related illnesses were classified as "other illnesses and injuries". This indirectly reflects that heat illnesses are not recognized as a major occupational health issue. In terms of time-lost, medical expenditure, and fatalities, the results indicate that injuries/illnesses due to exposure to heat and other environmental factors rank lower than injuries/illnesses due to mental stress, sound and pressure, and body stressing. This may explain why heat stress was not on the list of national occupational priorities.[39] The underlying impact of heat exposure on workers' health and safety may be substantial, as working in hot environments can increase the risk of work-related injury, reduce work efficiency, and compromise productivity.[19, 44, 116] However, many heat-aggravated diseases such as cardiovascular and respiratory diseases and mental disorders may not be clinically attributed to heat exposure. In many circumstances, heat is a synergistically contributing factor to illness or injury. Therefore, the effects of heat on workers' health and safety may be inevitably underestimated to some extent. Moreover, few studies have investigated the incidence and epidemiological distribution characteristics of heat illnesses, using historical occupational surveillance data.

In recent years, there has been growing research interest regarding the extent to which workers (especially those work outdoors or indoors without air conditioning) will be affected by heat in the context of a warming climate. The analysis of workers' compensation claims data provides a useful tool to explore this issue. The incidence of occupational heat illness claims in SA is discussed in the following chapter.

3.5 Conclusion

This Chapter provides implications for the time-series analyses of workers compensation claim data and weather data in the following chapters. First, the downward trend of claim rates during the study period indicates the necessity to adjust the effect of long-term trends. Second, the apparent less percentages of injury claims in December and January suggest a need to exclude public holidays from time-series analysis. Third, the effect of seasonality should be taken into account, as the number of injury claims differed significantly across months during the study period. Last, the majority of injury claims occurred in the Adelaide metropolitan area ensures the feasibility of selecting this as the study area and of using one weather station to represent the heat exposure status when analysing the association between claims and temperatures/heatwaves.

Chapter 4

Occupational heat illness in South Australia, 2001-2010

4.1 Introduction

Heat illness occurs as a direct consequence of thermoregulatory failure, and ranges from minor heat cramps to life-threatening heat stroke.[3] Compared with other occupational injuries, occupational heat illnesses are relatively uncommon due to a wide variety of reasons which may include underreporting, misclassification, increased use of machines, and air-conditioned workplaces.[37] Previous heat illness related epidemiological data analyses mainly focus on military personnel,[76, 129] athletes,[69, 266] or heat-related morbidity and mortality in the general community.[267] To date there is limited research using long-term historical surveillance data to investigate the comprehensive characteristics of heat illnesses among occupationally exposed populations[72] and their association with extreme heat exposure in the workplace.

The objectives of this Chapter are to describe the characteristics of occupational heat illnesses in South Australia, to quantify the association with ambient temperature in Adelaide, and to examine the impact of heatwaves on occupational heat illnesses.

4.2 Materials and methods

4.2.1 Workers' compensation claim data

As mentioned in Chapter 2, workers' compensation claim data were obtained from SWSA for the period from 1st July 2001 to 30th June 2010. The data included all accepted compensation claims from both registered and self-employed employers during the 9-financial year period. The Type of Occurrence Classification System (TOOCS) has been developed as coding guidelines for recording details of reported workers' compensation claims reported to workers' compensation agencies.[238] 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, bodily location, mechanism, and agency of injury/disease.[238] Each case is allocated 4 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.[256]

4.2.2 Identification of compensation claims due to heat illnesses in workplaces

As shown in the flowchart (Figure 4.1), workers' compensation claims for SA due to heat illnesses in the workplace were identified through a three step process. First, claims due to heat illnesses were searched for 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 as being heat-related by reviewing text-based diagnosis-related comments and workers' descriptions sourced from the WorkCover South Australia database. Finally, duplicate heat illness claims found using this search method were excluded.

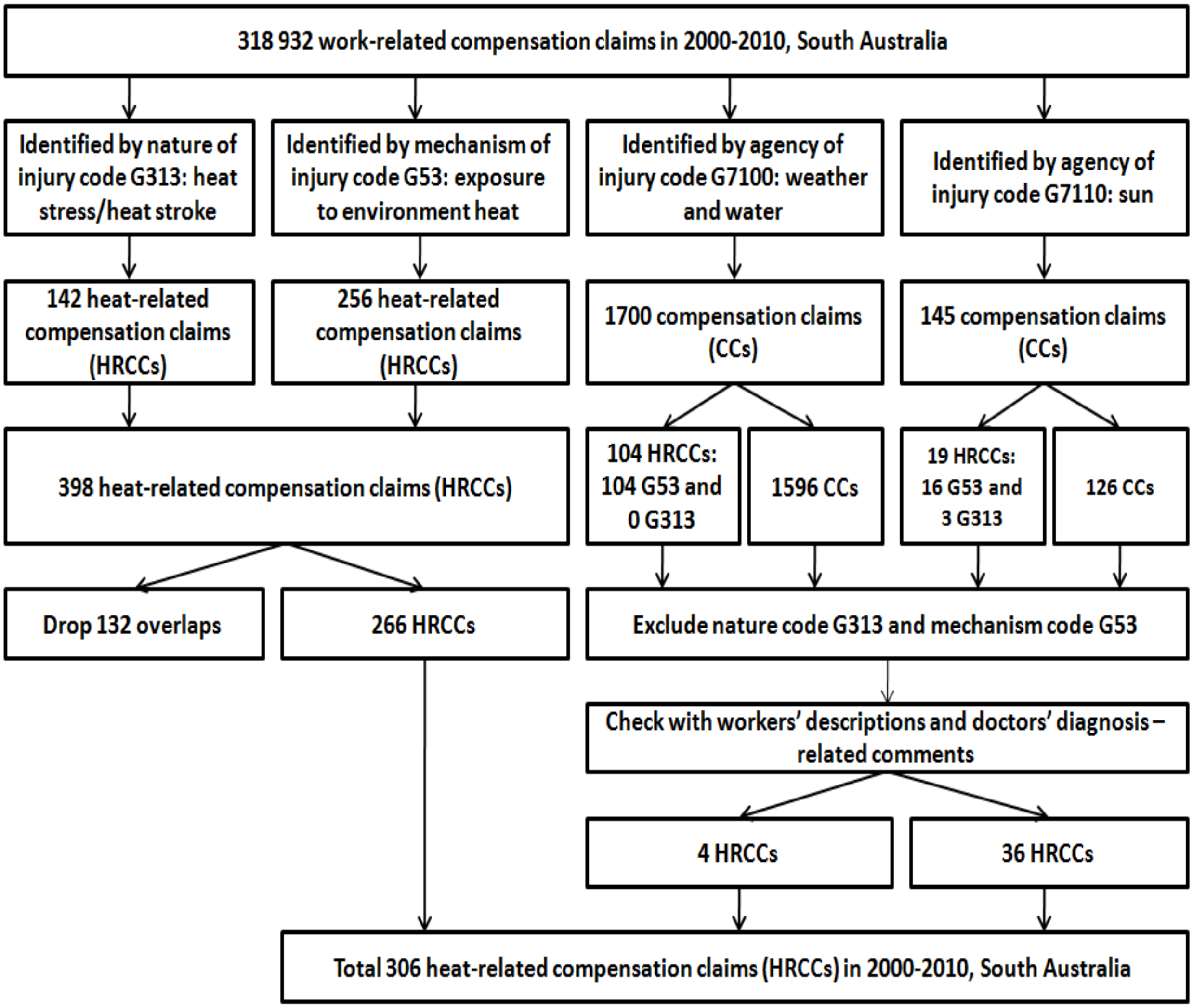

Figure 4.1 Flowchart: identification of heat-related compensation claims, South Australia, 2001-2010

4.2.3 Meteorological data

Historical weather data were obtained from the Australian Bureau of Meteorology. To quantify the temperature-occupational heat illness association 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.[11, 12] In this study, daily maximum temperature (T_{max}) was selected as the heat exposure indicator. A heatwave was defined as three or more consecutive days with T_{max} ≥35°C, as reported in previous studies in South Australia.[11, 12]

4.2.4 Statistical analyses

Descriptive analysis was first used to describe the epidemiological distribution of occupational heat illnesses occurring during the study period in South Australia. The second part of the analyses (daily temperature-heat illness claims association and the impact of heatwaves on heat illness claims) focussed 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 maximum temperatures in Adelaide was initially explored graphically using a LOWESS (locally weighted scatter plot smoothing) smoother performing a locally weighted nonparametric regression.[12] The association of T_{max} with daily heat illness claims in Adelaide was assessed using generalized estimating equation models 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 holiday and long-term trends.[27, 139]

Given 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 utilized to quantify the effect of ambient temperature on heat illness claims below and above a threshold temperature,[228] which was estimated using the hockey-stick model.[12] Results for the negative binominal regression models are expressed as incidence rate ratios (IRR) with 95% confidence interval (CIs), and interpreted as percentage change in heat illness claims with 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. In this study, both unidirectional (retrospective) and bidirectional (combination of retrospective and prospective) control samplings were used.[251, 268] For the retrospective sampling, the same weekdays 1, 2, 3 weeks before the occurrence of heat illness were selected as the control periods. For bidirectional sampling, the same weekdays 1, 2, 3 weeks before and after the occurrence of heat illness were defined as the control periods. 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 v12.0 (StataCorp LP, College Station, Texas). 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).

4.3 Results

4.3.1 Characteristics of occupational heat illness claims in South Australia

The distribution characteristics of heat illness claims and all claims are summarized in Table 4.1. For the details of the distribution characteristics of all compensation claims, refer to Chapter 3. There were 306 compensation claims identified as occupational heat illnesses from 1st July 2001 to 30th June 2010 in South Australia, representing 0.1% of all 318,932 claims reported during the study period. Of the 306 heat illness claims, 69.0% (211) occurred in the Adelaide metropolitan area as defined by postcode (Figure 4.2). The proportion of heat illness claims occurring in the metropolitan area was significantly less than that of all claims (Pearson χ^2=10.255, p=0.001).

Table 4.1 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[a] (n/ (%))	52 (17.0)	61,624 (19.3)
First language (n/ (%))		
English	302 (98.7)	312,219 (97.9)
Other	4 (1.3)	6,713 (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 (Oct-Mar)	266 (86.9)	158,373 (49.7)
Cool (Apr-Sept)	40 (13.1)	160,559 (50.3)
Employer size[b] (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)	25,4668 (79.9)
Self-employed	62 (20.3)	64,264 (20.1)
Compensated claims	n=262	n=292,912
Average cost per claim ($AU)	5,868	12, 520
Median cost ($AU)	436	423
Time lost from work	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)

[a] New worker: new workers are defined as the duration between injury date and start date with employer less than 1 year or a worker is less or equal to 18 years old;

[b] Employer size: the employer size is grouped by the number of employees as follows: small (1-20), medium (21-200), and large (≥201).[258]

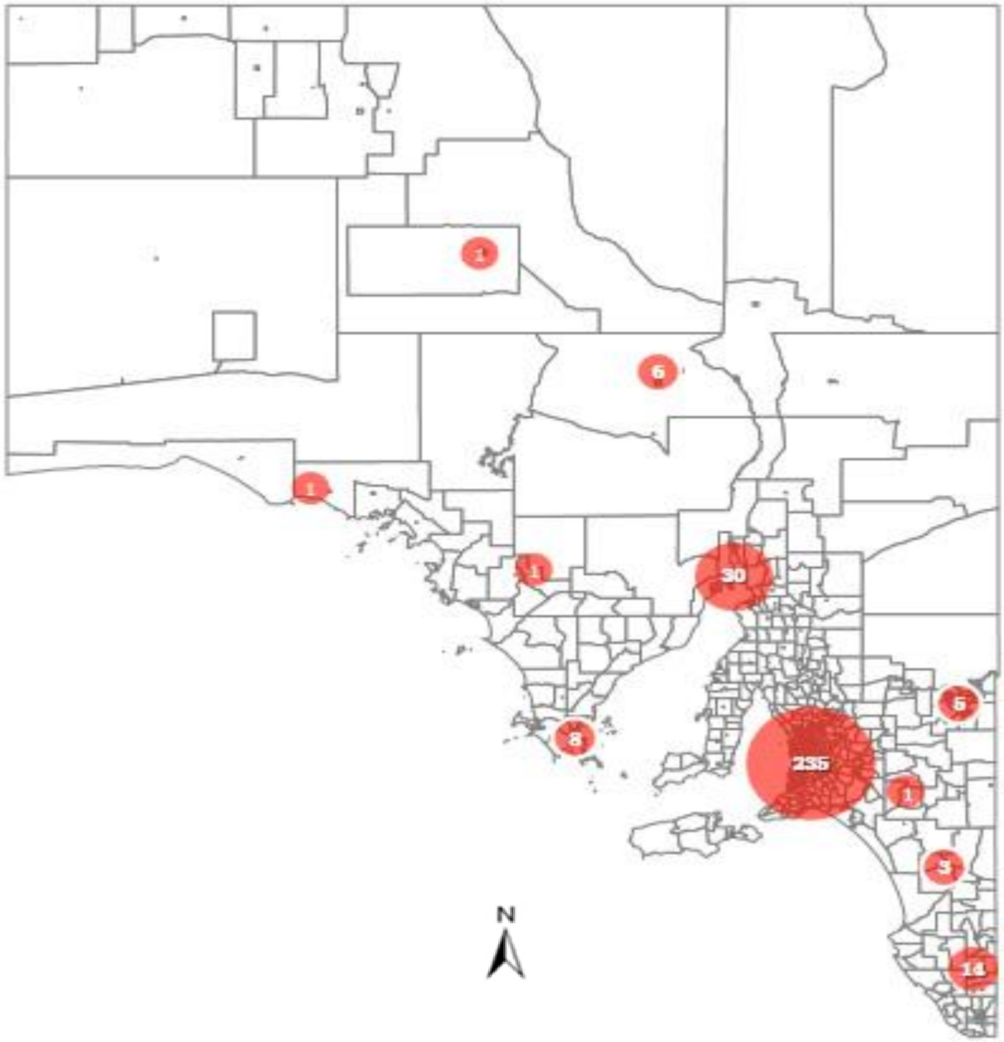

Figure 4.2 Spatial distribution of heat-related injury claims in South Australia, 2001-2010

4.3.1.1 Age and gender

Approximately 81% (248) of the total heat illness claims were for males. Male workers' proportion of heat illness claims was significantly more 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 old and the median age was 39 years. Accordingly, the average and median ages for all claims were 38.6 and 39 years respectively.

4.3.1.2 Season, month, and injury time

Approximately 86.9% of heat illness claims occurred in the warm season from October to March for South Australia, with 64.3% occurring in summer (Figure 4.3). By contrast, the percentage of all compensation claims reported in warm seasons was 49.7%. Roughly 65% of heat illness claims occurred during the hottest part of the day between 10am and 6pm (Figure 4.4). Similar to all compensation claims, about half of heat illness claims occurred in large businesses.

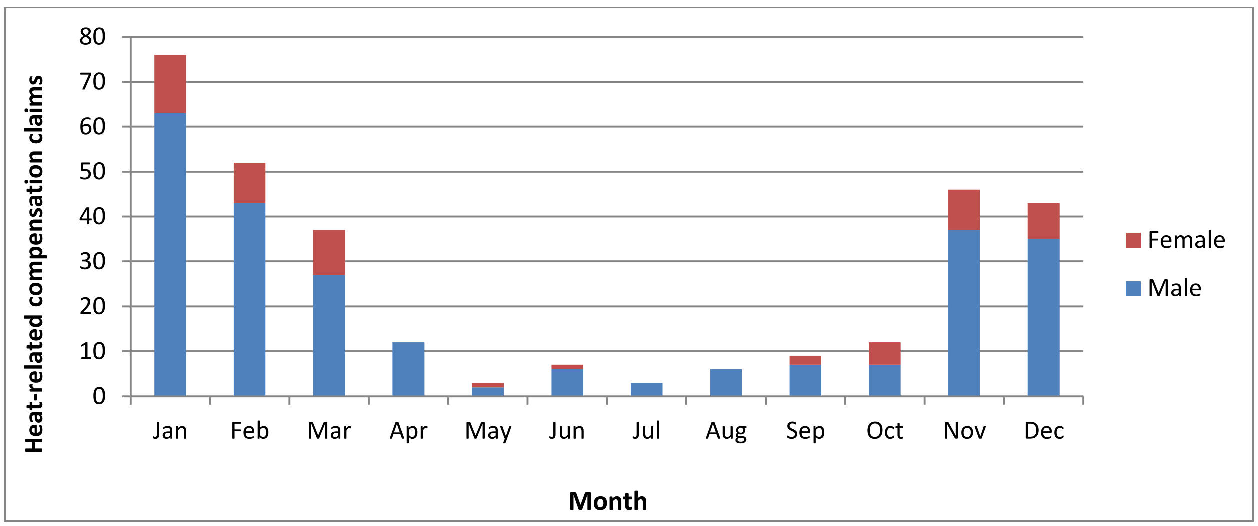

Figure 4.3 Distribution of heat illness compensation claims by month in South Australia, 2001-2010

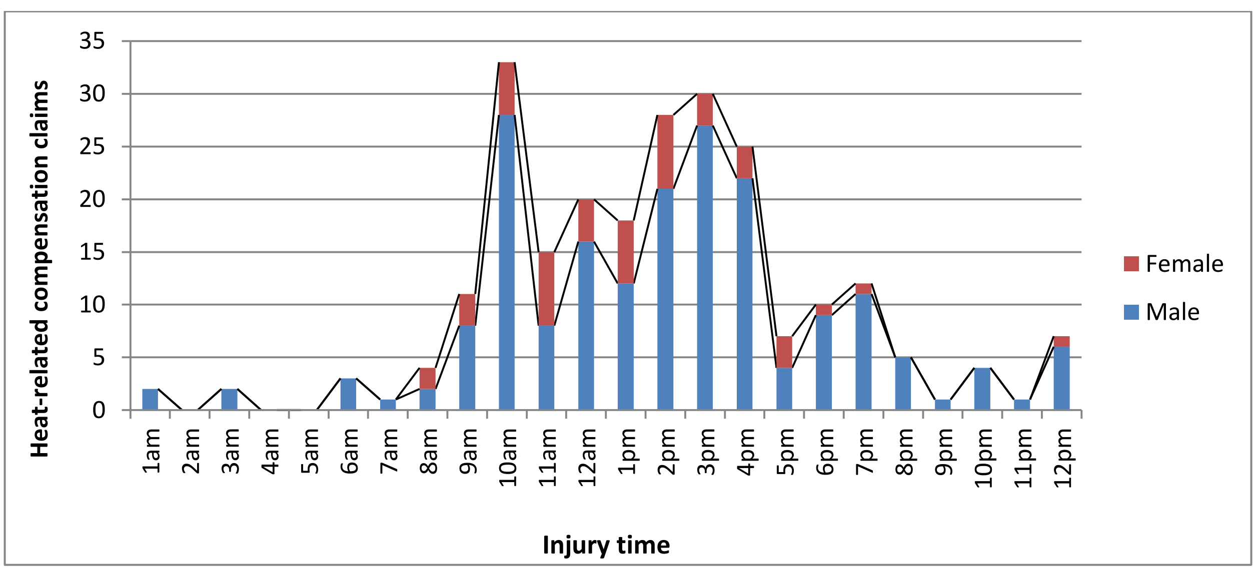

Figure 4.4 Distribution of heat illness compensation claims by injury time in South Australia, 2001-2010

4.3.1.3 Medical expenditure and time lost

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 4.1). The average expenditure for each heat illness claim was \$5,868, 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. The death rate for heat illness claims (3.3 ‰) was roughly more than 6 times that for all claims (0.5‰).

4.3.1.4 Industry

As shown in Table 4.2, 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 defense (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%).

Table 4.2 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			All compensation claims		
	n	%	Incidence rate[a]	n	%	Claim rate[b]
Agriculture, forestry and fishing	13	4.3	3.5	9,770	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	2,420	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	3,463	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	-	2,782	0.9	-
Total	306	100.0	4.5	318,932	100.0	4.7

[a] Incidence rate: per 100,000 employees;

[b] Claim rate: per 100 employees

4.3.1.5 Occupation

As shown in Table 4.3, 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 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).

Table 4.3 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			All compensation claims		
	n	%	Incidence rate[a]	n	%	Claim rate[b]
Advanced clerical and service workers	1	0.3	0.4	3,162	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 & administrators	2	0.7	0.3	5,336	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

[a] Incidence rate: per 100,000 employees;

[b] Claim rate: per 100 employees

4.3.2 Analyses focusing on Adelaide metropolitan area

4.3.2.1 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 4.5, there was no significant increase in daily occupational heat illness claims (IRR 0.990, 95% CI 0.975-1.006) in Adelaide with the increase of T_{max} below a threshold of 35.5℃ (95% CI 34.4℃-36.7℃, p<0.001), which was estimated using hockey stick model. However, when T_{max} was above 35.5℃, 1 ℃ increase of T_{max} was associated with 12.7% (IRR 1.127, 95% CI 1.067-1.190) increase of occupational heat illness claims in Adelaide.

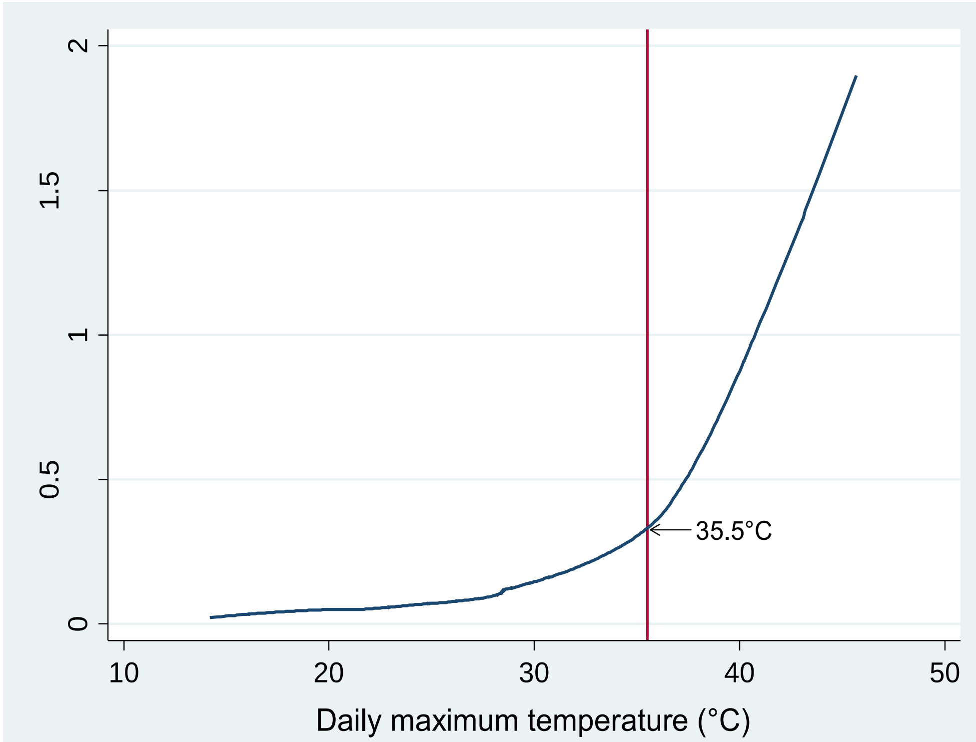

Figure 4.5 Association between daily maximum temperature and daily occupational heat illness claims in Adelaide, South Australia, 2001-2010

4.3.2.2 Impact of heatwaves on heat illness claims in Adelaide

A total of 21 heatwaves were recorded during the study period in Adelaide over the study period. Of the 211 heat illness claims which 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 3 control periods before the case period, the risk of occupational heat illness during heatwaves was about 7 times that during non-heatwaves (OR=6.775, 95% CI 4.032-11.383). Case-crossover models with one or two control referent periods before the case period when heat illness occurred produced similar results (OR=4.500, 95% CI 2.268-8.929; OR=5.341, 95% CI 3.074-9.279, respectively). For bidirectional sampling, ORs for 1, 2, 3 weeks before and after the occurrence of occupational heat illness were 6.121, 5.908, and 5.942 respectively.

Table 4.4 The odds ratios (OR) of occupational heat illness claims during heatwave periods compared with non-heatwave periods in different control groups, Adelaide, South Australia, 2001-2010

Control	OR	95% CI
Before case period		
7 d	4.500	2.268-8.929
7 and 14 d	5.341	3.074-9.279
7, 14 and 21 d	6.775	4.032-11.383
Before and after case period		
7 d	6.121	3.345-10.906
7 and 14 d	5.908	3.663-9.528
7, 14 and 21 d	5.942	3.888-9.081

4.4 Discussion

With predictions of increasing temperatures,[32, 35, 36] 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 mis-diagnosis, underreporting, and misclassification, 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 policy-making and in developing occupational health and safety education and promotion campaigns for extreme heat.

4.4.1 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 1995-2005.[72] However, the incidence rate in South Australia (4.5 per 100,000 employees) was higher than that in Washington State (3.1 per 100,000 employees).

Studies overseas have shown the reported heat stroke incidence rate in the US general population varies from 17.6 to 26.5 cases per 100,000 people.[269] In Saudi Arabia, the heat stroke incidence has been shown to vary seasonally, from 22 to 250 cases per 100,000 population. By contrast, reports show the incidence of mild heat illnesses such as heat exhaustion in Saudi Arabia ranges from 450 to more than 1,800 cases per 100,000 population.[270] The remarkably higher heat illness incidence rates in the community compared to the workplace may be firstly attributed to the healthy worker effect, as infants, children (<15 years), the elderly (>75 years), and people with disabilities and chronic diseases in the community are relatively more vulnerable to extreme heat than healthy working people. Secondly, it may be because of underreporting of heat illnesses in the workplace. This is could be due to (1) some workers believing their condition is too minor to make a claim, (2) too inconvenient to claim, or (3) the workers could be worried about future employment.[260] The occupational heat illness incidence rate in this study was also far less than recorded heat illness claims among the military personnel[271] and athletes,[272] as they often perform strenuous exercise during extremely hot weather.

In Australia, heat stress has not been listed in the six national 2012-2022 occupational health priorities,[38] which could be due to its low incidence when compared with other occupational injuries. The results in this study showed that both average cost and average days lost per heat illness claim were much less than the average levels for all claims, which is consistent with the findings of Bonuato et al's USA study.[72] 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.[3] 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, and result in loss of work time.[36] This is particularly so for low-middle income countries where adequate protective measurements may be lacking.[234]

4.4.2 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.[72, 76] However, although studies have shown women to be less heat tolerant than men,[116, 146] both male and females workers should be targeted in the preventive measurements. The results also showed that about half of heat illnesses occurred in the 35-54 years age group. This is similar to previous 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.[273] This could be due to aging-induced degraded thermoregulation functions, relatively high prevalence of some heat-triggered chronic diseases, the use of certain medications, or pertinent morphological factors.[14, 274] However, young workers are likely to have greater heat exposure, undertake more strenuous tasks during hot days and lack heat prevention skills when compared with older workers.[139, 141] Therefore, preventive measures should be targeted to all age groups.

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.[71, 72, 76] The findings in this study showed that approximately 65% of heat illness claims occurred between 10am and 6pm, which is similar to the hour distribution of overall injury claims as shown in Figure 3.2 (Chapter 3). 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.

The association between temperature and heat illness claims was quantified after controlling for confounding factors such as day of the week, public holiday and long-term trends. The estimated 35.5℃ 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.[181] This study may provide scientific evidence to develop or refine heat-related regulations and guidelines in relevant industries. Moreover, the results showed that relatively higher heat illness incidence rates were observed in the mining and ‘electricity, gas and water’ industries, and those employed as labourers and tradespersons.

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 during heatwaves was between 4-7 times higher than that during non-heatwave periods in the workplace, 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.

4.4.3 Heat illness prevention

Occupational heat illness is preventable. 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[53, 54]. Multidisciplinary collaboration is essential for the successful control and management of heat stress. This may involve employers, employees, occupational physicians and nurses, and worker health and safety representatives, occupational hygienists, managers, and decision makers. To prepare for the challenge of increasing weather-related heat stress the following two issues should be 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 were not well prepared for climate change related rising temperatures.[108, 116] To address lack of awareness of the dangers of working in hot weather, the US Occupational Safety & Health Administration recently launched a nationwide campaign.[171] 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 (ISO) is currently re-considering its current heat-related standards to meet future requirements.[52]

4.4.4 Limitations

There are several limitations in this study. First, to facilitate the understanding of the temperature-heat illness relationship, maximum dry air temperature was selected as the heat exposure indicator rather than some composite heat indices which take account of the combined effects of temperature, relative humidity, wind speed, and solar radiation (i.e. WBGT). However, evidence shows that different heat indices have similar predictive abilities.[275] Second, the quantitative effects of heatwaves on occupational heat illnesses may be overestimated, as health care providers may more readily recognize and diagnose heat illnesses during hot days in summer.[72] Third, the relatively small number of occupational heat illnesses (306 over the 10 year period) dictates cautious interpretation of results. Fourth, workers are more likely to take holidays over summer, which may result in occupational heat illnesses being underestimated due to a decreased workforce. Fifth, 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. Finally, we did not investigate the impacts of some personal risk factors such as medical conditions, use of certain medications, and levels of fitness and acclimatization on the occurrence of heat illness, due to unavailability of data.

4.5 Conclusion

Relatively high heat illness incidence rates were observed in mining and 'electricity, gas and water' industries, and 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}, characterized with a significant increase when T_{max} over 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 minimize 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.

Chapter 5

The association between high temperature and work-related injuries

5.1 Introduction

As mentioned in Chapter 1, excessive workplace heat exposure without sufficient protection may not only directly cause heat illnesses but also increase the risk of work-related injuries/accidents.[27-29, 226] Moreover, it has been recognized that working in hot environments may result in considerable economic productivity loss due to the reduced work efficiency and afternoon work time.[20, 36, 41, 42, 44, 45, 131, 276] In recent years, there has been a growing concern in the literature about the impact of heat-related events on workers' health and safety,[19-21] especially with the projected increase of extremely hot weather in a warming climate. However, the specific categories of workers impacted by heat exposure remain unknown. It is also unclear if there is a direct link between occupational injuries/accidents and high temperatures, given possible impacts on hydration and concentration levels;[20, 29] and of profuse sweating on visual acuity[60] and ability to safely handle tools and machinery.[166] The paucity of international literature on this topic highlights the fact that this important area of occupational heat-health remains under-researched.

Many epidemiological studies have found that extremely hot weather was associated with excess morbidity and mortality in the general population. [5-9, 11-18] However, research on occupational heat exposure is more limited than those from general communities and it has been argued that occupational heat exposure due to climate change effects has received little attention.[19-21, 37, 40, 64,

[168] The purposes of this chapter were therefore to: (1) examine the association between hot weather and work-related injuries in Adelaide; 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.

5.2 Materials and methods

5.2.1 Workers' compensation claim data

As mentioned previously, workers' injury claims data for Adelaide were obtained from SWSA for the period of 1st July 2001 to 30th June 2010. The data include all accepted injury claims from both registered and self-employed employers in the Adelaide metropolitan area during the 9-financial year period. Information identifying individual workers or employers was removed prior to 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 (i.e. time lost from work and total medical expenditure).

5.2.2 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.[11, 12] 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 the similar predictive abilities,[275] 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.

5.2.3 Statistical analyses

The workers injury claim data were transformed into 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 nonparametric regression, with a bandwidth of 0.8 (utilizing 80% of the data).[12]

The association of temperature with daily workers' injury claims was assessed by using generalized 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 generalized 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.[11, 13, 15, 16, 18, 27, 139, 222] 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 utilized to account for non-linearity and quantify the effect of workplace heat exposure on work-related injuries below and above a threshold temperature.[228] The threshold temperatures were estimated by using a hockey-stick model.[12]

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. Possible 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 based on 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.[258]

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 remaining other 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 Schwarz's Bayesian information criterion (SBIC), the Akaike's information criterion (AIC), and the Hannan-Quinn information criterion (HQIC), using the Stata command 'varsoc'.[139] The 0.05 level of statistical significance was adopted for each test. Results for the GEE models are expressed as incidence rate ratios (IRR) with 95% confidence interval (CIs), and interpreted as percent change in daily injury claims per degree increase of T_{max} below or above threshold temperatures. All analyses were conducted using Stata v12.0 (StataCorp LP, College Station, Texas).

5.3 Results

The daily average maximum and minimum temperatures during the period of 1st July 2001 to 30th June 2010 were 22.8℃ and 12.4℃ respectively. The average daily relative humidity (9am and 3pm readings) was 59.2%. The corresponding indicators in the warm season were 27.0℃, 15.2 ℃, and 50.6%, respectively (Table 5.1).

This study included 252,183 workers' injury claims reported during the 9-financial year period in the Adelaide metropolitan area, representing 76.7% of all injury claims during the same period in SA. Figure 5.1 demonstrates the scatter plot of daily injury claims for Adelaide. Overall, there is a gradual downward trend with two clusters, the upper cluster representing daily claims during week days, the lower representing weekends and public holidays.

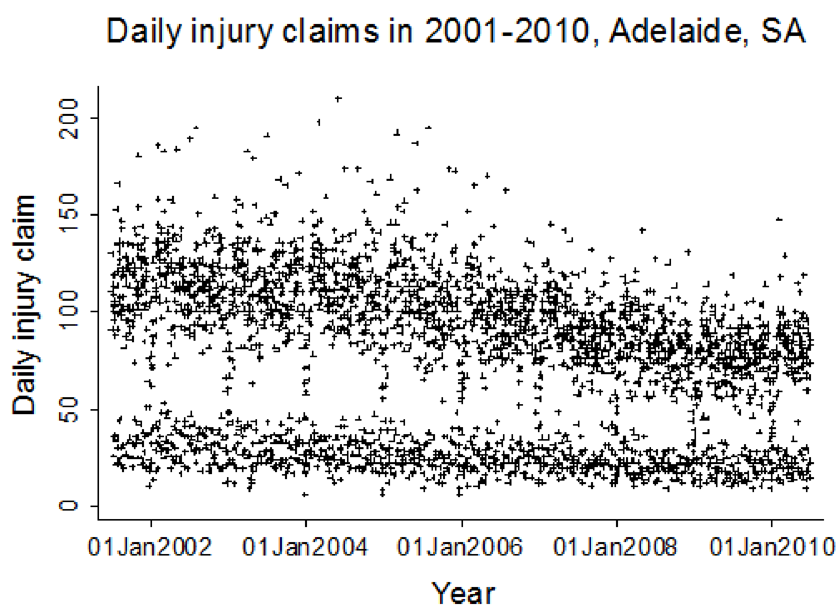

Figure 5.1 Characteristics of daily injury claims in 2001–2010, Adelaide, South Australia

As shown in Table 5.2, during the study period the percentage of workers' injury claims for males was twice that of females. Almost half (48.8%) of total injury claims in Adelaide occurred in the 35-54 age group. A total of 65,798 injury claims occurred in the large enterprises, representing just over half (52.5%) of all claims. Mean daily injury claims on weekdays (121.1) were more than three times that on weekends (35.1) and more than twice that on public holidays (47.8) during the study period.

Table 5.1 Summary statistics for meteorological indicators in Adelaide, South Australia, 2001-2010

Meteorological indicators	Warm seasons			All seasons		
	Mean (SD*)	5% Percentile	95% Percentile	Mean (SD*)	5% Percentile	95% Percentile
Daily maximum temperature	27.0 (6.2)	17.9	38.5	22.8 (6.8)	14.2	36.1
Daily minimum temperature	15.2 (4.4)	8.8	23.3	12.4 (4.7)	5.1	21.3
Daily average temperature	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

*SD: Standard deviation

Table 5.2 Number and percentage of workers' injury claims in Adelaide, South Australia, 2001-2010

Classification	Warm season	All seasons
Total	125,267	252,183
Gender		
Male	85,138 (68.0%)	170,864 (67.8%)
Female	40,129(32.0%)	81,319 (32.2%)
Age group		
≤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		
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)

5.3.1 Threshold temperature

A reversed U-shaped exposure-response relationship between T_{max} and overall daily injury claims was observed (Figure 5.2-A). Daily workers' injury claims increased with the increase of T_{max}, but declined markedly when temperatures were extremely hot. In principle, three or more piecewise regressions may more accurately reflect the shape of the temperature-claim association, but the introduction of two or more cut-points may make the interpretation of results and comparison within each stratum more difficult.[22] Therefore, one cut-point (threshold) was used to reduce the impact of non-linearity.

Often, extreme heat is defined as above 95% percentile of local maximum temperature,[11, 277, 278] which was 38.5℃ in this study. The threshold estimated by a hockey stick model was 37.7℃ for all claims (Table 5.3). Therefore, 37.7℃ 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 sub-groups, specific thresholds were estimated by different strata to quantify the temperature-claim association (Table 5.3). The threshold temperatures ranged from 31.8℃ to 38.9℃, with an average of 37.1℃.

5.3.2 Total effects

As shown in Table 5.3 (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 1.001-1.004) increase in daily injury claim was observed with an increase of 1 degree of T_{max} below 37.7℃. However, the overall daily injury claims decreased by 1.4% (IRR 0.986, 95% CI 0.975-0.998) per degree when the T_{max} was above 37.7℃.

5.3.3 Age and gender

Daily claims increased by 0.4% for male workers (IRR 1.004, 95% CI 1.002-1.006) per degree increase of T_{max} below 37.7℃. By contrast, significant change for female workers was not observed. When the temperature exceeded threshold temperatures, daily injury claims significantly decreased by 1.8% (IRR 0.982, 95% CI 0.964-0.999) 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 1.002-1.008) increase in injury claims per degree of T_{max} below 37.9℃. When the T_{max} exceeded threshold temperatures, a significant decrease in injury claims was observed in all age groups except the ≥55 years age group.

5.3.4 Business size

As shown in Table 5.3, 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 1.003-1.011) and 0.4% (IRR 1.004, 95% CI 1.002-1.006), respectively with degree increase of T_{max} below thresholds. In contrast, no significant change for large enterprises was observed.

5.3.5 Industry and occupation

As shown in Table 5.3, 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 daily claims, followed by labourers (20.4), and intermediate production and transport workers (19.8).

Table 5.3 Daily injury claims, thresholds, and IRR estimates of T_{max} (lag 0) on daily injury claims by gender, age group, industry and occupation in warm seasons (October-March), Adelaide, South 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 (35.2-40.1)	1.002 (1.001-1.004)	0.027	0.986 (0.975-0.998)	0.017
Gender						
Male	69.1 (18.9)	37.7 (35.2-40.2)	1.004 (1.002-1.006)	0.000	0.982 (0.964-0.999)	0.048
Female	30.9 (9.1)	37.5 (34.8-40.1)	0.998 (0.994-1.001)	0.206	0.995 (0.981-1.011)	0.550
Age group						
≤24	17.1 (5.7)	37.9 (35.5-40.3)	1.005 (1.002-1.008)	0.000	0.977 (0.960-0.994)	0.009
25-34	22.5 (8.2)	37.4 (34.8-40.0)	1.002 (0.999-1.005)	0.206	0.979 (0.961-0.998)	0.036
35-54	48.7 (13.9)	37.7 (35.3-40.0)	1.001 (0.999-1.003)	0.211	0.982 (0.967-0.998)	0.028
≧55	11.6 (4.4)	38.2 (32.4-43.9)	1.000 (0.997-1.003)	0.928	1.020 (0.984-1.057)	0.284
Business size						
Large	51.8 (15.1)	36.2 (32.1-40.3)	1.000 (0.997-1.002)	0.741	0.996 (0.978-1.014)	0.656
Medium	32.1 (8.8)	37.1 (34.8-39.4)	1.004 (1.002-1.006)	0.001	0.978 (0.953-1.005)	0.110
Small	16.0 (5.6)	31.8 (27.9-35.6)	1.007 (1.003-1.011)	0.001	0.982 (0.958-1.007)	0.153
Industrial sectors						
Outdoor industries (sub-total)	8.9 (3.5)	37.8 (34.2-41.3)	1.005 (1.001-1.009)	0.009	0.966 (0.956-0.977)	0.000
Agriculture, forestry and fishing	0.9 (1.0)	37.9 (33.5-42.3)	1.007 (1.001-1.013)	0.018	0.905 (0.808-1.013)	0.083
Construction	7.3 (3.1)	37.7 (34.1-41.3)	1.006 (1.002-1.011)	0.002	0.954 (0.936-0.972)	0.000
Electricity, gas and water	0.8 (0.9)	37.2 (34.8-40.0)	0.992 (0.977-1.008)	0.328	1.029 (1.002-1.058)	0.039
Indoor industries (sub-total)	91.0 (23.6)	37.0 (34.9-39.1)	1.002 (0.999-1.004)	0.063	0.988 (0.977-1.000)	0.052
Communication	0.1 (0.3)	36.7 (26.0-47.4)	1.006 (0.975-1.038)	0.685	0.841 (0.449-1.576)	0.589
Community services	28.4 (8.5)	37.1 (34.4-39.9)	1.001 (0.998-1.004)	0.547	0.991 (0.976-1.006)	0.225
Finance, property and business services	4.4 (2.4)	38.3 (30.7-45.9)	1.008 (0.999-1.017)	0.073	0.905 (0.808-1.013)	0.083
Manufacturing	27.2 (10.9)	37.0 (34.7-39.4)	1.002 (0.998-1.006)	0.271	0.991 (0.957-1.026)	0.592
Public administration and defense	3.3 (2.1)	36.9 (30.0-43.8)	0.998 (0.993-1.004)	0.542	0.956 (0.894-1.023)	0.197
Recreational, personal and other services	4.7 (2.4)	37.7 (34.0-41.4)	1.002 (0.996-1.007)	0.576	0.965 (0.922-1.010)	0.124
Transport and storage	5.5 (2.7)	37.0 (33.4-40.6)	1.006 (1.000-1.012)	0.062	0.987 (0.945-1.030)	0.542
Wholesale and retail trade	16.9 (5.2)	37.9 (34.7-41.1)	1.001 (0.999-1.004)	0.304	0.991 (0.963-1.020)	0.554
Occupations						
Advanced clerical and service workers	1.3 (1.7)	35.0 (32.5-39.4)	1.014 (0.994-1.034)	0.180	0.974 (0.923-1.034)	0.342
Associate professionals	9.0 (4.8)	38.4 (35.7-41.0)	1.002 (0.999-1.005)	0.146	0.970 (0.943-0.998)	0.037

Elementary clerical, sales and service workers	7.6 (4.8)	35.2 (23.1-47.3)	0.998 (0.992-1.004)	0.466	1.003 (0.980-1.027)	0.788
Intermediate clerical and service workers	10.3 (4.4)	36.0 (32.6-39.4)	0.997 (0.992-1.002)	0.307	0.996 (0.967-1.026)	0.805
Intermediate production and transport workers	19.8 (7.5)	37.6 (34.1-39.5)	1.003 (1.001-1.005)	0.004	0.987 (0.965-1.009)	0.233
Labourers and related workers	20.4 (10.4)	36.8 (34.1-39.5)	1.005 (1.001-1.010)	0.018	0.988 (0.965-1.012)	0.323
Manager & administrators	1.6 (1.5)	38.9 (31.9-45.9)	1.002 (0.993-1.011)	0.622	0.995 (0.894-1.109)	0.933
Professionals	8.1 (3.8)	32.9 (28.4-37.5)	1.000 (0.994-1.006)	0.969	0.983 (0.965-1.001)	0.069
Tradespersons and related workers	21.5 (7.6)	37.3 (34.8-39.8)	1.002 (1.001-1.005)	0.035	0.988 (0.961-1.015)	0.379

Shaded cells denote statistical significance at the p<0.05 level

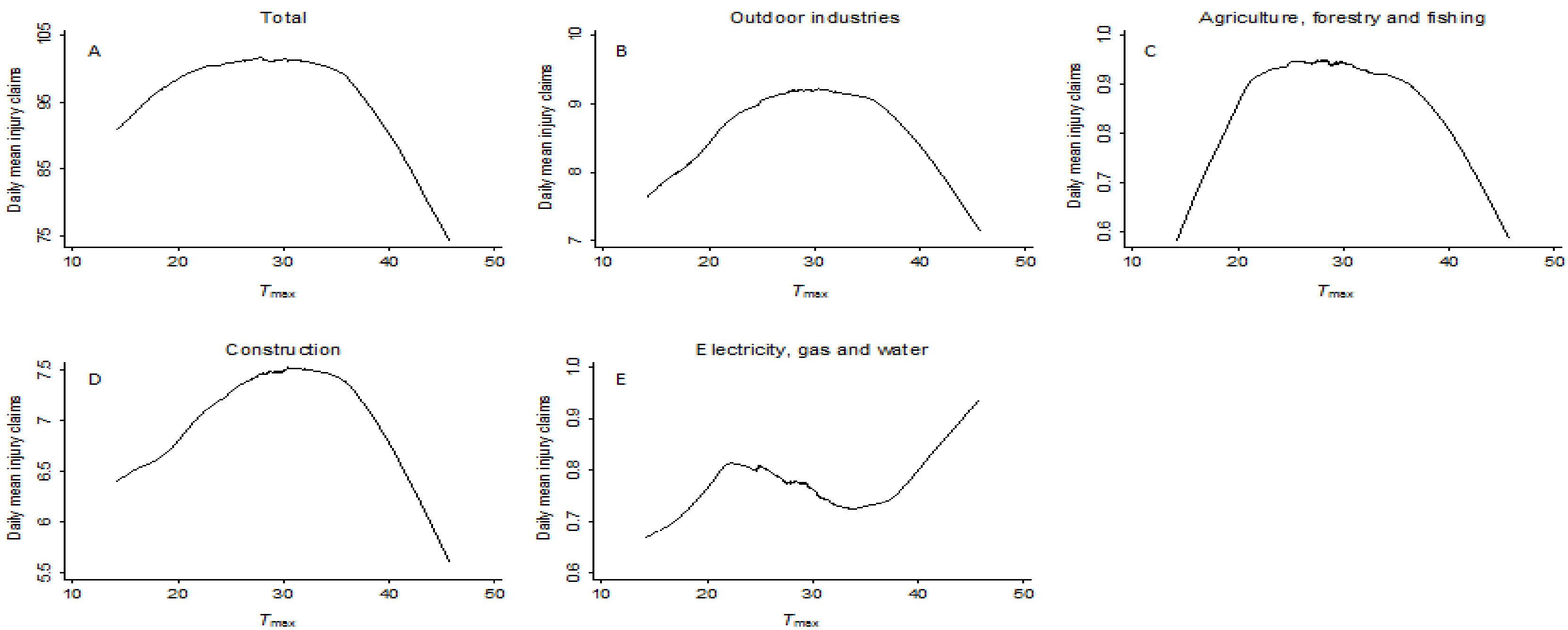

Figure 5.2 (A-E) Exposure–response relationships between daily maximum temperature and daily injury claims for (A) total effects, (B) outdoor industries,(C) agriculture, forestry and fishing, (D) construction and (E) electricity, gas and water. Data were smoothed using a **LOWESS (locally weighted scatter plot smoothing) smoother, bandwidth=0.8**.

For overall outdoor industries (IRR 1.005, 95% CI 1.001-1.009), a 0.5% increase of injury claims was observed with degree increase of T_{max} below 37.8℃, however, daily claims decreased by 3.4% when T_{max} exceeded 37.8℃ (Figure 5.2-B). By contrast, no significant association between claims and temperature was detected in overall indoor industries. Industry-specific analysis showed that the following industries had an increase of injury claims with increasing T_{max} below the thresholds: agriculture, fishing and forestry (IRR 1.007, 95% CI 1.001-1.013) (Figure 5.2-C); and construction (IRR 1.006, 95% CI 1.002-1.011) (Figure 5.2-D). However, a significant increase of 2.9% (IRR 1.002, 95% CI 0.998-1.058) was observed in 'electricity, gas and water' (Figure 5.2-E), when T_{max} was above 37.2℃, indicating the workers in this industry may have been working outside for service purposes. Occupation-specific analysis showed that labourers (IRR 1.005, 95% CI 1.001-1.010), intermediate production and transport workers (IRR 1.003, 95% CI 1.001-1.005), and tradespersons (IRR 1.002, 95% CI 1.001-1.005) had a significant increase of injury claims with the increase of T_{max} below threshold temperatures. Significant decreases of injury claims were observed in associate professionals when T_{max} exceeded thresholds.

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

5.4 Discussion

Despite increasing concerns about heat-related impacts on occupational health,[19, 21, 233] few studies have examined the extent to which workers are affected by heat exposure, perhaps due to the limited availability and quality of occupational health and safety databases.[20] This study, the first of its kind in Australia, utilizes workers' injury claim data to investigate the association between temperatures and work-related injuries in a temperate city.

5.4.1 Association between temperatures and work-related injuries

The results from this study demonstrated 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.[27] Australia currently has no released mandatory regulations and guidelines specifying standards for maximum temperature in the workplace,[19] 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 due to the variations in work environments, preventive measures, heat acclimatization level, and public health infrastructure.

The results suggest that the overall risk of work-related injuries was positively associated with T_{max} below 37.7℃. However, daily injury claims dropped noticeably when the weather was extremely hot, as some workplaces, industries and trade unions in South Australia may have in place effective protective measures such as hot weather policies which advise the cessation of work when the temperature is extreme.[181] This may explain the observed decline in injury claims when the temperature reaches the threshold. The unexpected increase observed in "electricity, gas and water" when T_{max} exceeded the threshold (37.2℃), may be attributed to the fact that workers may 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 workers.

5.4.2 Vulnerable sub-groups

The vulnerable groups in workplaces during hot weather have been identified by gender, age group, business size, industry, and occupation. The results indicate that male workers had a significant increase of injury claims with the increase of 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 that only young workers (aged less than 24 years) had an increase in injury claims in association with temperature. However, studies elsewhere on heat tolerance suggest that middle-aged workers are more work-heat intolerant and suffer from more heat strain than younger individuals,[138] which was not evident in this study. The greater risk for the young experiencing work-related injuries in hot weather could be due to a number of reasons. Firstly, young workers often undertake more strenuous tasks and have less safety training and skills compared with older workers. Secondly, studies have shown that young workers can be less likely to recognize the risk of heat exposure and have low compliance with preventive measures.[140, 141] Additionally, 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.

The 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.[40] A study from Germany has estimated that small and medium sized enterprises had a 33% greater accident rate (from all origins) than large enterprises.[279] It can be assumed that it is likely to be the same for heat stress problems. Usually, small and medium sized enterprises are the most common employer. The number of small businesses occupied 44% of all businesses in 2001 in South Australia, with about one-third of the state's labour force working in companies with less than 20 employees.[258] Therefore, it is essential to put more focus on small and medium sized enterprises in terms of workplace heat exposure prevention.

The association between injury claims and temperature varies by occupation and industry. The results in this study demonstrated that 'labourers and related workers' had the greatest injury risk with increasing T_{max}. This would be 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 injuries in the heat. In addition to labourers, tradespersons, and intermediate production and transport workers were also identified as having an elevated 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.[122]

In terms of industrial sectors, analyses showed that for outdoor industries (combined 'agriculture, forestry and fishing', 'construction', and 'electricity, gas and water'), one degree increase of T_{max} below the threshold of 37.7°C was associated with 0.5% increase in daily claims. Agriculture, forestry and fishing had the greatest risk of work-related injury with 0.7% increase of daily injuries per degree increase of T_{max}. These industries are generally exposed to outdoor heat extremes for long periods of time due to the nature of their work, and often there is a lack of occupational health and safety guidelines. Currently, there has been very limited published literature assessing heat stress in agricultural workers. A cross-sectional survey found that approximately 94% of farmers in North Carolina US reported working in extreme heat in 2009, among which 40% experienced heat stress related symptoms.[92] According to the US heat-related mortality statistics for the period of 1992-2006, the heat-related mortality rate of crop production farmers was approximately 20 times greater than for all civilian workers.[74] 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.

Findings also showed that there was an association between injury claims and temperature in the construction industry. The constant use of machinery and powered tools, working on elevated surfaces, heavy workload, being sub-contracted on a daily payment basis, and constant and direct exposure to sunlight may all contribute to the higher injuries. Many field studies have investigated the impacts of heat exposure on construction workers' health and safety, most of which showed that construction workers were physiologically challenged by heat exposure and suffered from heat strain symptoms.[66, 87] However, if preventive measures were sufficient on building sites, workers may be able to reduce the risk of heat-related illnesses and injuries.[85, 86] Therefore, relevant regulations and guidelines should be considered in all jurisdictions, together with occupational health and safety education among the workers to ensure their health and safety could be protected.

5.4.3 Limitations

There are several limitations to this study. First, as mentioned previously daily injury claims may be underestimated due to underreporting of workers' compensation claims.[260] Second, the relatively small number of daily injury claims in some industries such as 'communication' and 'electricity, gas and water' dictates cautious interpretation of results. Third, analysis based on time series format design in our study was characterized by aggregated daily observations.[222]

This may result in the inherent risk of biases due to the lack of information about individual characteristics. Fourth, the possible variation of labour force during the study period may potentially bias the results, as it is usually assumed that the denominator does not change meaningfully when analysing the exposure-count outcome association in a time-series study,[227] although the impact of long-term trends has been adjusted. The validity of effect estimates may be improved if utilizing daily injury claim rates. 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 which could potentially bias our findings, the effect should be minimal as an examination of Australian Bureau of Statistics data show a non-significant decrease in the labour force during the summer quarter.[256] 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.[227] Nevertheless, different industries will have variations in the age profiles of employees which may account for some age-effects observed. Additionally, some potentially possible time-varying confounders such as air pollutants were not taken into account in this study. Lastly, only one weather station was selected for representing daily temperature of the Adelaide metropolitan area, although the station should be representative of the whole city.

5.5 Conclusion

The results of this study suggest that the risk of work-related injuries is significantly associated with heat exposure in Adelaide, especially for vulnerable groups in the workplace. Specifically, these include: males; young workers aged ≤24 years; those working in the industries such as ‘agriculture, forestry and fishing’, ‘construction’, and ‘electricity, gas and water’; or employed as labourers, production and transport workers, and tradespersons in small and medium sized businesses. This study may provide 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. Industrial specific workplace hot weather alert and response mechanisms need to be developed via multi-sectoral cooperation to improve vulnerable groups' risk perceptions and knowledge about harm minimisation strategies during extremely hot weather. Policies need to be formulated to strengthen workers' self-protection capability by providing heat stress relevant trainings via induction and ongoing continuing education programs. 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.

Chapter 6

The effects of heatwaves on work-related injuries

6.1 Introduction

The empirical association between daily ambient temperature and work-related injuries has drawn little attention in the international literature, although some work has been undertaken in Italy[27] and USA[28]. A recent study in Adelaide has preliminarily found that there was a three-fold increase in work-related ambulance callouts during heatwaves in the industrial suburbs.[280] However, so far little is known about the extent to which workers are affected by heatwaves and which types of illnesses/injuries are associated with heatwaves i.e. when ambient temperatures remain high over several consecutive days. It is possible that heatwaves may have an effect on worker's level of fatigue[122] and sleep quality at hot summer nights,[63] and consequently compromise health and safety. According to the weather projections for Adelaide, [32, 35] extremely hot weather may present a growing challenge for occupational health and safety,[20] particularly for those working outdoors or those close to heat sources.

This Chapter builds on the study in Chapter 5 ('The association between high temperature and work-related injuries'[139]) and aims to assess the extent to which 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. In addition, currently there is no standard heatwave definition, a small change of which may considerably affect the heat-health outcomes in the general population.[281] Therefore, two different heatwave definitions were used in this study to compare the differences in effect estimates. Understanding the impact of heatwaves on workers' health and safety (WHS) may provide valuable information to decision makers and relevant stakeholders to formulate extreme heat preparedness and emergency response plans in the workplace.

6.2 Materials and methods

6.2.1 Workers' compensation claim data

As stated in previous chapters,[139] 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.[255]

6.2.2 Meteorological data

Climatic data for Adelaide including daily maximum and minimum temperature for the study period were obtained from the Australian Bureau of Meteorology. As suggested in previous studies,[8, 11, 12, 139] an observation station near the central business district was selected to represent weather conditions across the Adelaide metropolitan area.

6.2.3 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 previous Adelaide studies.[8, 11, 12] We also used the Australian Bureau of Meteorology (BOM) definition of ≥5 consecutive days of T_{max} ≥35°C; or ≥3 consecutive days of T_{max} ≥40°C to compare findings.[282]

6.2.4 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 as in previous studies in this thesis. 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 for, as Adelaide is characterized as typically having dry hot weather in summers.[139]

As work-related compensation claims reduced significantly during weekends and public holidays, all analyses were focused on week days in this study. Possible 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' as in the previous chapter. 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 percent 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).

6.3 Results

The mean daily T_{max} during the period of 1st July 2001 to 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℃) 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 3-15 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, 7,043 (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, 3,885 (1.5%) claims occurred during 59 heatwave days (8 heatwaves), with a daily mean of 91 claims compared with 100 during non-heatwave periods.

6.3.1 Effect estimates by gender, age, occupation and industry

As shown in Table 6.1, 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, ‘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 6.1 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	7,043	118,224	0.983 (0.943-1.024)	0.408
Gender				
Male	4,794	80,344	1.001 (0.947-1.012)	0.960
Female$^{\Delta-}$	2,249	37,880	0.935 (0.897-0.974)	0.001
Age group				
≤24	1,250	20,276	1.035 (0.981-1.091)	0.213
25-34	1,511	26,515	0.973 (0.928-1.019)	0.246
35-54	3,369	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	1,059	1.447 (1.125-1.861)	0.004
Construction	521	8,145	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)	6,384	108,970	0.976 (0.930-1.025)	0.338
Communication	3	83	0.402 (0.096-1.679)	0.211
Community services$^{\Delta-}$	2,061	34,769	0.931 (0.878-0.986)	0.015
Finance, property and business services	346	5,184	1.067 (0.885-1.286)	0.498
Manufacturing	1,780	32,115	1.009 (0.928-1.098)	0.832
Public administration and defence	192	3,719	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	6,635	0.932 (0.859-1.012)	0.094
Wholesale and retail trade $^{\Delta+}$	1,236	20,025	1.015 (0.965-1.069)	0.559
Occupations				
Advanced clerical and service workers	101	1,260	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	9,510	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	1,335	22,674	1.021 (0.942-1.107)	0.615
Labourers and related workers$^{\Delta+}$	1,332	23,583	1.054 (1.023-1.086)	0.000
Manager & administrators	120	1,878	0.960 (0.842-1.096)	0.548
Professionals$^{\Delta-}$	554	9,580	0.906 (0.833-0.985)	0.021
Tradespersons and related workers$^{\Delta+}$	1,463	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} ≥35°C. Δ+ / Δ- 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} ≥35°C or ≥3 consecutive days with T_{max} ≥40°C, where detailed IRR estimates and p values were not listed in the Table.

Table 6.2 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; and in terms of age, only workers aged ≥55 years showed a significant increase of 76.3% (95% CI 16.1%-267.6%).

Table 6.2 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.

6.3.2 Types of work-related illnesses and injuries

As shown in Table 6.3, 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 approximately12-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.

Table 6.3 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$^{\Delta-}$	2,741	50,498	0.903 (0.863-0.946)	0.000
C129-C169	Wounds, lacerations, and amputations$^{\Delta+}$	1,642	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	8,161	1.119 (0.955-1.311)	0.165
I702-I719	Mental disorders$^{\Delta-}$	295	4,714	0.945 (0.826-1.081)	0.412
B111-B119	Fractures	282	4,645	0.965 (0.856-1.087)	0.556
L761-L779	Nervous system and sense organ diseases	211	3,974	0.968 (0.828-1.131)	0.681
D171-D179	Burn$^{\Delta+}$	170	2,439	1.161 (1.010-1.334)	0.035
K741-K759	Skin and subcutaneous tissue diseases	119	1,807	1.012 (0.825-1.240)	0.912
J721-J739	Digestive system diseases	69	1,115	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 when heatwaves defined as ≥3 consecutive days with T_{max} ≥35°C. Δ+ / Δ- 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} ≥35°C or ≥3 consecutive days with T_{max} ≥40°C, where detailed IRR estimates and p values were not listed in the Table.

6.3.3 Injury mechanisms

As shown in Table 6.4, 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 '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.

6.3.4 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℃, and claims in 'wholesale and retail trade' increased significantly only for the BOM definition (Table 6.1). In terms of injury diagnosis, only the BOM definition had a significant decrease of mental disorders claims (Table 6.3). 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 6.4).

Table 6.4 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$^{\Delta-}$	2,517	45,673	0.909 (0.870-0.951)	0.000
G11-G13	Hitting objects with a part of the body $^{\Delta+}$	1,312	20,883	1.052 (0.972-1.139)	0.211
G01-G03	Falls, trips and slips of a person $^{\Delta-}$	1,013	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	5,674	0.894 (0.747-1.071)	0.224
G81-G88	Mental stress	292	4,625	0.949 (0.819-1.110)	0.487
G51-G59	Heat, electricity and other environmental factors$^{\Delta+}$	251	3,035	1.390 (1.180-1.638)	0.000
G61-G69	Chemicals and other substances$^{\Delta+}$	233	3,248	1.201 (1.050-1.373)	0.007
G31-G39	Sound and pressure	111	1,686	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} ≥35°C. Δ+ / Δ- 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} ≥35°C or ≥3 consecutive days with T_{max} ≥40°C, where detailed IRR estimates and p values were not listed in the Table.

6.4 Discussion

The previous study (Chapter 5) examined the association between daily high temperature and injury claims.[139] In this paper, the impact of heatwaves (consecutive extreme heat exposure) on work-related illnesses and injuries in a temperate Australian city was investigated, using workers' compensation claims data. To the author's knowledge, this is the first study of its kind in Australia. The findings 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,[93, 95, 101, 116] with the majority showing that heat stress levels exceed the recommended criteria of American Conference of Governmental Industrial Hygienists.[179] 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.[234] 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.

6.4.1 Vulnerable sub-groups during heatwaves

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 Adelaide. Evidence shows that construction workers in Japan are not physically challenged by heat stress if effective prevention measures are taken on building sites.[86] 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” [181] which may explain, at least in part, this 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,[134, 135] indicating a potential increased work load for workers in this industry.

The findings 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.[74, 283] Studies have reported a high prevalence of heat stress related symptoms among US migrant farm workers (33%),[93] Japanese forestry workers (32%),[101] Costa Rican sugarcane workers,[95] and South African horticultural workers.[116] 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 OH&S rights[93] and more work needs to be done in this area. In addition to field equipment to monitor heat stress conditions,[74] enforceable legal regulations may be needed to ensure the implementation of heat stress control and prevention standards such as the California Code of Regulations (Title 8, Section 3395),[49] 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.[139, 141] 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 US agricultural workers.[78] 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.[274] They may also have ageing-induced dysfunctional thermoregulatory mechanisms, and a higher prevalence of pre-existing illnesses.[14] 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.

6.4.2 Diseases and injuries associated with heatwaves

The impact of heatwaves on claims due to heat stress was also investigated, and it was found that heat illnesses increased by approximately 12 fold compared with non-heatwave periods. Heat illnesses are relatively uncommon when compared with other injuries. The number of heat stress related claims was very small, perhaps due to underreporting and misclassification,[260] 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,[284] or the increased absorption rate of liquid chemicals through the skin in higher ambient temperatures.[285] This highlights the importance of continued education in the use of PPE during heatwaves among those exposed to chemical substances.[284] By contrast, the decrease of 'falls, trips and slips' may be attributable to effective heat intervention policies in South Australia.[181]

6.4.3 Limitations

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 as previously mentioned,[260] 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. Additionally, the relatively small number of daily injury claims in some categories requires cautious interpretation of results. Second, interaction effects between heatwaves and subgroup variables were not considered as the 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.[139, 227] Third, evidence has shown that a small change in heatwave definition may appreciably affect the heat health outcome estimates.[281] In this study, two heatwave definitions were used, 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.[286] 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, specific characteristics such as duration, intensity, timing, and lag effects were not taken into account when analysing the heatwave effects.

6.5 Conclusion

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 which were 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 strategies locally or/and internationally to reduce the impacts of extreme heat events on WHS, particularly in susceptible subgroups.

SECTION III

PERCEPTIONS OF WORKPLACE HEAT EXPOSURE

Introduction

In the study of climate change adaptation, adaptive strategies need to be considered to protect human health during higher temperatures, particularly for those subject to higher exposure. It is therefore useful to understand the perceptions, knowledge, attitudes, behaviour and adaptation barriers among different community members, risk groups and relevant stakeholders so that better solutions, measurements, strategies, policies and guidelines could be developed to protect population health. Many research activities have been conducted about the perceptions of the impact of climate change, global warming and heatwaves among different levels of the society in North America,[287-293] Europe,[294-297] China,[298] and Australia.[299-301] Findings of these studies have provided useful baseline information, indications and evidence for the formulation of effective heat adaptation and mitigation policies to minimize the impact of climate change on population health.[302]

In recent years, studies have found that extreme heat events may not only present a growing challenge to workers' health and safety, but also affect economic productivity.[20, 42-44, 61, 63, 303, 304 46] A good understanding of how workers, employers, and relevant stakeholders involved in heat stress prevention and management perceive the risk of workplace heat exposure may benefit the development of extreme heat and occupational health and safety policies, contribute to the development and implementation of relevant heat regulations, and promote the co-operation and collaborations among different government organisations, service providers, employers, unions and workers. However, as mentioned in the literature review chapter, limited studies have investigated the perceptions of workplace heat exposure.

This section comprises two chapters. Chapter 7 investigates how workers perceive the risk of heat exposure, whilst Chapter 8 provides occupational hygienists’ views on heat stress management and current preparedness for the likelihood of increasing hot weather.

Chapter 7

Workplace heat exposure and OH&S: Perceptions from workers

7.1 Introduction

Studies undertaken in Sydney and Adelaide have shown that a high proportion of residents are concerned about the impacts of climate change related extreme heat on population health.[299-301] The findings of studies investigating the public's heat knowledge, attitudes, and adaptive behaviours provide valuable implications for the development of extreme heat action plans.[305]

Heat illnesses are largely preventable and heat risk awareness and knowledge are an important integral part of heat preventive measures. However, few studies have investigated how working people perceive the risk of extreme heat in Australia, although heat stress levels have be found to be high in some occupations (e.g. miners, shearers, and road maintenance workers).[46, 64, 139] Moreover, recently several heat-related deaths have been reported in Australian workplaces,[306-308] and the results in Chapters 5 and 6 also indicated that work-related injury claims are significantly associated with ambient temperatures and heatwaves.[139, 329]

With predictions of more frequent and intense bouts of hot weather,[31, 32] outdoor workers and those undertaking physically demanding work in non-cooled environments will become more vulnerable to extreme summer heat if prevention measures are not sufficient.[19-21] As an existing occupational hazard with the progress of ongoing climate change, there is a need to understand workers' beliefs and views about heat exposure, which is important for the implementation of extreme heat preparedness and action plans. Therefore, this Chapter aims to investigate workers' perceptions and behavioural responses towards extreme heat exposure in the South Australian workplaces.

7.2 Materials and methods

A cross-sectional study design was implemented, with a questionnaire survey conducted between 15 August and 6 November 2012 in Adelaide, South Australia amongst workers and trades apprentices.

7.2.1 Questionnaire design

The questionnaire, which aimed to gather perceptions about working in hot conditions, was developed after a comprehensive review of the literature on heat exposure and occupational health. The draft questionnaire was reviewed by relevant experts and piloted among 10 outdoor workers in Adelaide. Relevant revisions were made to ensure all questions were clear and understandable.

The questionnaire consisted of 5 demographic variables and 16 questions involving aspects of the working environments, previous history of heat-related illness and injury, heat prevention management, perceptions of extreme heat exposure and OH&S, and specific attitudes towards the development of heat prevention strategies and measurements. Some questions had both closed and open-ended responses. Some multiple choice questions investigated individual work habits, access to heat stress prevention information, and heat prevention measures. Likert-scale questions were used to measure heat-related perceptions and attitudes.

7.2.2 Participant recruitment

The inclusion criteria for participants were those working outdoors, or indoors but close to heat sources without air conditioning, in the following four industries: "agriculture, fishing and forestry", "construction", "electricity, gas and water", and "mining", according to the findings of literature review (Chapter 1) and the results from workers compensation claims data analyses (Chapter 5 and 6).

With the support of SafeWork South Australia (SWSA), a total of 164 employers in South Australia were invited (Appendix D) to participate in the study and to provide assistance in the distribution of survey questionnaires (Appendix F), envelopes, and information sheets (Appendix E) to workers who meet the inclusion criteria.

As shown in Table 7.1, in each of above four industries, 41 employers were contacted for each industry through invitation letters (Appendix D). Considering the potential impacts of business size on the perception of heat exposure on their employees (due to the differences in heat prevention measures), in each selected industry the numbers of employers from small, medium, and large businesses were 21, 10, and 10, respectively. Within each business size stratum, companies (indicated only by code numbers so no identity could be disclosed) with relatively more injury claims during the period of 2001-2010 were selected, according to the workers compensation claims dataset obtained from the SWSA.

Table 7.1 Sampling framework: the number of employers invited to provide assistance in the distribution of questionnaires to workers

Business size*	Construction	Agriculture	Electricity, gas and water	Ming	Total
Large	10	10	10	10	40
Medium	10	10	10	10	40
Small	21	21	21	21	84
Total	41	41	41	41	164

*: 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.[258]

It was believed important to include the perceptions of young workers in this study. However, considering young workers may be less inclined to participate in surveys due to various reasons, TAFE (Technical and Further Education) students, who are largely young people, were recruited. A large proportion of part-time students enrolled in the TAFE system, many of whom undertake their studies while working as apprentices. Therefore, TAFE students were selected to represent young workers and trainees.

In total, [309] students enrolled in the courses likely to lead to outdoor work such as "building, construction and furnishing", automotive, "electrical and refrigeration", "electrical and metal fabrication", "carpentry, furnishing and plumbing", and "horticulture" in a local TAFE College were invited to participate in the survey. After initial contact and meeting with the TAFE College management team and relevant lecturers, questionnaires were distributed to target students by the course lecturers. On the basis of the questionnaire for workers (Appendix F), the questionnaires for TAFE students (Appendix G) were slightly modified on the two demographic questions relating to occupation and industry.

Participants filled out the questionnaires independently in their own time. Completed questionnaires were returned by participants using supplied reply-paid envelopes. The participants were therefore free of any potential pressure from their employers and supervisors during the completion of the questionnaire.

7.2.3 Data analyses

A total of 1,471 questionnaires were distributed and 749 were returned, with a response rate of 50.9%. Data entry and validation were performed using 'Microsoft Excel 2007', and imported into Stata (version 12.0) for data manipulation and analyses. The "SVY" commands of Stata were used to calculate point estimates and 95% confidence intervals for the prevalence estimates.[301]

Five indicators were used to represent workers' perceptions of workplace heat exposure from different aspects. They were (1) workers' concerns about heat exposure, (2) attitudes towards more training, (3) policy support, (4) the adjustment of work habits, and (5) degree of satisfaction of current preventive measures. To identify the factors significantly associated with perceptions of workplace heat exposure, bivariate and multivariate logistic regression analyses were conducted using a stepwise backwards model. All variables with statistical significance of $p<0.05$ were included in the final model.

7.3 Results

7.3.1 Demographic characteristics

The 749 participants consisted of 511 TAFE students and 238 workers, accounting for 68.3% and 31.7%, respectively. Of the 511 TAFE students, 91.4% were part-time, with only 8.6% were full-time. As shown in Table 7.2, the majority (96.0%) of participants were male young people (≤24 years) accounted for more than half (53.5%) of all participants. In terms of highest educational attainment, more than half (51.3%) of participants had completed high school, 42.6% had a trade certificate, and 6.1% had a university degree. Almost three-quarters (73.2%) of participants were employed as tradespersons and related workers. Labourers accounted for 5.7% of participants. More than half (51.0%) of participants mainly undertook work outdoors. The construction industry had the highest percentage (37.1%) of participants, followed by manufacturing (27.5%), mining (14.6%), 'electricity, gas and water' (13.1%), and 'agriculture, forestry & fishing' (2.0%). Approximately three-quarters (75.9%) of participants considered that their jobs were moderately or highly physically demanding, while 38.1% reported that they worked close to heat sources. Two-thirds (67.8%) of participants were required to wear personal protective equipment at work.

Table 7.2 Perceptions of workplace heat exposure: prevalence estimates and 95% CI by different subgroups

Independent variable	n	%	Concern for extreme heat %(95% CI)	Attitude for more trainings %(95% CI)	Attitude for more regulations %(95% CI)	Attitude for adjusting work habits %(95% CI)	Satisfaction for preventive measures %(95% CI)
Total	749	100	51.2 (50.0-57.4)	56.3 (50.1-61.9)	63.8 (57.3-69.9)	68.8 (63.4-73.7)	51.4 (42.6-60.0)
Gender							
Male	719	96.0	51.1 (44.7-57.5)	56.5 (51.1-61.7)	64.1 (57.5-70.2)	69.2 (63.9-74.0)	50.9 (42.3-59.5)
Female	30	4.0	53.3 (34.1-71.6)	53.3 (28.9-76.3)	56.7 (37.7-78.9)	60.0 (40.5-76.8)	62.1 (39.8-80.2)
Age group							
≤24	401	53.5	44.0 (38.5-49.6)	50.0 (43.1-56.9)	66.9 (58.7-74.3)	66.4 (59.2-73.0)	42.0 (35.6-48.7)
25-34	101	13.5	58.5 (48.9-67.5)	63.5 (56.4-70.1)	74.0 (63.8-82.0)	76.3 (64.0-85.5)	44.1 (31.7-57.3)
35-54	161	21.5	63.5 (48.3-76.4)	66.7 (53.2-77.9)	59.0 (48.2-69.0)	73.7 (63.2-82.1)	68.8 (58.1-77.9)
≧55	86	11.5	59.8 (44.3-73.5)	64.6 (46.5-79.4)	48.8 (37.2-60.5)	65.9 (51.3-78.0)	70.9 (55.7-82.5)
Education level							
High school	384	51.3	46.8 (40.7-53.0)	53.4 (46.6-60.1)	66.2 (58.4-73.2)	67.6 (60.5-73.9)	46.4 (37.1-55.9)
Trade certificate	319	42.6	56.1 (48.5-63.3)	58.7 (52.6-64.5)	64.0 (56.7-70.7)	69.8 (63.5-75.4)	51.8 (42.0-61.5)
University degree	46	6.1	53.3 (43.4-63.0)	62.2 (49.3-73.6)	42.2 (24.1-62.7)	73.3 (52.8-87.1)	86.7 (71.9-94.3)
Occupation							
Tradespersons and related workers	548	73.2	50.5 (44.5-56.4)	55.1 (49.5-60.6)	66.7 (59.9-72.8)	70.0 (65.3-74.4)	46.6 (38.5-55.0)
Clerical and administrative workers	30	4.0	40.0 (19.8-64.2)	70.0 (28.1-93.3)	46.7 (21.6-73.6)	66.7 (36.6-87.4)	86.2 (64.8-95.5)
Machinery operators and drivers	55	7.3	65.5 (32.1-88.4)	58.2 (27.8-83.4)	61.8 (36.9-81.7)	54.6 (42.9-65.7)	63.6 (42.7-80.4)
Labourers and related workers	43	5.7	51.2 (32.5-69.5)	55.8 (47.7-63.7)	62.8 (38.3-82.1)	69.8 (54.4-81.7)	45.2 (30.0-61.4)
Full-time TAFE students	44	5.9	40.9 (21.0-79.0)	54.6 (39.6-68.7)	59.1 (48.3-69.1)	67.4 (53.4-78.9)	56.1 (35.6-74.7)
Professionals	16	2.1	81.3 (62.0-92.0)	68.8 (30.0-91.9)	37.5 (15.7-65.9)	81.3 (53.1-94.3)	87.5 (51.5-97.9)
Other	13	1.7	46.2 (17.2-77.9)	61.5 (24.9-88.5)	46.2 (16.7-78.6)	69.2 (37.7-89.3)	76.9 (34.1-95.6)
Industry							
Agriculture, forestry & fishing	15	2.0	50.0 (24.4-75.6)	62.5 (41.3-79.8)	66.7 (49.4-80.4)	58.3 (37.2-76.8)	69.6 (51.6-83.0)
Mining	109	14.6	57.0 (45.5-67.8)	51.3 (35.2-67.2)	59.1 (38.4-77.0)	67.3 (44.9-83.8)	59.5 (32.6-81.7)
Manufacturing	206	27.5	44.2 (37.9-50.8)	49.5 (32.5-66.7)	67.5 (45.7-83.6)	66.7 (48.7-80.8)	36.4 (25.8-48.6)
Construction	278	37.1	52.4 (38.8-65.6)	58.8 (51.6-65.6)	67.0 (59.5-73.8)	69.3 (63.9-74.3)	50.2 (43.2-57.2)

Electricity, gas & water	98	13.1	57.6 (33.3-78.7)	67.9 (60.7-74.4)	52.8 (43.4-62.1)	75.5 (64.4-84.0)	71.7 (43.8-89.2)
Other	43	5.7	38.5 (9.4-78.9)	53.9 (28.8-77.1)	61.5 (23.8-89.1)	69.2 (35.6-90.1)	46.2 (12.8-83.3)
Workplace environment							
Completely indoors	59	7.9	45.7 (37.0-54.8)	74.6 (57.5-86.4)	71.2 (53.9-83.9)	69.0 (52.1-82.0)	37.3 (21.4-56.5)
Mainly indoors	282	37.7	44.4 (35.7-53.6)	52.5 (43.0-61.8)	58.5 (48.4-68.0)	68.6 (62.7-74.0)	59.5 (44.6-72.8)
Completely outdoors	82	10.9	71.6 (55.7-83.5)	63.4 (49.5-75.4)	70.7 (58.6-80.5)	63.8 (46.3-78.2)	44.3 (29.9-59.7)
Mainly outdoors	300	40.1	53.2 (48.6-58.3)	55.3 (50.0-60.6)	63.7 (57.1-69.7)	68.9 (61.6-75.4)	49.0 (41.5-56.5)
Physically demanding							
Not at all	49	6.5	40.4 (29.3-52.7)	63.8 (38.8-83.1)	51.1 (32.4-69.4)	73.9 (61.8-83.2)	82.6 (69.0-91.0)
A little	132	17.6	44.5 (35.9-53.5)	53.1 (39.1-66.6)	47.7 (35.5-60.2)	59.8 (47.3-71.2)	70.6 (53.5-83.4)
Moderately	280	37.4	48.0 (40.3-55.8)	56.1 (50.3-61.8)	64.0 (56.6-70.8)	72.0 (65.4-77.7)	50.9 (44.8-57.0)
Very much	288	38.5	59.9 (50.7-68.4)	56.6 (50.0-63.1)	72.7 (66.3-78.4)	69.5 (63.9-74.6)	37.8 (30.0-46.5)
Work close to heat sources							
Yes	285	38.1	52.4 (46.7-58.0)	56.8 (49.9-63.4)	67.0 (59.1-74.0)	69.8 (64.9-74.2)	44.8 (35.6-54.4)
No	464	61.9	49.3 (39.8-58.8)	56.5 (46.5-66.0)	59.3 (50.8-67.3)	68.4 (60.1-75.6)	61.7 (50.5-71.7)
Use of personal protective equipment							
Yes	508	67.8	55.8 (49.7-61.8)	58.0 (52.4-63.3)	64.2 (58.0-70.0)	69.9 (64.4-74.8)	50.1 (40.5-59.7)
No	241	32.2	41.4 (34.0-49.4)	52.9 (45.0-60.7)	62.9 (49.7-74.5)	66.5 (58.1-74.0)	54.1 (40.7-66.9)
Heat illness experience							
Yes	279	37.2	62.4 (52.2-71.5)	65.2 (56.8-72.8)	70.3 (62.9-76.7)	73.9 (67.8-79.2)	38.5 (30.6-47.0)
No	470	62.8	44.5 (39.5-49.6)	51.4 (44.2-58.5)	60.4 (52.9-67.4)	66.1 (60.1-71.6)	59.0 (48.2-69.1)
Injury experience during hot weather							
Yes	194	25.9	67.0 (57.0-75.7)	65.0 (57.0-72.1)	72.2 (60.6-81.4)	71.2 (62.7-78.4)	29.5 (23.5-36.2)
No	555	74.1	45.6 (39.9-51.5)	53.3 (47.5-59.1)	60.9 (54.0-67.4)	68.0 (62.5-73.0)	59.0 (48.8-68.5)

7.3.2 Heat illnesses and injuries occurring during hot weather

Overall, 37.2% of participants had experienced heat illnesses during hot days. The most common type of heat illnesses reported were heat exhaustion (60.6%), followed by heat rashes (43.0%), heat stroke (26.2%), and heat cramps (18.3%) (Figure 7.1). The percentage of participants injured at work during very hot weather was 25.9%. More than half (54.1%) of injuries were caused by burns, 44.3% by falls, trips and slips, 27.8% by hitting objects, and 10.3% by being hit by moving objects (Figure 7.2).

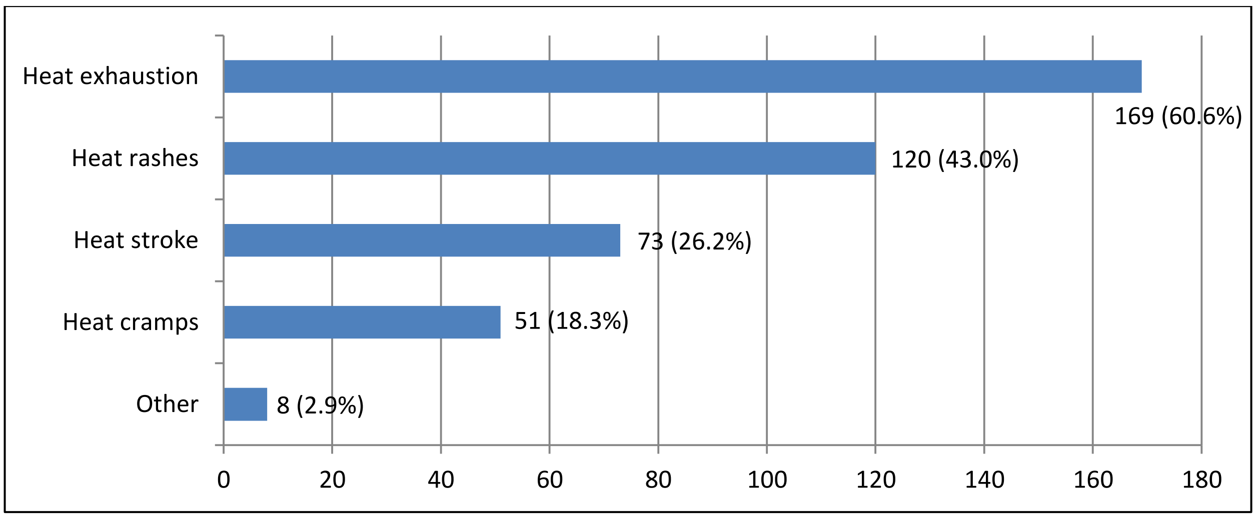

Figure 7.1 Heat-related illnesses experienced by participants: number and percentage

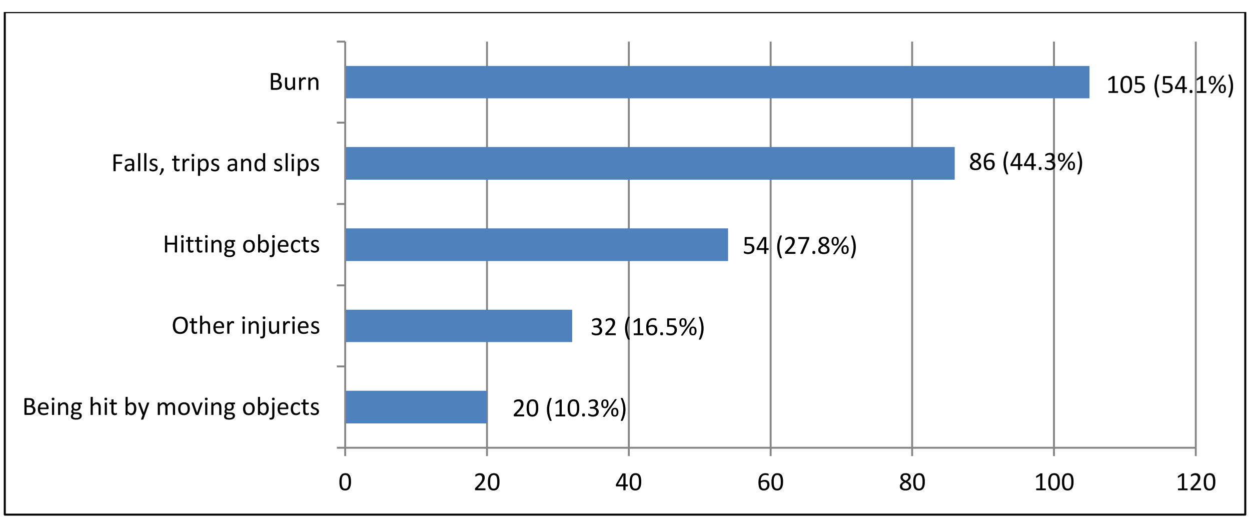

Figure 7.2 Type of injuries experienced by participants during hot weather: number and percentage

About one-quarter (25.2%) of participants responded that they have witnessed an injury to another worker during very hot weather. The most common type of injuries witnessed was falls, trips and slips (55.0%), followed by burns (42.3%), hitting objects (22.8%), and being hit by moving objects (17.5%), as demonstrated in Figure 7.3.

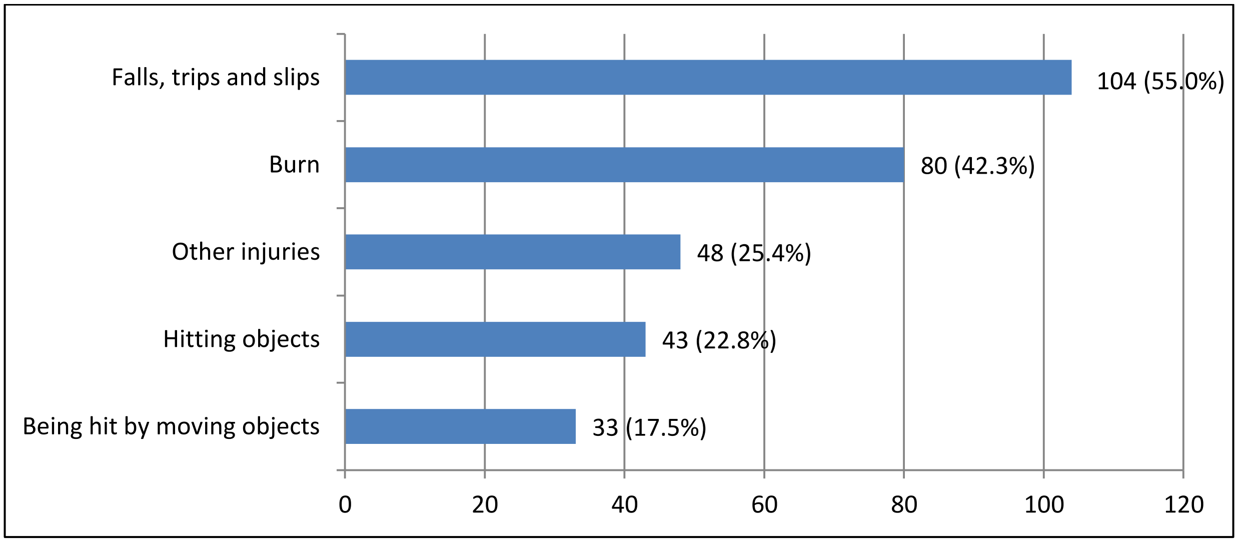

Figure 7.3 Type of injuries witnessed by participants during hot weather: number and percentage

7.3.3 Risk perceptions of workplace heat exposure

7.3.3.1 Concerns about heat exposure

Overall, 51.2% of participants were moderately or very much concerned about the risk of heat illness at work during very hot weather (Table 7.2). Results of bivariate analyses (Table 7.3) showed that the following respondents were significantly more concerned about extreme heat exposure than the comparison group: age in categories (25-34; 35-54; and ≥55 years, comparing to ≤24 years group), education level of trade certificate, employed as professionals, working in mining industry, undertaking work completely outdoors, conducting very physically demanding work, wearing personal protective equipment (PPE), and previous heat illness and injury experience during hot weather.

Results of stepwise logistic regression analyses (Table 7.3) indicated that the following factors were associated with workers' concerns over heat exposure, including age in categories (25-34; 35-54; and ≥55 years), physically demanding (very much), and the use of PPE, heat illness history, and injury experience during hot weather.

7.3.3.2 Attitudes towards more heat-related training

Analysis showed that 56.3% of respondents indicated that there was a need for more heat-related training for workers to reduce the risk of heat stress (Table 7.2). Results of bivariate analyses (Table 7.3) showed that the following workers tended to support more heat training: those aged ≥25 years, working in "electricity, gas and water" industry, and respondents having experienced previous heat illness and injury during hot weather. On the contrary, compared with those working completely indoors, respondents working mainly outdoors or indoors, thought that there was less need for more heat-related trainings.

In the multiple logistic regression analyses (Table 7.3), the results suggested that the following factors were significantly associated with workers' attitudes towards heat-related trainings: those aged 25-54 years, previous heat illness history, and injury experience during hot weather.

7.3.3.3 Attitudes towards more heat-related policies

Results showed that 63.8% of participants agreed that there should be more heat-related regulations and guidelines for working during very hot weather (Table 7.2). Regarding the reasons why the remaining 36.2% held the opposite view, as shown in Figure 7.4, over half (52.3%) thought "there are enough regulations", while 21.5% considered workplace heat exposure to not be a serious problem. Using attitudes towards more heat-related policies as the dependent variable, bivariate logistic regression indicated that workers who undertook physically demanding work (very much) or had experienced heat illness were more likely to support there being more regulations or guidelines regarding heat stress (Table 7.3). However, the following workers were not supportive of more legal requirements or restrictions for working during very hot weather: those aged 55 years, with a university degree, and working mainly indoors. Multiple logistic regression analyses results (Table 7.3) suggested that very physically demanding work and heat illness experience were the two factors associated with workers' attitudes toward more heat-related policy support.

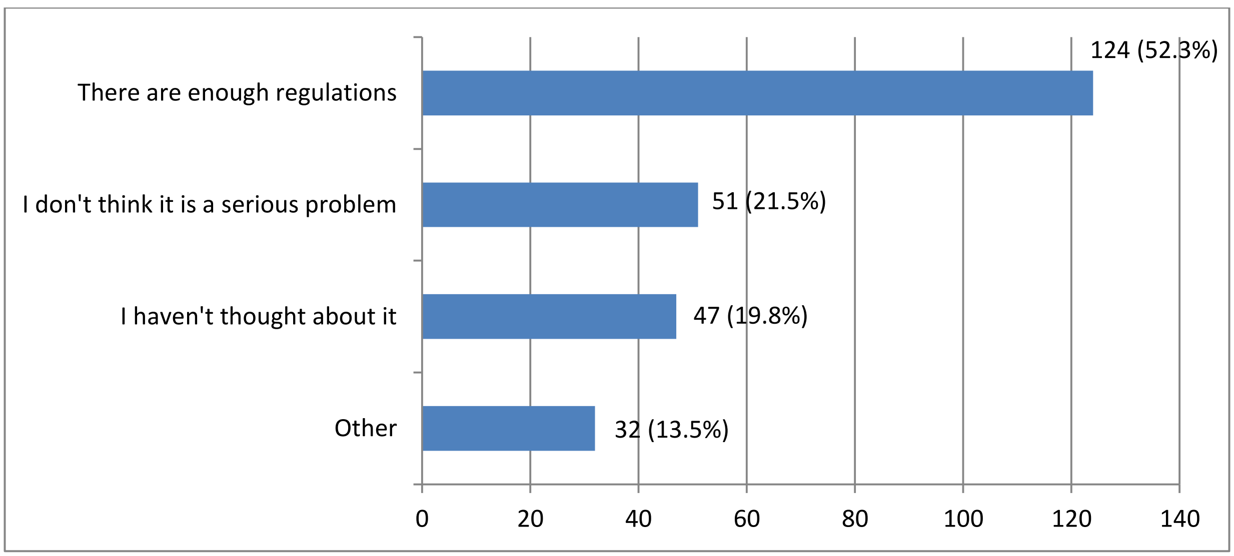

Figure 7.4 Reasons why there is no need for more heat-related regulations and guidelines

7.3.3.4 Attitudes towards the adjustment of work habits

More than two-thirds (68.8%) of participants answered they were willing to adjust their current work habits to adapt to the impact of extreme heat (Table 7.2). As to the reasons the remaining 31.2% did not consider the adjustment of work habits during hot weather (Figure 7.5), one-third

(33.3%) thought "Enough has been done already", followed by "I don't think I am at risk" (30.3%), and "I don't think it is a serious problem" (24.4%).

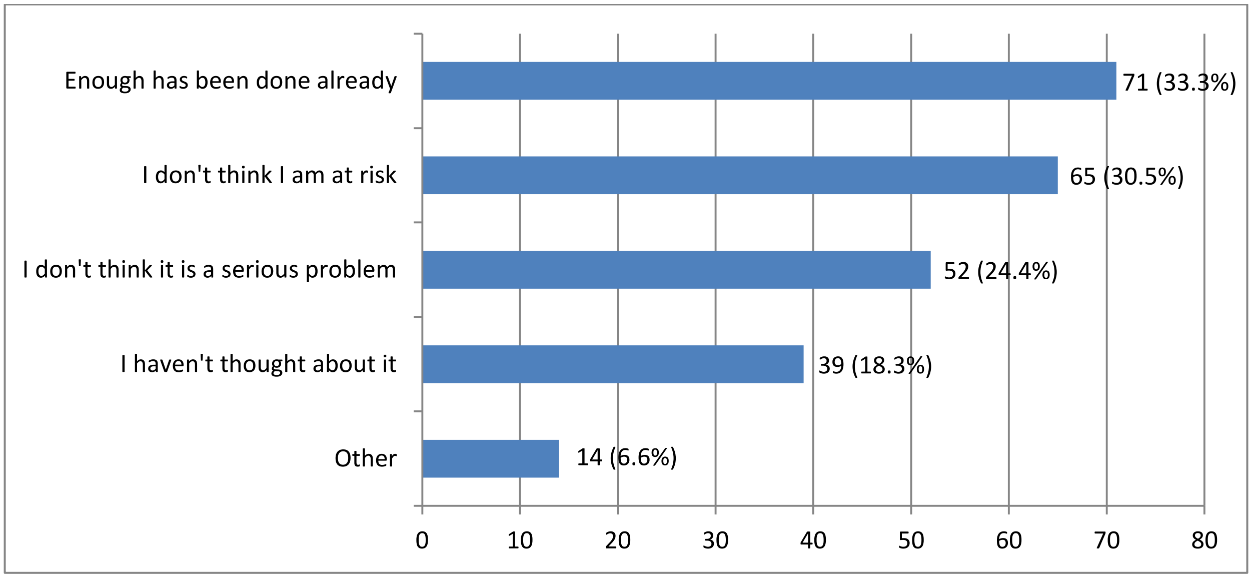

Figure 7.5 Reasons why workers did not consider adjusting work habits during hot weather

Results of bivariate logistic analyses showed that workers undertaking little physically demanding work were less likely to undertake adaptive behaviours, whereas workers having experienced previous heat illness were more likely to adjust their work habits during hot weather. Multiple logistic regression analyses indicated that only previous heat illness experience (OR 1.45, 95% CI 1.15-1.84) affected workers' heat-related work habits.

7.3.3.5 Satisfaction degree of current heat-related prevention measures

More than half (51.4%) of participants were satisfied with the heat prevention measures currently adopted in the workplace in South Australia (Table 7.2).These included workers aged ≥35 years, those with a university degree, working mainly indoors, and employed in "agriculture, forestry and fishing", "construction", and "electricity, gas and water" (Table 7.3). Occupation-specific analyses showed that tradespersons, machinery operators and drivers, labourers and related workers, and full-time TAFE students were not satisfied with current heat prevention measures. In addition, workers undertaking moderately and very physically demanding work, working close to heat sources, and having had a previous heat illness and injury during hot weather were also not satisfied with current heat prevention measures.

As shown in Table 7.3, multiple logistic regression analyses suggested that the following variables could affect workers' satisfaction in terms of current heat prevention measures: age in categories (35-54 and ≥55 years), education level (university degree), physically demanding (moderate to very much), previous heat illness experience and injury experience during hot weather.

7.3.4 Personal behaviours during hot days

As shown in Figure 7.6, the majority (64.4%) of participants drank fluids regularly during work, while 16.4% responded that they only drank when feeling thirsty, and 15.2% answered that they drank plenty of fluids before starting work. About one-fifth of participants' claimed all of these were applicable.

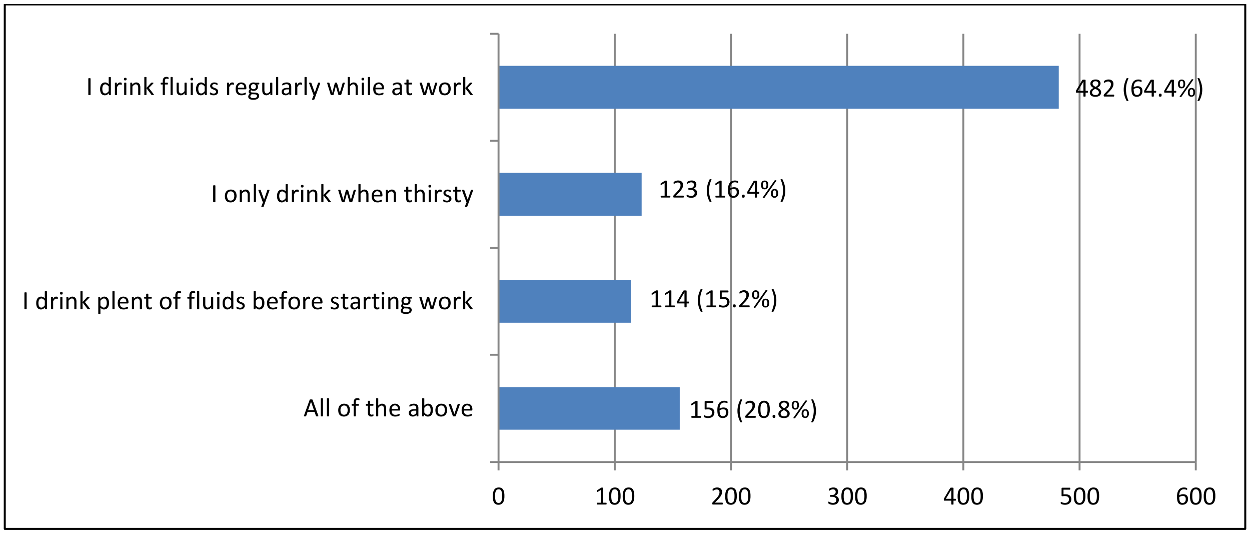

Figure 7.6 Participants' drinking habits during hot weather

Table 7.3 Factors associated with attitude and perception for workplace heat exposure, more heat-related training and regulations, the change of work habits, and satisfaction for prevention measures: bivariate analysis and multiple stepwise logistic regression an

Independent variable	Concern for extreme heat		Attitude for more trainings		Attitude for more regulations		Attitude for adjusting work habits		Satisfaction degree of prevention measures	
	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Gender										
Female	1.00		1.00		1.00		1.00		1.00	
Male	0.92 (0.44-1.91)		1.13 (0.49-2.65)		1.37 (0.66-2.82)		1.50 (0.76-2.95)		0.63 (0.29-1.39)	
Age group										
≤24	1.00	1.00	1.00	1.00	1.00		1.00		1.00	1.00
25-34	1.80 (1.25-2.57)	1.82 (1.18-2.80)	1.74 (1.24-2.45)	1.75 (1.27-2.39)	1.40 (0.76-2.61)		1.63 (0.77-3.48)		1.09 (0.65-1.82)	0.94 (0.61-1.44)
35-54	2.21 (1.18-4.16)	2.73 (1.45-5.12)	2.00 (1.06-3.79)	1.96 (1.05-3.65)	0.71 (0.43-1.17)		1.42 (0.83-2.42)		3.05 (1.92-4.85)	2.54 (1.66-3.88)
≥55	1.19 (1.01-3.52)	2.77 (1.73-4.43)	1.83 (0.87-3.83)	1.93 (0.99-3.76)	0.47 (0.28-0.80)		0.98 (0.51-1.85)		3.36 (1.61-7.00)	2.12 (1.00-4.48)
Education level										
High school	1.00		1.00		1.00		1.00		1.00	1.00
Trade certificate	1.45 (1.14-1.84)		1.24 (0.92-1.66)		0.91 (0.66-1.24)		1.11 (0.77-1.61)		1.24 (0.83-1.87)	1.12 (0.75-1.67)
University degree	1.30 (0.85-1.99)		1.44 (0.94-2.19)		0.37 (0.17-0.83)		1.32 (0.59-2.93)		7.51 (2.73-20.69)	4.79 (1.65-13.94)
Occupation										
Clerical and administrative workers	1.00		1.00		1.00		1.00		1.00	
Tradespersons and related workers	1.53 (0.72-3.24)		0.53 (0.13-2.16)		2.28 (0.90-5.76)		1.17 (0.46-3.00)		0.14 (0.05-0.41)	
Machinery operators and drivers	2.84 (0.65-12.45)		0.60 (0.20-1.74)		1.85 (0.74-4.65)		0.60 (0.26-1.40)		0.28 (0.11-0.69)	
Labourers and related workers	1.57 (0.65-3.79)		0.54 (0.13-2.20)		1.93 (0.41-9.05)		1.15 (0.44-3.00)		0.13 (0.04-0.39)	
Full-time TAFE students	1.04 (0.36-2.99)		0.51 (0.12-2.23)		0.98 (0.21-4.62)		1.04 (0.35-3.05)		0.20 (0.07-0.63)	
Professionals	6.50 (2.20-19.20)		0.94 (0.17-5.16)		0.69 (0.23-2.07)		2.17 (0.75-6.27)		1.12 (0.16-7.78)	
Other	1.29 (0.51-3.21)		0.69 (0.21-2.20)		0.98 (0.21-4.62)		1.13 (0.42-2.99)		0.53 (0.07-3.85)	
Industry										
Manufacturing	1.00		1.00		1.00		1.00		1.00	
Agriculture, forestry & fishing	1.26 (0.65-2.46)		1.70 (0.81-3.56)		0.97 (0.43-2.19)		0.70 (0.33-1.49)		3.99 (2.22-7.18)	

Mining	1.67 (1.10-2.55)		1.07 (0.50-2.31)		0.70 (0.27-1.83)		1.03 (0.41-2.60)		2.56 (0.99-6.60)	
Construction	1.39 (0.81-2.36)		1.45 (0.77-2.74)		0.98 (0.45-2.12)		1.13 (0.60-2.14)		1.76 (1.12-2.77)	
Electricity, gas & water	1.71 (0.94-3.11)		2.16 (1.20-3.89)		0.77 (0.13-4.44)		1.54 (0.80-2.97)		4.42 (2.05-9.56)	
Other	0.79 (0.18-3.38)		1.19 (0.42-3.35)		0.54 (0.26-1.13)		1.13 (0.30-4.19)		1.50 (0.42-5.34)	
Workplace environment										
Completely indoors	1.00		1.00		1.00		1.00		1.00	
Mainly indoors	0.95 (0.64-1.42)		0.38 (0.19-0.74)		0.57 (0.37-0.87)		0.98 (0.54-1.80)		2.47 (1.80-3.38)	
Completely outdoors	2.99 (1.44-6.22)		0.59 (0.24-1.46)		0.98 (0.44-2.18)		0.79 (0.33-1.91)		1.34 (0.56-3.17)	
Mainly outdoors	1.19 (0.70-2.01)		0.42 (0.21-0.86)		0.71 (0.37-1.38)		1.00 (0.54-1.84)		1.61 (0.77-3.39)	
Physically demanding										
Not at all	1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00
A little	1.18 (0.81-1.73)	1.26 (0.87-1.83)	0.64 (0.32-1.28)		0.87 (0.55-1.39)	0.87 (0.56-1.34)	0.53 (0.33-0.83)		0.51 (0.22-1.19)	0.67 (0.28-1.58)
Moderately	1.36 (0.77-2.40)	1.73 (0.92-3.28)	0.72 (0.30-1.77)		1.71 (0.79-3.68)	1.66 (0.79-3.49)	0.91 (0.58-1.41)		0.21 (0.11-0.44)	0.43 (0.24-0.79)
Very much	2.20 (1.27-3.82)	2.77 (1.73-4.43)	0.74 (0.26-1.92)		2.56 (1.28-5.11)	2.38 (1.21-4.66)	0.80 (0.54-1.19)		0.13 (0.07-0.24)	0.31 (0.16-0.60)
Work close to heat sources										
No	1.00		1.00		1.00		1.00		1.00	
Yes	1.21 (0.83-1.52)		1.02 (0.63-1.67)		1.41 (0.94-2.12)		1.08 (0.80-1.46)		0.51 (0.33-0.79)	
Use of personal protective equipment										
No	1.00	1.00	1.00		1.00		1.00		1.00	
Yes	1.79 (1.34-2.40)	1.47 (1.13-1.91)	1.23 (0.95-1.58)		1.06 (0.63-1.77)		1.17 (0.84-1.62)		0.85 (0.50-1.44)	
Heat illness experience										
No	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Yes	2.07 (1.41-3.02)	1.57 (1.01-2.45)	1.77 (1.16-2.72)	1.58 (0.97-2.58)	1.55 (1.16-2.07)	1.39 (1.05-1.83)	1.45 (1.15-1.84)	1.45 (1.15-1.84)	0.43 (0.29-0.65)	0.53 (0.36-0.76)
Injury experience during hot weather										
No	1.00	1.00	1.00	1.00	1.00		1.00		1.00	1.00
Yes	2.42 (1.71-3.44)	2.05 (1.47-2.86)	1.62 (1.23-2.14)	1.44 (1.09-1.91)	1.66 (0.99-2.80)		1.17 (0.84-1.63)		0.29 (0.20-0.43)	0.38 (0.27-0.54)

Shaded cells denote statistical significance at the p<0.05 level

As shown in Figure 7.7, heat-related training (49.7%) and at the workplace (48.9%) were the most common way for participants to obtain information about heat stress prevention, followed by information from friends and families (22.4%), colleagues (21.6%), TV and radio (15.8%), SafeWork SA (15.1%), the internet (8.1%), and newspapers (5.5%). Some 10.3% of participants stated that they could not access any information about heat stress prevention.

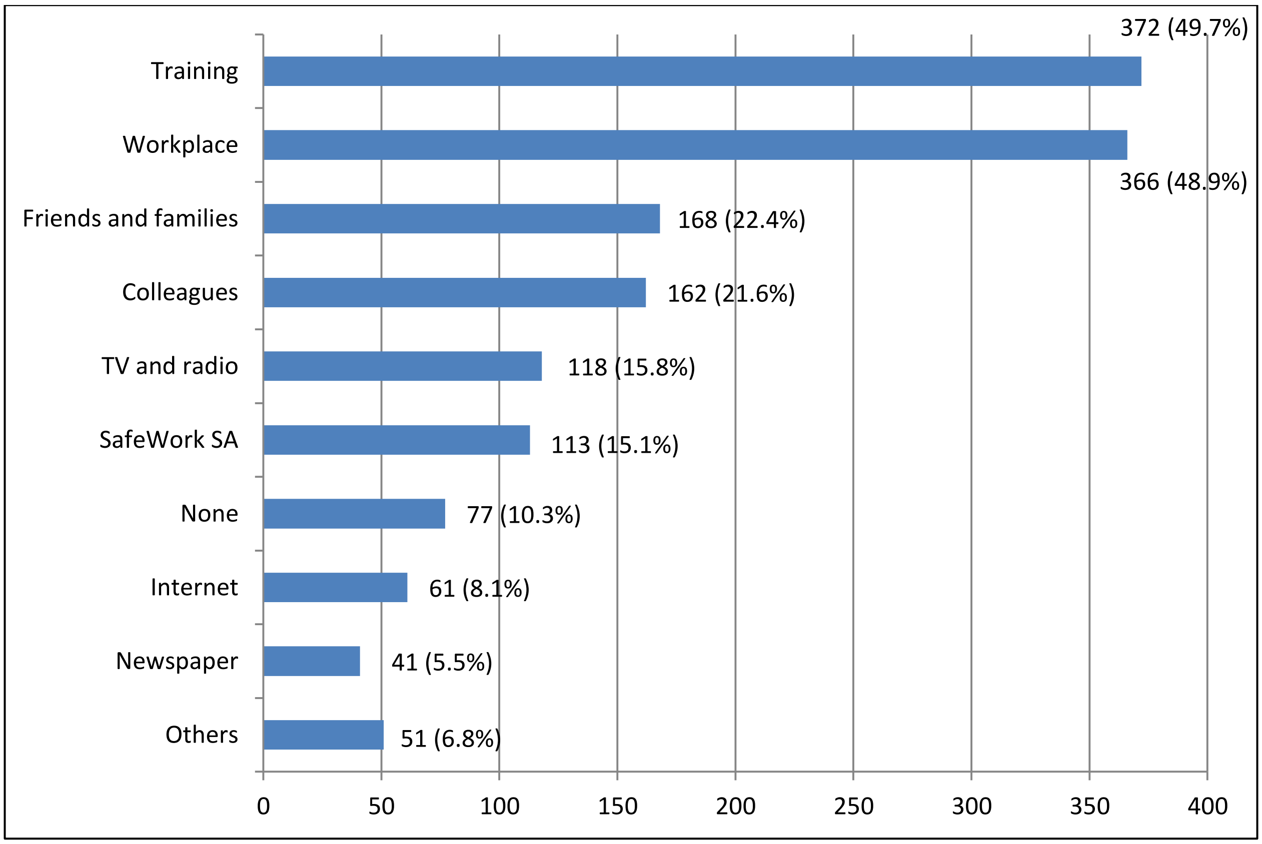

Figure 7.7 Main sources of information about heat prevention

Respondents were asked if they worked at their own pace during very hot weather and the majority (70.4%) answered in the affirmative. As to the reasons why the remaining 29.6% did not work at their own pace, more than two-thirds (68.0%) attributed this to the pressure from work demands, followed by the pressure from supervisors (46.1%), and peer pressure (24.3%).

In addition, 11.2% replied that there was no need to slow down work rate during hot weather because "Enough has been done to cool the workplace" (Figure 7.8).

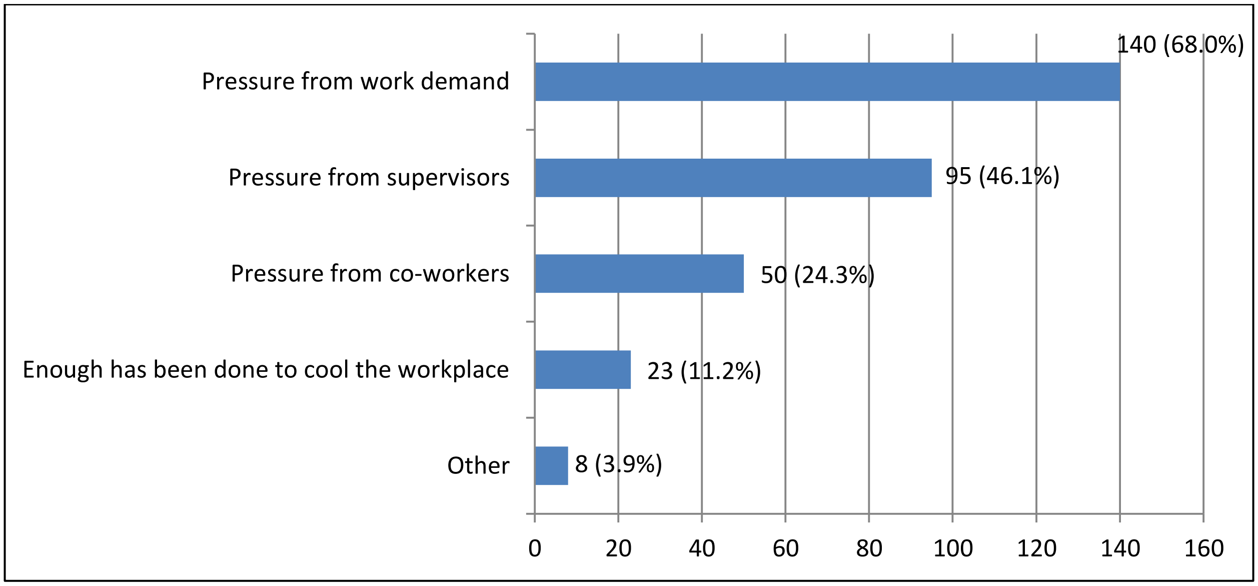

Figure 7.8 Reasons that some workers did not work in their own pace during very hot weather

7.3.5 Current heat prevention measures

As shown in Figure 7.9, the provision of cool drinking water (69.8%) was the most common prevention measure adopted in the workplace against heat exposure, followed by wearing broad brimmed hats (39.0%), rescheduling work time (33.8%), central cooling and air conditioning (33.6%), electric fans (33.6%), and shady rest area (33.1%). Only 19.6% answered "stopping work" or a prevention measure when the temperature was extremely hot (e.g. >40°C).

When asked if there were guidelines for heat stress prevention during extremely hot weather, 50.9% of respondents answered "Yes". Whilst 43.4% had attended a heat-related training course, 60.0% participants had received instructions on first aid procedures for serious heat illnesses.

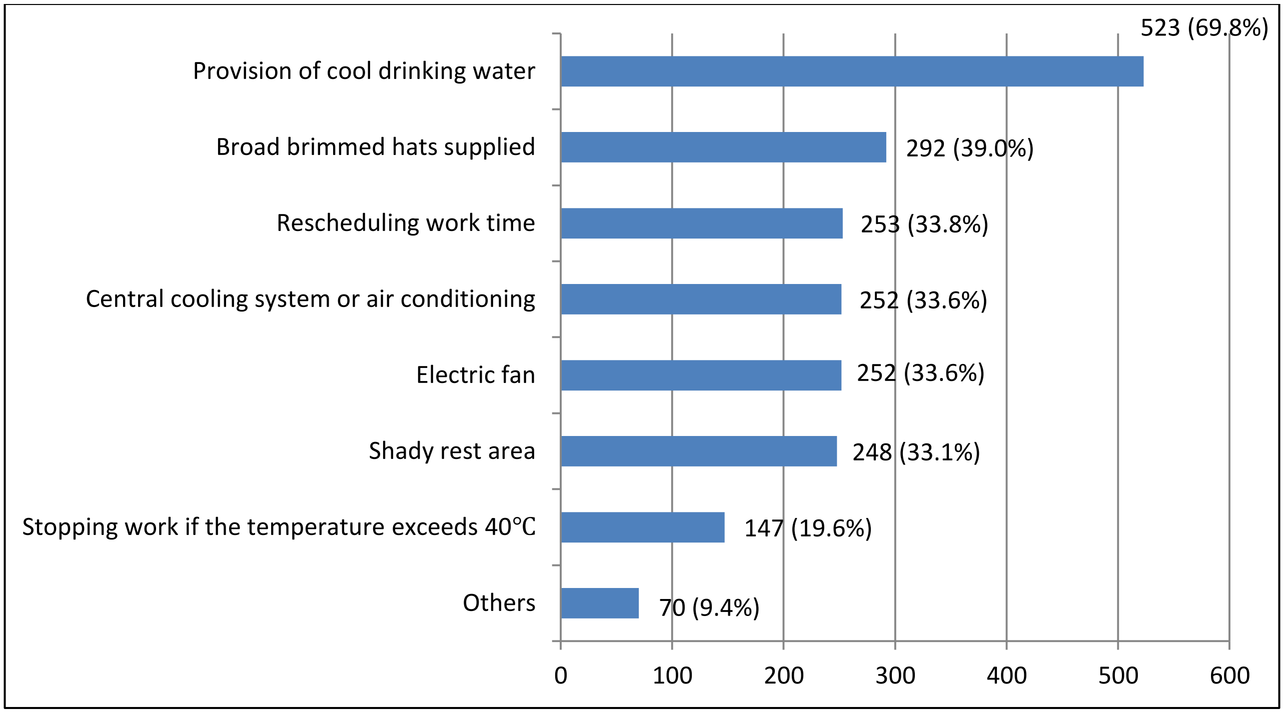

Figure 7.9 Heat prevention measures currently adopted in the workplace

7.4 Discussion

It is important to understand workers' perceptions on workplace extreme heat exposure, as this information may provide scientific evidence for relevant stakeholders for policy-making and adaptation strategy and practical guideline development. However, most of the currently available information is from qualitative studies conducted amongst Indian industrial workers,[108] South African outdoor manual workers,[116] and Costa Rican sugarcane workers.[97] This survey is a modest step towards this goal in a developed country, using a quantitative approach.

It is generally considered that workers in middle-low income countries will be more vulnerable to heat-related illnesses and injuries if global warming continuously progresses. This may be due to a number of factors including poor services in the countries, inadequate workplace legislation and guidelines, and workers' poor awareness of the negative health impacts of working in the heat.[233] There appears to be a mismatch between the growing concerns regarding the impact of extreme heat on workers' health and safety in the literature, and the overall heat stress risk perceptions among workers in the middle-low income countries (e.g. India, South Africa, and Costa Rica). For instance, many interviewees in South Africa said they had not perceived any changes in weather patterns, and some of them even felt that the average temperatures were declining.[116]

Limited evidence suggests that workers' perceptions regarding extreme heat exposure in high income countries are not optimistic. In recent years, the impacts of heat exposure on farmworkers' health and safety have drawn much research attention in the USA,[21, 37] due to the disproportionate heat-related deaths[73] and high prevalence of heat illness symptoms among farmworkers.[92, 93] In the Mexican Immigration to California: Safety and Acculturation (MICASA) Study, more than 92% of 474 hired farmworkers were not at all or a little concerned about the risk of heat illness at work in 2008-2010.[169] This may be partly the reason why the US OSHA launched the national-wide Heat Illness Prevention Campaign in 2011 to raise awareness of the harm that can caused by heat exposure in the workplace.[171]

7.4.1 Heat exposure concern in Australia

To the author's knowledge only one qualitative study has explored Australian workers' heat risk perceptions. This study, which involved semi-structured telephone interviews,[43] revealed that exposure to high temperatures during the hot summer months in Australia was regarded by participants as 'routine' and 'cannot easily be avoided'. The author also found that "vestigial stereotypical attitudes" to heat exposure (e.g. strong masculine cultures) prevailed in the Australian workforce.[43] Given Australia's existing thermal environments and predicted increasingly hot summers, there was a misalignment of perceived occupational health risk [43]. To the author's best knowledge, the present study is the first in Australia to investigate workers' risk perceptions of heat exposure and identify factors affecting individuals' heat perceptions using a questionnaire survey.

This study revealed that about half of respondents were moderately to very much concerned about their occupational health and safety when working during very hot weather. The percentage (50%) concerned in "agriculture, forestry and fishing" in South Australia was about 6 times higher than that (8%) in a study of Californian hired farmworkers in the USA.[169] The relatively higher heat awareness among the Australian public may reflect cultural and demographic difference in study populations.

The results from this study suggested that young workers were less concerned about heat exposure than older workers. Moreover, middle aged workers supported having more heat-related training compared to young and older workers. There are many concerns about Australian young workers' attitudes towards occupational health and safety, of which heat stress is only one. According to the national Motivations, Attitudes, Perceptions and Skills (MAPS) survey, up to 28% of Australian young workers reported resenting dealing with workplace health and safety requirements, and 42% forgot about safety during working practice.[310] As mentioned in Chapter 5, young workers are at high risk of heat-related illnesses and injuries when the temperature below a certain threshold (e.g. 37.9℃).[27, 28, 139] By contrast, older workers (≥55 years of age) are more vulnerable to heat-related illnesses/injuries in certain outdoor industries during heatwaves (Chapter 6). Therefore, more educational programmes should be targeted to these two age groups. Further research is also needed to explore the paradoxical phenomena that young workers were less satisfied with heat prevention measures but expressed more negative attitudes towards heat prevention efforts, compared with older workers. The compliance and implementation of heat prevention and adaptation policies would be undermined if the sentiments of unwillingness to cooperate existed among young workers.[310]

Undertaking very physically demanding work and wearing PPE was also found to be associated with workers' concern about heat exposure. Both of these are very important factors determining human body heat balance, and can be indirectly reflected in the standard workplace heat stress management procedure.[53] The results also suggest that heat exposure concern is also related to whether or not individuals have had a previous heat illness and injury.

7.4.2 Heat-related training

Although one study in California found that over 91% of farmworkers received training on heat-related illness,[169] most of the recent studies conducted among USA farmworkers have revealed that a majority of workers did not receive any heat-related training.[93, 173, 174] In this study in South Australia, about 43% of respondents indicated that they have received heat-related training. The relatively higher proportion of workers receiving heat prevention training in this study maybe partly because of the lessons learnt from the past. Previously, less training and education had been provided in OH&S, and this was identified as one of the top three causes of occupational injuries and accidents in Australia.[311] Therefore relevant work health and safety training has recently been incorporated into secondary, vocational and university level education from the mid-to late 1990s in Australia.[311]

The results indicated that heat training was the workers' major source of information about heat stress prevention, and this is the case for occupational health and safety in general.[311] Overseas, published literature has suggested that the majority of outdoor physical workers in the USA and

South Africa have a good knowledge of the symptoms and severe outcomes of excessive heat exposure,[116, 169, 173] although in one study there was poor knowledge about heat acclimatization and medication use,[172] and in another about the potential impact of climate change on occupational health and safety.[116] Similarly, a minority of outdoor physical workers in South Africa thought that hot weather did not affect their health and safety,[116] whilst most workers in heavy truck and vehicle manufacturing sectors in India were not aware of the consequences of heat stress.[108]

Although workers' average level of knowledge on heat stress remains unknown in the present study, 16% of respondents said they only drank when they were thirsty. This indirectly reflects the necessity to reinforce messages about dehydration in the workplace. Relevant training and education should focus on young workers and those aged over 55 years, as these groups expressed less willingness to receive more heat training. Moreover, studies have shown they are at relatively higher risk of heat-related illness and injury.[78, 139, 274] More supportive attitudes towards heat-related training in the age group of 25-54 years may account for their greater concerns over heat exposure. As to the reasons why workers aged ≥55 years did not show stronger willingness to support more heat-related training whilst being more concerned about heat compared to young workers, they may be more satisfied with current preventive measures in place or they may undertake more sedentary jobs with less heat exposure. Further research is needed to address this issue. In addition to training and workplace, the role of mass media in popularizing heat stress prevention knowledge could be strengthened, as some respondents (up to 10%) in this study claimed to have had no sources of heat prevention information.

7.4.3 Individual behavioural response

The majority of respondents expressed their willingness to adjust work habits to adapt to possible increasing hot weather, and this may be useful for future heat intervention measures. The results from this study suggested that previous heat illness experience was the only factor associated with the adjustment of work habits. A good level of heat stress knowledge and awareness does not necessarily translate into individual behavioural change. For instance, some Latino farmworkers in the USA drank alcohol, coffee, and energy beverages to quench thirst or increase alertness, although they realized it was inappropriate.[173] Some female farmworkers even deliberately wore dark clothes at work to lead to sweating for weight loss.[173] Such knowledge-behaviour gaps may provide opportunities for additional heat prevention and education strategies. In addition, a study conducted among US farmworkers has shown that cultural beliefs and incorrect heat strain treatment using traditional medicine were also identified as potential barriers to individual heat adaptation behaviours.[97, 173] In particular, for the culturally diverse Australian workforce, about 28% of which were born overseas,[312] heat prevention measures should take into account the role of cultural beliefs and language barriers.

Self-pacing (adjusting work rate to avoid physiological heat strain) has been used to explain (at least partially) why workers were not heat stress challenged when working in hot environments.[82, 111, 114, 115, 231] In the present study, up to 70% of respondents expressed that they worked at their own pace during very hot weather. For others, pressure from work demand and supervisors was the major reason that workers did not slow down their work rate. Profit-oriented production and performance targets have been shown to be a common reason overshadowing or marginalizing heat stress prevention.[43]

Heat stress is not commonly considered as major occupational risk[43] and employee-based behavioural change is not enough to reduce heat-related illness and injury as employees may be powerless in an occupational health and safety management system.[43, 93] Relevant heat prevention campaigns, even legislation, should target employers to highlight the importance of heat stress prevention, which not only impacts workers health and safety but also may compromise productivity.[19-21] However, to date few studies have investigated how employers in industry perceive the risk of heat exposure.

7.4.4 Heat prevention measures

In this study about one-quarter of respondents claimed to have witnessed heat-related illnesses or injuries during extremely hot weather which indirectly reflects the high incidence, despite the limited numbers of heat-related compensation claims identified in previous chapters. Fortunately, all heat-related illnesses, injuries and deaths are preventable. Heat prevention strategies mainly include regulations, administrative controls, and engineering modifications. Currently, there is no federal occupational standard specifically addressing heat illness and injury prevention in Australia.[19] About 64% of respondents in this study thought there was a need for more heat-related regulations. Meanwhile, about half of respondents were not satisfied with current prevention measures, indicating the necessity of the development of policies, especially for young workers with low education levels and undertaking physically demanding work outdoors.

Maintaining hydration is very important for heat prevention. In this study, approximately 30% of respondents replied that cool drinking water was not available in the workplace. Moreover, about 16% of respondents only drank when thirsty. Thirst cannot be relied upon as a guide for the need for water, as 1% of the total body weight in water is already lost when an individual senses thirst.[156] According to the national Model Code of Practice (managing the work environment and facilities),[313] "an adequate supply of clean drinking water must be provided free of charge for workers at all times." However, its implementation and effectiveness are questionable, as evidence has shown that a poor hydration status has been observed among workers employed in a range of industries in Australia.[112, 113] Heat prevention measures seem straightforward, common-sense, and simple (e.g., drinking water frequently, wearing light colour and permeable clothes, taking breaks in the shade, and responding to early symptoms), however a variety of factors at multiple levels in the workplace may constrain such implementation, such as the piece-rate payment systems, production quotas, worries of being considered 'soft', and workers' fears of losing their job.[43, 314]

In this study, findings showed that when the temperature was extremely hot e.g. over 40℃, only 20% of respondents selected "stopping work" as a heat prevention measure. However, according to the heat stress management policy of the Construction, Forestry, Mining and Energy Union (CFMEU) South Australia Branch, "if temperature is over 37°C all work ceases unless working in air conditioned area".[181] In this study, the majority (67%) of participants were recruited from agriculture, forestry, mining, construction, and energy industries, and about half of them worked outdoors. Therefore, this raises concerns regarding the compliance of heat policies. In 2010, California became the first State in the USA to enact a stringent heat law to protect workers from heat exposure.[49] Two years later, however, inspectors found that more than half of the employers they audited did not comply with the heat standard.[315] It has been proven that without proper enforcement heat standards are likely to pose little restrictions to non-compliant employers.[314] Therefore, local regulators should enforce regulations during extremely hot days.

7.4.5 Limitations

There are several limitations in this study. First, the vast majority (96%) of respondents were males. Caution should be used when generalizing the results to female workers. Moreover, as the participation of the survey was completely voluntary, those with previous heat illness and injury experience may have been more likely to participate in the survey, which may generate potential selection bias and therefore overestimate workers' heat concerns. Second, the level of workers' heat-related knowledge was not specifically measured in this study. However, published papers have consistently found that most workers in both developing and developed countries have a good knowledge of heat illnesses.[116, 169, 173, 174] Third, evidence has shown that mail surveys published in medical journals had a response rate of 60% on average.[316] The relatively low response rate (50.9%) in this study may generate potential non-respondent bias. Although there is not necessarily a relationship between response rates and bias, there are more opportunities for non-response bias if respondents significantly differ from non-respondents.[316] Fourth, 31.7% of participants were TAFE students rather than established workers, although the majority worked as apprentices on a part-time basis. Lastly, the survey was not conducted during the hottest part of the year, posing the opportunity for recall bias. Moreover, seasonal migrant workers may not be included in this study.

7.5 Conclusion

This study provides important insights and baseline information regarding workers' perceptions and attitudes towards workplace heat exposure. Workers in South Australia were moderately concerned about heat exposure. Heat educational programmes and training should focus on those undertaking physically demanding work outdoors, in particular young workers and those over 55 years with low education level. Further qualitative research is required to explore how workers in different heat-exposed industries and employers perceive the risk of heat exposure and better understand their heat experiences and coping strategies. Effective heat stress prevention and management needs intersectoral joint efforts from multiple aspects of the OH&S system. In addition, workers' heat risk perception investigations should be expanded to employers, government OH&S decision makers, and other relevant stakeholders (e.g. occupational nurses, physicians, and consultants).

Chapter 8

Workplace heat exposure and OH&S: Perceptions from occupational hygienists

8.1 Introduction

As mentioned previously, the growing threat of heat stress and its potential impacts on occupational health and safety (OH&S) and productivity loss has been addressed in recent years.[19-21, 37] Evidence has shown that higher average temperatures and increasing periods of extremely hot weather could may place outdoor physical workers in Australia at moderate to high risk of heat strain by 2070.[32, 35] This may result in a significant reduction in afternoon work time,[36] as well as possible increases in heat-related illnesses and injuries.[19, 20, 64, 139]

Effective heat stress management in the workplace needs comprehensive efforts and cooperation from a range of stakeholders as previously mentioned. Better understanding of how people involved in OH&S at different levels view the risk of workplace heat exposure will help to inform heat prevention and adaptation strategies and practical guidelines.

Occupational hygienists are at the frontline protecting workers' health and safety by recognizing, evaluating, and controlling environmental hazards. As professionals, they play central and crucial roles in heat stress training, monitoring, assessment and management, and prescribe heat prevention recommendations to employers. Hence, their perspectives are of particular importance and may be helpful when considering heat-related health and safety reforms. This Chapter aims to provide insights into hygienists' and related occupational specialists' perceptions on this issue and current and future preparedness for extreme heat.

8.2 Materials and methods

A cross-sectional self-administered survey was conducted with a questionnaire during the 30th Annual Conference & Exhibition of the Australian Institute of Occupational Hygienists Inc. held in Adelaide from 1st to 5th December 2012.

8.2.1 Questionnaire design

The design of the survey questions was guided by both previous relevant academic literature[20, 108, 116, 317] and our research questions (Chapter 2). The instrument contained three demographic questions (job position, years of OH&S experience, and State/Territory) and questions focusing on the following aspects (Appendix I). First, to measure concern and awareness of current workplace extreme heat exposure and climate change, three 5-point Likert-scale questions were asked (see Table 8.2 for the wording of questions). Second, to investigate participants' heat stress management experience and companies' preparedness for such challenge in a warming climate, eight specific items were developed, as shown in Table 8.4. Third, to understand current heat preventive measures and identify existing adaptation barriers, participants were asked: (1) "What measures are adopted in the workplace or workplaces that you consult in during very hot weather?" and (2) "What do you foresee as potential barriers for the prevention of heat stress in the workplace?" The final question was open-ended: "Do you have any further recommendations or suggestions for the prevention of heat-related illnesses and injuries in Australian workplaces?" Some secondary questions also had open-ended responses.

The survey instrument was pre-tested for length, clarity and comprehension with a convenience sample of five hygienists recruited from the Occupational and Environmental Health Laboratory, The University of Adelaide. Minor modifications were made according to the feedback before the instrument was finalized.

8.2.2 Participant recruitment

With the support of the conference organizing committee, 371 registered conference delegates (professional hygienists and relevant occupational specialists) in attendance were invited to participate in this survey. A purposive convenience sampling method was used.[318] Questionnaires (Appendix I) and information sheets (Appendix J) were distributed to the delegates at the conference registration desk. Participation was totally voluntary. An eye-catching questionnaire return box was placed at the conference reception desk to facilitate the return of completed questionnaires. To promote the participation rate, delegates who returned the completed questionnaire were included in a draw for a $100 gift card and a $200 Christmas donation to charity. The survey was approved by both the Human Research Ethics Committee at the University of Adelaide (H-200-2011) and the conference organizing committee.[319]

8.2.3 Data analyses

Data input and validation were performed using Microsoft Excel 2010. Data analyses were conducted using Stata v12.0 (StataCorp LP, College Station, Texas). Descriptive analysis was used to calculate the frequency of variables. Chi-square tests were used to investigate the correlation between heat concern, satisfaction, and attitudes towards further heat prevention efforts, and to compare the differences in heat concern between occupational hygienists and non-occupational hygienists. In addition, due to the booming mining industry (where heat stress can be common) in Western Australia and Queensland in recent years in Australia, the heat concern level between participants from these two States and other States was compared.

8.3 Results

As shown in Table 8.1, 180 of the 371 conference delegates participated in the survey during the 5-day conference period, with a participation rate of 48.5%. Of the 180 participants, 94.4% (170) had OH&S work experience, ranging from 1 to 44 years, with an average of 16 years. There were 89 occupational hygienists, representing about half (49.4%) of all respondents, followed by occupational consultants (26.7%), relevant stakeholders such as OH&S product exhibitors and staff from companies providing OH&S services (21.1%), and workplace OH&S managers (2.8%). Of the 89 hygienists, 35 (39.3%) were general industry hygienists. The numbers and percentages of hygienists from the mining industry, government, university, and military hygienists were 34 (38.2%), 12 (13.5%), 7 (7.9%), and 1 (1.1%), respectively (Figure 8.1). The majority of participants were from Western Australia, followed by New South Wales (20.6%), Victoria (16.7%), South Australia (12.2%), and Queensland (10%).

Table 8.1 Demographic information of the participants

Category	n	%
Total	180	100.0
Occupation		
Hygienist	89	49.4
Occupational consultant	48	26.7
OH&S manager	5	2.8
Other	38	21.1
Area		
Western Australia	45	25.0
New South Wales	37	20.6
Victoria	30	16.7
South Australia	22	12.2
Queensland	18	10.0
Overseas	13	7.2
Tasmania	9	5.0
Australian Central Territory	4	2.2
Northern Territory	2	1.1

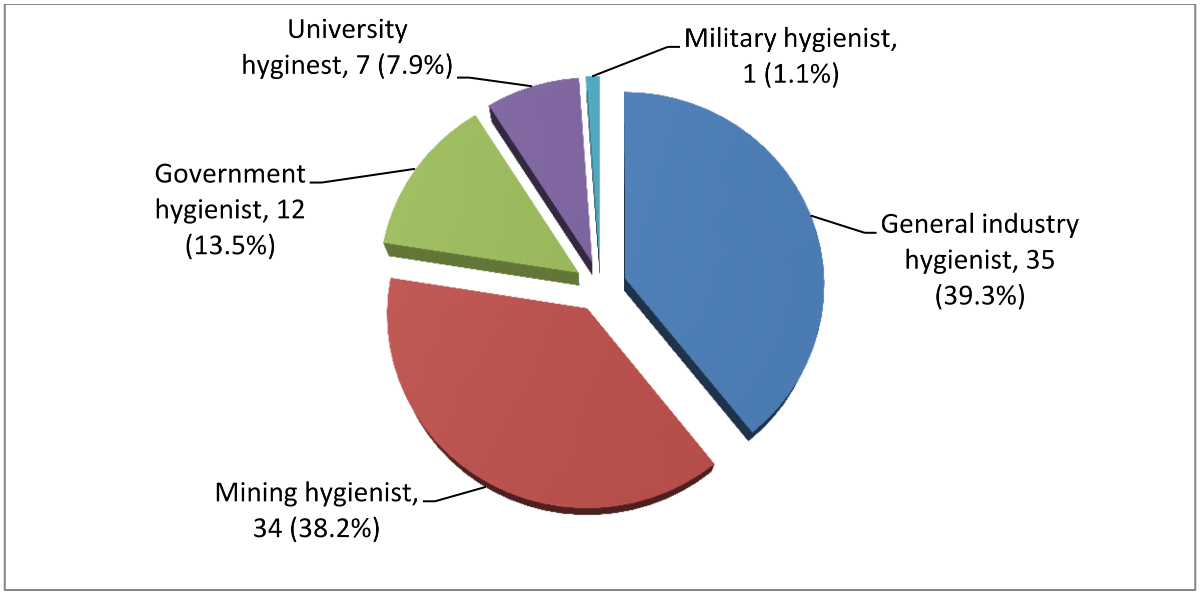

Figure 8.1 Number and percentage of different hygienist categories

8.3.1 Concern and awareness

As shown in Table 8.2, nearly 90% of participants were moderately or more concerned about extreme heat resulting in increased hazards in the workplace. Almost two thirds of participants agreed that extremely hot weather due to a changing climate may present a future challenge for heat stress management. Half (50.0%) of participants were satisfied or strongly satisfied with the heat preventive measures currently adopted in workplaces. By contrast, 19.4% were not satisfied.

As shown in Table 8.3, no significant differences were observed between hygienists and others on heat concern, attitudes toward climate change-related heat stress challenge, and satisfaction level of current heat prevention measures. Similarly, no significant differences were identified between Western Australia and Queensland and other Australian States.

Table 8.2 Number and percentage of respondents' concern and awareness on workplace extreme heat exposure

	Question	Response	n	%
1.	How concerned are you about extreme heat resulting in increased hazards in the workplace?	Extremely	27	15.0
		Very	93	51.7
		Moderately	43	23.9
		A little	13	7.2
		Not at all	4	2.2
2.	Do you agree or disagree that extremely hot weather due to changing climate presents a future challenge for workplace heat management?	Strongly agree	21	11.7
		Agree	96	53.3
		Neutral	44	24.4
		Disagree	15	8.3
		Strongly disagree	4	2.2
3.	Overall, are you satisfied or dissatisfied with the measures currently adopted for reducing the risk of heat illnesses and injuries in the workplace or workplaces that you consult in during very hot weather?	Strongly satisfied	5	2.8
		Satisfied	85	47.2
		Neutral	55	30.6
		Dissatisfied	35	19.4
		Strongly dissatisfied	0	-

Table 8.3 Comparison of heat concern, attitudes toward future heat challenge, and satisfaction level of heat prevention measures by occupation and area

	Heat concern			Future heat stress challenge			Satisfaction of heat prevention measures		
	Yes	No	p-value	Yes	No	p-value	Yes	No	p-value
Occupation									
Hygienists	63	26	0.246	58	31	0.963	48	42	0.297
Non-Hygienists	57	34		59	32		41	49	
Area									
WA and Qld*	43	20	0.740	36	27	0.105	36	27	0.130
Other States	77	40		81	36		53	64	

*WA and Qld: Western Australia and Queensland

8.3.2 Preparedness and management

As shown in Table 8.4, 68.9% of participants indicated that there were hot weather plans or heat stress policies currently available in their workplaces or workplaces where they consult. When further asked which industrial sectors had hot weather plans or polices (data not shown), 62.1% mentioned the mining industry, followed by manufacturing (25.0%), electricity, gas and water (8.9%), construction (8.1%), and defence (3.2%). Ninety percent of participants responded that they had heard workers express concerns over heat during hot weather, of which 7.4% said it was "always", with the frequency for "often", "sometimes", and "seldom" being 36.8%, 44.2%, and 10.4%, respectively. About half (52.8%) of respondents reported that they have investigated heat-related illnesses or injuries in the past five years.

Roughly 61% of respondents agreed that there was a need to increase heat-related training in workplaces. Approximately one third of respondents held the opposite view, with 85.3% believing that "training is generally adequate" and 14.8% considered "it is not a serious problem" (data not shown). When asked which aspects of heat-related training should be strengthened, one respondent suggested:

"Hydration maintenance, self-pacing, heat acclimatization, and early symptoms of heat illness"

When asked if there is a need for more heat-related regulations, 51.7% answered "yes", 36.7% said "no", and 11.7% replied "not sure". Among those with negative responses, 65.1% thought "there are enough heat-related regulations already" and 11.1% considered "it is not a serious problem" (data not shown).

The results showed that most (81.7%) respondents did not know of organizations planning for the predicted increase of extremely hot weather. Furthermore, 73.3% of respondents did not know of companies that have made changes to reduce the impact of extremely hot weather. Only 26.1% of respondents intended to alter their heat-related prevention recommendations in a warming climate. By contrast, 52.8% of respondents did not intend to alter recommendations to management or companies.

Table 8.4 Number and percentage of extreme heat preparedness and management

Question	Number (%)		
	Yes	No	Not sure
1. Is there a hot weather plan or heat stress policy in your workplace or any workplaces that you consult in?	124 (68.9)	42 (23.3)	14 (7.8)
2. In your experience have workers ever expressed concern about heat in your workplace (or workplaces you consult in) during very hot weather?	162 (90.0)	18 (10.0)	-
3. In the last five years, have you had to investigate the circumstances around injuries or illnesses that could be attributed to extreme heat (air temp greater than 38°C)?	95 (52.8)	85 (47.2)	-
4. Do you think there is a need for more training about working in very hot weather in your workplace or workplaces that you consult in?	109 (60.6)	69 (38.3)	2 (1.1)
5. Do you think there should be more regulations for reducing the risk of heat-related illnesses and injuries in very hot weather applicable to your workplace or workplaces that you consult in?	93 (51.7)	66 (36.7)	21 (11.7)
6. Do you know of any organizations planning for increased frequency of extremely hot weather events?	33 (18.3)	147 (81.7)	-
7. Do you know of any companies that have recently made changes to maintain OH&S in work environments where extreme heat may become more common?	48 (26.7)	132 (73.3)	-
8. Do you intend to alter your recommendations to management or companies due to the likelihood of increased hot weather?	47 (26.1)	95 (52.8)	38 (21.1)

8.3.3 Preventive measures and adaptation barriers

As shown in Figure 8.2, "provision of cool drinking water" was the most commonly mentioned preventive measure currently adopted in the Australian workplaces for reducing the impact of heat exposure, followed by "heat stress related training" (76.1%), "central cooling system or air conditioning" (70.0%), "shady rest area" (68.9%), "rescheduling work time" (67.2%), and "electric fan" (52.2%). Furthermore, 41.7% of participants recommended "the cessation of work if the temperature is extreme". Other heat prevention measures suggested by the respondents through the "other" option mainly included:

"Standardized heat checklist", "personal heat stress monitoring", "heat vulnerability screening", and *"raising awareness through school education and mass media"*

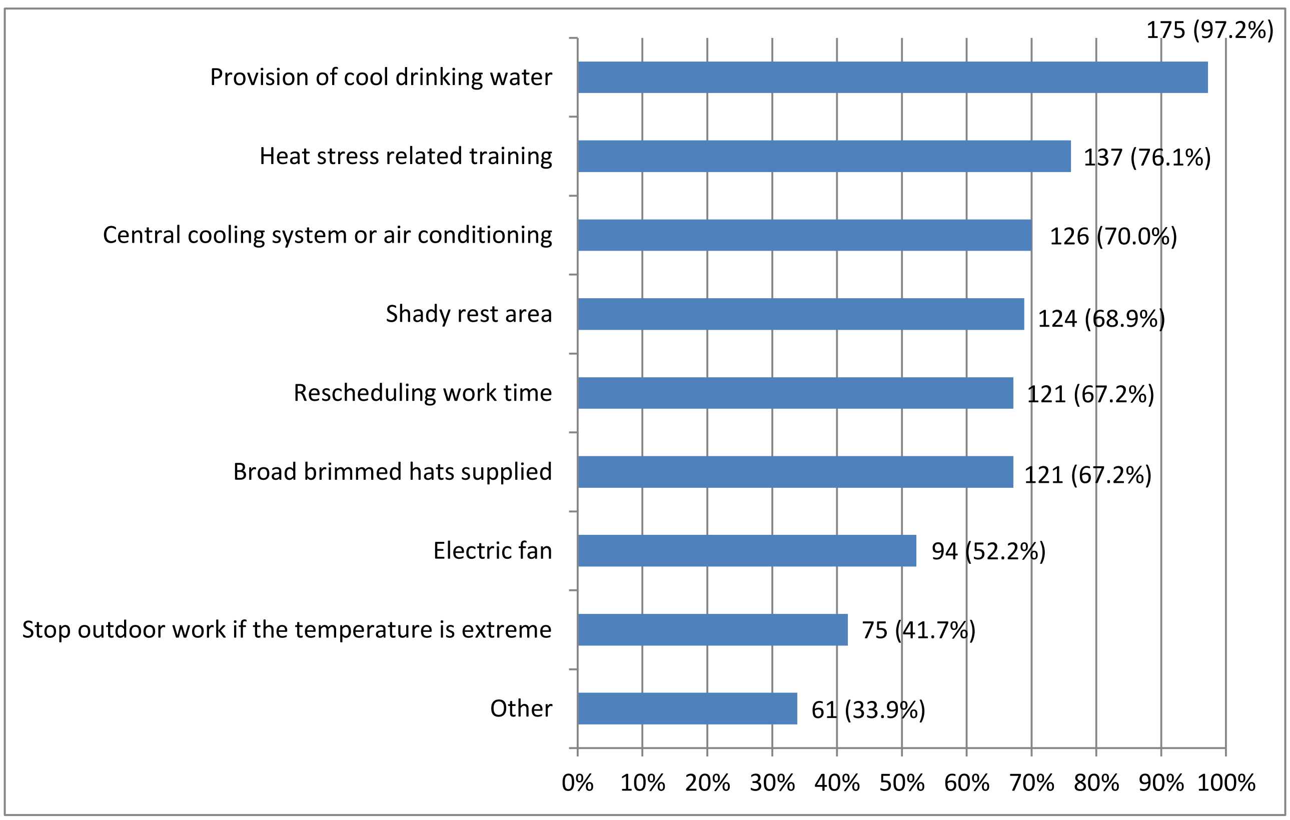

Figure 8.2 Heat-related preventive measures currently adopted in the workplace

As shown in Figure 8.3, the most frequently mentioned heat prevention barrier was "lack of awareness" (68.3%), followed by "lack of training" (56.1%), "lack of management commitment" (52.2%), "low compliance and implementation of heat stress prevention programs" (40.0%), "lack of financial resources to bring in engineering controls" (37.2%), and "lack of specific heat-related guidelines and regulations" (36.7%). Other potential barriers suggested by the respondents through the "other" option were:

"The conflict between increased personal protective equipment (PPE) requirements and heat dissipation", "work demands/priority", "peer pressure", "workers' poor self-management", "lack of engineering controls", "cultural and ethnic issues", and *"lack of heat acclimatization due to the fly-in/fly-out (FIFO) work regime"*

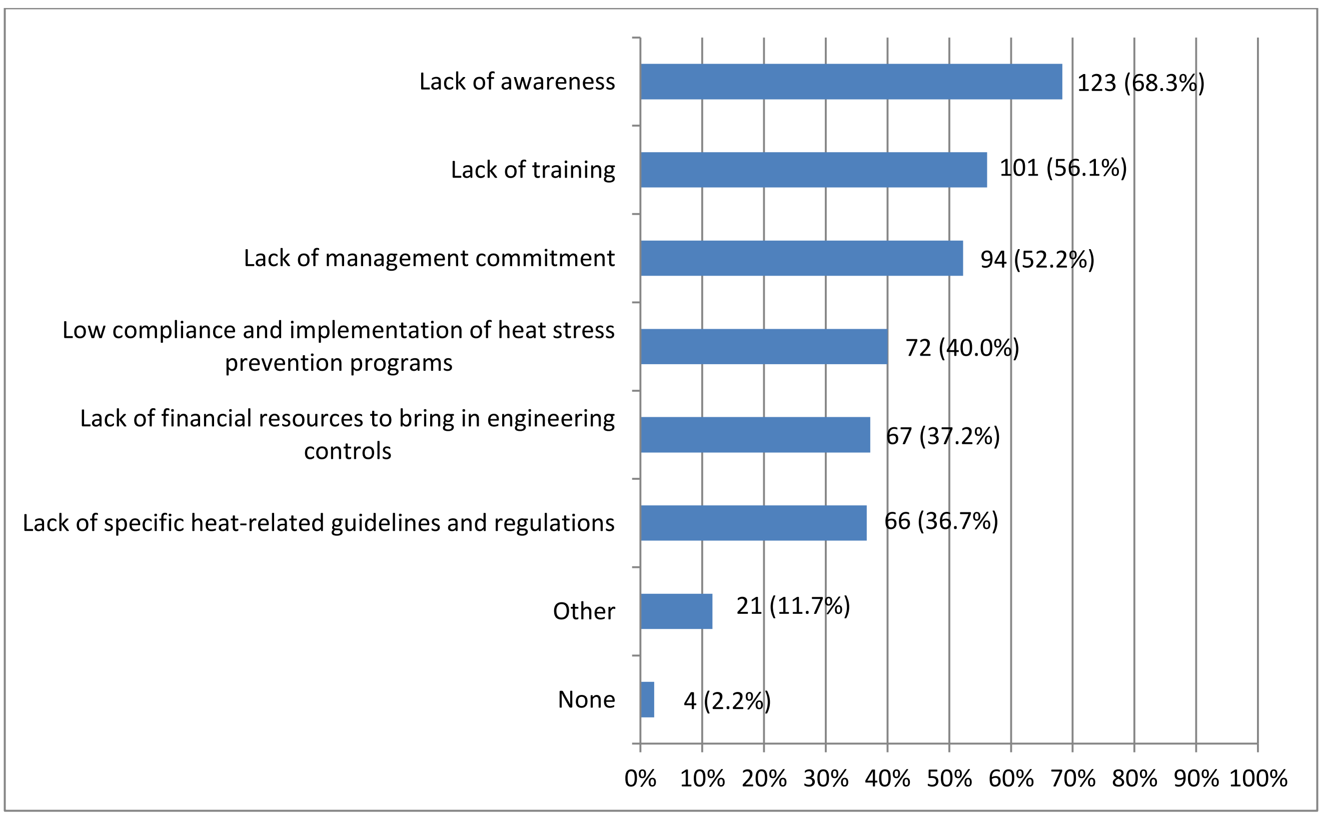

Figure 8.3 Heat prevention and adaptation barriers existing in the workplace

8.3.4 Relationship between heat concern, satisfaction and heat prevention efforts

As shown in Table 8.5, participants who have concern about heat exposure were more likely to support the strengthening of heat-related training and regulations, and also more likely to alter their recommendations to their management team or companies. Those not satisfied with current heat prevention measures showed stronger views on more heat-related training and regulations and the adjustment of heat prevention advice.

Table 8.5 Relationship of heat concern and satisfaction level on the attitudes towards more training and regulations, and the adjustment of heat prevention recommendations

Classification	More training required			More regulations required			Suggested amending recommendations		
	Yes	No	p-value	Yes	No	p-value	Yes	No	p-value
Concern about heat exposure									
Yes	82	38	0.003	75	45	0.000	40	80	0.002
No	27	33		18	42		7	53	
Satisfied with heat prevention									
Yes	45	45	0.004	40	52	0.025	21	69	0.396
No	64	26		53	35		26	64	

8.4 Discussion

Perceptions about weather-related heat stress and its potential impacts on OH&S have been investigated among South African outdoor labourers,[116] Indian manufacturing workers,[108] US migrant farmers,[169] and Australian outdoor physical workers (Chapter 7). However, to date there is no research investigating the perceptions and activities from the perspective of professionals such as occupational hygienists who work at the coalface in controlling environmental and occupational hazards. Therefore, this study, the first of its kind in Australia or elsewhere, provides valuable baseline information and expert opinion on heat-related OHS hazards.

8.4.1 Heat exposure concern

The results of this survey showed that a vast majority of occupational hygienists and specialists were concerned about workplace heat exposure. Almost all respondents often heard workers' concerns on heat exposure during hot weather, indicating that workers' thermal comfort has been compromised by heat exposure in the Australian workplaces. This is supported by previously published studies investigating workers' physiological responses to heat exposure.[46, 112, 320] A study conducted in Western Australian showed that nearly 70% of aboveground miners were poorly hydrated.[112] Heat strain has also been reported among South Australian shearers, carpenters, and railway track maintenance workers when temperatures exceeded 37°C.[46] Moreover, in the present study more than half of respondents had the experience of investigating injuries and accidents occurring during extremely hot weather, supporting the notion that the occurrence of serious heat-related illnesses, injuries and even deaths in Australian workplaces is not uncommon.[70, 306-308] This suggests that heat stress prevention methods currently adopted in Australian workplaces may not sufficiently and effectively protect vulnerable workers from heat-related illnesses and injuries. Relevant actions should be taken on the aspects of administrative controls, educational training, personal behaviours adjustment, and the development of heat prevention policies.

With projections of warmer temperatures, heat exposure may present a growing challenge on workers' health and safety.[19, 20, 35] The results in this study showed that a majority of occupational hygienists and specialists agreed with this view. However, only 26% of participants intended to amend their heat-related prevention recommendations to companies. The awareness-practice gaps may be explained by the fact that some participants believed that climate change related heat impacts on OH&S are not a current threat. Using a respondent's words from an open-ended question, it is "*not confirmed science*".

The major reasons accounting for some hygienists' lack of concern over heat exposure were they felt there were adequate measures already being implemented and scepticism about the realistic impact of climate change on workers' health and safety. Relevant training, workshops, or forums in the future may improve occupational hygienists' awareness of the impact of climate change on workers' health and safety.

8.4.2 Heat exposure preparedness

From the surveyed delegates' point of view in this survey, Australian workplaces are not well-prepared for the likelihood of a warmer climate, as most of these skilled OH&S professionals did not know of any companies that have taken actions to reduce the impact of heat stress. Although most workplaces reportedly had hot weather plans, significant increase of injury claims for vulnerable sub-groups were still observed during heatwaves in Adelaide according to the findings in Chapter 6.

When asked which industries had a hot weather plan, the respondents mentioned mining, manufacturing, 'electricity, gas and water', construction, and defence. However, agricultural sectors and seasonal workers were not mentioned, probably because hygienists are not usually employed in this sector and therefore could not draw from their experience in that industry. Evidence has also shown that farmworkers and forestry workers are at high risk of heat illnesses and injuries,[92-94, 97, 101, 139] especially for seasonal and migrant workers.[125, 321, 322] Australia has a large group of seasonal and migrant farmworkers due to farm labour shortages, relatively high hourly wages, and the provision of working holiday visa (sub-class 416 and 417).[160] Some undocumented (illegal) workforce participants e.g. unauthorized residents, overseas students working in excess of permitted hours, and travellers working without authorisation, may also meet Australian seasonal labour market needs in the harvest season of some labour-intensive crops such as fruits and vegetables.[160] Agricultural workers, especially migrant and seasonal farm labourers, are one of the most underserved and understudied occupational populations.[321] Therefore, more heat prevention programmes should be directed to this heat vulnerable group.

8.4.3 Current heat prevention measures

The results showed that about half of respondents were not satisfied with current heat prevention measures, reflecting the necessity to upgrade current policies and strategies. Australia has mandatory heat regulations in place to protect workers from extreme heat; however at present there are many ambiguities which may hinder the implementation and effectiveness. According to the survey results, provision of cool drinking water was the most common heat prevention measures, which is also required by the national Model Code of Practice (managing the work environment and facilities);[313] however, this is not available in all Australian workplaces. A similar problem exists in other countries as well, especially in some low-middle income countries. According to a study in Costa Rica, sugarcane workers had to supply their own drinking water and wrapped water jugs in wet clothes to keep water from over-heating in the direct sunlight, as sometimes there was no shady rest area nearby.[97]

Some non-governmental institutions (e.g. the Australian Institute of Occupational Hygienists Inc. (AIOH)[53] or trade unions (e.g. the Construction, Forestry, Mining and Energy Union

(CFMEU)[181]) have made specific heat stress management guidelines. Nevertheless, the unenforceable and non-mandatory nature of the guidelines may raise the problem of low compliance. As some respondents reported:

"Guidelines and procedures are available but not used efficiently and consistently" and *"A lot of people do not take it seriously, guidelines such as ACGIH WBGT should be taken up into regulations"*.

According to the Construction, Forestry, Mining and Energy Union (CFMEU), "if temperature is over 37°C all work ceases unless working in air conditioned area".[181] However, in this study only 40% of respondents selected "stop outdoor work" as a preventive measure when the temperature was extremely hot. Some workers such as emergency (e.g. fire-fighting) and utility maintenance staff are inevitably exposed to extreme heat due to the nature of tasks. In this case, the incorporation of technology advances into engineering controls may be a solution. For example, more breathable personal protective equipment could be developed or the wearing of cooling vests considered.

8.4.4 Heat prevention barriers

In this study, a majority of Australian respondents thought that lack of awareness was the major barrier for heat stress prevention, which is supported by a study conducted in the USA.[169] In 2011, the US OSHA launched a nationwide campaign to raise heat risk awareness in the workplace.[171] Heat prevention barriers may also include lack of training and management commitment, low compliance and implementation of heat prevention policies, and lack of financial resources, which have been identified by previous heat studies in the USA.[173, 314] In addition, the increase of the fly-in/fly-out (FIFO) work regime may prove a challenge for heat acclimatisation. Currently, approximately 49% of Western Australia's mining sites are operating on a FIFO basis.[48] If workers are flown in from a cool area to an extremely hot area, they may be not acclimatized to heat and would be more susceptible to heat-related injuries.

8.4.5 Limitations

The limitations to this study include that a purposive convenience sampling method was employed. Due to the relatively small sample size, caution should be exercised regarding the generalization of the results. Nevertheless, a large proportion (estimated to be about 50%) of senior occupational hygienists in Australia participated in the survey. Further research is needed to explore why a considerable proportion of occupational hygienists and associated professionals were not satisfied with current heat prevention measures, and how employers and policy-makers perceive the risk of workplace heat exposure. Despite the limitations, this survey may add to current knowledge and provide valuable expert opinion in terms of the development of heat prevention strategies.

8.5 Conclusion

Australian occupational hygienists and specialists showed concerns over heat stress, but did not show strong willingness to amend heat prevention recommendations to management or companies. The Australian workplaces may not be well-prepared for the likelihood of increasing incidence of heat stress due to climate change. The major heat prevention barriers recognized by the participants were lack of awareness, lack of training, lack of management commitment, and low compliance of heat prevention policies. The high proportion of participants not satisfied with current heat prevention measures indicates there is a need to further develop current heat management strategies in the Australian workplaces.

SECTION IV

DISCUSSION AND CONCLUSION

Chapter 9

Discussions and conclusions

9.1 Introduction

This thesis mainly explored two issues on occupational heat exposure: (1) the effects of hot weather on workers' health and safety at the population level; and (2) the risk perceptions of workplace heat exposure and preparedness for a likelihood of increasing hot weather in South Australia. Time-series regression analyses were used to investigate the association between daily high temperatures and workers' injury claims (Chapter 5). Beyond the daily temperature-injury claims relationship, additional effects of several consecutive days' high temperatures on workers' health and safety were also examined (Chapter 6). Two separate questionnaire surveys (Chapter 7 and 8) were conducted to investigate workers and occupational hygienists' heat risk perceptions. This Chapter outlines the key findings of the thesis, addresses strengths and limitations of the study as well as the significance of the study. Implications and recommendations are discussed. Several options for further research on occupational heat exposure are suggested.

9.2 Key findings of this thesis

A synthesis of the key findings of previous chapters is summarized as below:

9.2.1 Analyses of workers' compensation claim data

Characteristics of overall workers' compensation claims during the study period

- There were 318 932 notified workers' compensation claims during the 9-financial year period of 2001-2010 in South Australia, with an overall claim rate of 4.7 per 100 employees. The majority (76.7%) of claims occurred in the Adelaide metropolitan area.
- Workers' compensation claim rates demonstrated a downward trend over the study period, indicating the necessity to adjust the effect of long-term trends when conducting time-series analysis.
- Relatively less claims occurred in December and January compared with other months. This may be due to public holidays and that people are more likely to take annual leave during the summer months. It suggests a need to exclude public holidays from time-series analysis.

Characteristics of occupational heat illnesses

- There were 306 injury claims identified due to heat exposure during the period of 2001-2010 in South Australia, with an incidence rate of 4.5 per 100,000 employees, representing 0.1% of all injury claims during the study period. The majority (69.0%) of heat illness claims occurred in the Adelaide metropolitan area. Approximately 81% of heat illness claims were made by males. The average age of heat illness claimants was 39.4 years old and the median age was 39 years.
- The majority of heat illness claims occurred in the warm season (October to March for South Australia), and the hottest part of the day between 10am and 6pm.
- Relatively higher heat illness incidence rates were observed in 'mining' and 'electricity, gas and water' industries, and those employed as labourers and tradespersons in South Australia during the study period.

- There was no significant increase in daily occupational heat illness claims in Adelaide with the increase of T_{max} below a threshold of 35.5℃. However, when T_{max} was above 35.5℃, 1 ℃ increase of T_{max} was associated with 12.7% increase of occupational heat illness claims.
- The results of case-crossover analysis suggest that during heatwave periods the risk of heat illness was about 4-7 times higher than that of non-heatwave periods.

The association between high temperature and work-related injuries in Adelaide

- A reversed U-shaped exposure response relationship between daily maximum temperature (T_{max}) and overall daily injury claims were observed. The overall risk of work-related injuries was positively associated with T_{max} below 37.7 ℃. However, daily injury claims dropped noticeably when the weather was extremely hot.
- For overall outdoor industries, a 0.5% increase of injury claims was associated with per degree increase of T_{max} below 37.8℃, however, daily claims decreased by 3.4% when T_{max} exceeded 37.8℃. By contrast, no significant association between claims and temperature was detected in overall indoor industries.
- Significant temperature-injury claims relationships were also found in the following sub-groups with increasing T_{max} below certain threshold temperatures ranging from 31.8℃ to 38.9℃: young workers aged ≤24 years; those working in the industries such as ‘agriculture, forestry and fishing’, ‘construction’, and ‘electricity, gas and water’; or employed as labourers, production and transport workers, and tradespersons in small and medium sized businesses.
- When the temperature was extremely hot (e.g. over 38℃), almost all industries decreased in injury claims. The only exception is ‘electricity, gas and water’ industry. Daily injury claims increased by 2.9% with per degree increase of T_{max} above 37.2℃.

- No delayed effects of hot weather (T_{max} above thresholds) on injury claims were found for all industries and outdoor industries, indicating the impact of temperature on workers' health was acute.

The impact of heatwaves on workers' health and safety

- During heatwaves, there were no significant changes in the number of injury claims among male workers. By contrast, female workers had a significant decrease of 6.5% 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 injury claims during heatwave periods compared with control periods.
- 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 found to be significantly associated with extreme heat, together with injuries resulting from moving objects, chemical exposures, and environmental factors.
- Using two heatwave definitions, similar results were observed in overall claims and the effects stratified by gender, age, outdoor industry, and occupation. The differences in effect estimates were found in indoor industries such as 'public, administration and defence' and 'wholesale and retail trade'. The results of injury mechanism specific analysis between the two definitions were basically consistent, except 'hitting objects with a part of the body' which only increased significantly for the stricter BOM heatwave definition.

9.2.2 Workers' perceptions on workplace heat exposure

- Overall, workers in South Australia were moderately concerned about heat exposure. Young workers were less concerned than older workers. Workers undertaking very physically demanding work, wearing PPE, or having heat illness/injury experience were more concerned about heat exposure.
- Less than half of the respondents in South Australia indicated that they have received heat-related training and more than half indicated that there was a need for more training to help reduce the risk of heat stress. More supportive attitudes towards heat-related training were reported in workers those 25-54 years who had experienced a heat illness/injury. Heat-related training (49.7%) was the most common way for workers to obtain information about heat prevention.
- Roughly 63.8% of participants agreed that there should be more heat-related regulations and guidelines for working during very hot weather whereas the remainder thought "there are enough regulations" or considered workplace heat exposure to not be a serious problem.
- More than two-thirds of participants were willing to adjust their current work habits in the heat, and having a previous heat illness experience was an influencing factor.
- More than half of the participants were satisfied with current heat prevention measures. The provision of cool drinking water was the most common prevention measure, followed by wearing broad brimmed hats, rescheduling work time, having central cooling and air conditioning, the use of electric fans, and having a shady rest area. Only 19.6% answered "stopping work" as a prevention measure when the temperature was extremely hot (e.g. >40℃).

- Up to 70% of respondents expressed that they worked at their own pace during very hot weather.

9.2.3 Occupational hygienists' perceptions on heat exposure

- Australian occupational hygienists and specialists showed great concerns over heat stress, but they did not show strong willingness to amend heat prevention recommendations to management or companies.
- From occupational hygienists' point of view, Australian workplaces may not be well-prepared for the likelihood of increasing heat stress due to climate change.
- The major heat prevention barriers recognized by occupational hygienists were lack of awareness among workers, lack of training, lack of management commitment, and low compliance of heat prevention policies.
- The high proportion (50%) of participants not satisfied with current heat prevention measures indicates there is a need to further develop current heat management strategies in Australian workplaces.

9.3 Significance of this Thesis

Heat exposure is an important but overlooked occupational hazard, which is not only a matter of occupational health and safety but also productivity and economic loss. It may affect all levels of our society – socially (due to health impacts and their broader implications) and economically (due to loss of productivity in industry and health sector costs), and deserves special consideration. Many epidemiological studies have confirmed that extremely hot weather may result in excess morbidity and mortality in the general population. However, research on the impact of hot weather on occupational health and safety has received little attention.

This study is significant firstly because it fills knowledge gaps in the field of occupational heat exposure on the following two aspects: (1) Findings of workers' compensation claim data analyses (Section II) provide valid and reliable epidemiological evidence for confirming the effects of high temperatures on workers' health and safety at the population level. The estimation of the quantitative heat-injury claims relationship and the characteristics of occupational heat illnesses enable a better understanding of the extent to which workers are affected by high temperatures. This information may be meaningful for decision makers to develop strategies against the possible OH&S-related impacts of climate change. (2) The two questionnaire surveys are the first of their kind in Australia to investigate heat exposure perceptions from the perspective of workers and occupational health experts, the results will provide baseline information for the development of heat health promotion methods in the workplace.

In addition to filling knowledge gaps, this study is also significant from the perspective of heat prevention practice. The identification of heat vulnerable sub-groups and work-related illnesses/injuries associated with heat exposure is useful when formulating targeted heat prevention measures and optimizing the allocation of heat prevention resources. The investigation of perceptions of heat exposure among workers and occupational hygienists provides firsthand information from the workplace regarding current heat prevention and adaptation problems, and preparedness for the likelihood of warmer weather. Therefore, findings of this study provide valuable implications for the development of heat policies to reduce the impact of hot weather on workers' health and safety. A potential reduction of heat-related injuries may contribute to the fulfilment of the Australian Work Health & Safety Strategy 2012-2022 national targets.[38]

From a wider perspective, effective control of workplace heat exposure may not only benefit workers but also employers, in terms of reducing heat-related claims costs due to productivity loss and the improvement of workers retention rates.

9.4 Strengths and limitations

There are several strengths of this study. First, the study is unique in that no previous study has investigated in detail the effects of extreme heat on workers' health and safety at the population level using compensation claims data. Standard time-series analysis with GEE models and linear-spline functions has been used to quantify the heat-injury claims relationships after the adjustment of confounding factors. Case-crossover design was used to estimate the risk of heat illness during heatwaves.

Until now, there has been a knowledge deficit regarding the risk perceptions of workplace heat exposure in Australia, despite several studies undertaken in other countries such as the USA,[169, 173, 174] India,[108] and South Africa.[116] Therefore, the investigation of workers and occupational hygienists' perceptions of heat exposure may be of great interest to employers, policy-makers, occupational hygienists and relevant stakeholders involved with OH&S.

Findings of this study may make a valuable contribution to the knowledge of the impact of heat exposure on workers' health and safety. It may also provide implications for heat-related policy development and practical interventions locally and internationally.

The main limitations of this study have generally been addressed in each chapter. In summary, for the analyses of workers' compensation claims (Section II), work/heat-related injuries may be underestimated due to the underreporting of compensation claims. Second, daily maximum dry air temperature for Adelaide was selected as the heat exposure index when analysing the heat-injury claim relationships. Indeed, some composite heat indices such as AT (apparent temperature) which have been applied in some heat-related morbidity and mortality studies in Europe[244, 245, 247, 323] and the USA[324] might better represent the approximate thermal comfort status in the workplace. However, an Australian study has shown that different heat indices have similar predictive abilities when analysing the temperature-health outcomes association.[275] Moreover, Adelaide is known as the driest capital city in Australia, and humidity keeps consistent and is not considered to be a major concern during the warm season because of its climatic characteristics. Third, only one weather station (Kent Town, Adelaide) was selected for representing the heat exposure status of all workplace in the Adelaide metropolitan area. Nevertheless, the temperature of each individual's workplace may vary considerably. Fourth, the temperature/heatwave-injury claims association for mining industry was not examined in this study, as the analyses were restricted to the Adelaide metropolitan area; however, almost all mine sites were located in rural areas of the state. Fifth, due to the unavailability of some surveillance variables and the inherent nature of ecological study, the effects of some personal risk factors such as the use of certain medication, chronic disease history, and levels of fitness and acclimatization have not investigated. Sixth, the relatively small number of some category-specific analyses dictates cautious interpretation of results. Seventh, in recent years distributed lag non-linear models have been increasingly used in time-series analysis to quantify the non-linear exposure-response relationships.[354, 355] This methodology is recommended in the future studies, as it can flexibly and accurately model the exposure-lag-response association. Finally, specific characteristics of heatwaves such as duration, intensity, timing, and possible lag effects were not taken into account when analysing the heatwave effects.

For the survey of workers' perceptions of workplace heat exposure (Chapter 7), limitations may include the relatively low response rate (50.9%), the over-representation of male workers, and possible recall bias as the survey was partly conducted during the cold season. Additionally, workers' knowledge of heat was not investigated in this study. For the survey of occupational hygienists' views of heat exposure (Chapter 8), limitations are mainly in relation to the convenience sampling method and the generalization of the results due to the small sample size.

9.5 Implications and recommendations for workplace heat prevention

Many cross-sectional studies have found that outdoor workers are affected by extremely hot weather[58, 71, 86, 98, 112, 115, 117, 122], as summarized in Chapter one. With the predicted increase in the frequency and intensity of extremely hot weather,[31, 32, 276] occupational heat exposure may present a growing realistic threat to workers' health and safety in the future.[19, 20, 35] By estimating the effects of heat exposure on work-related injuries at the population level and investigating the heat risk perceptions among workers and occupational hygienists, findings of the present study provide useful implications for the possible development of heat stress management and prevention as follows.

9.5.1 Heat policy implications

As mentioned previously, many heat studies focusing on the general population have found a U, V, or J-shaped relationship between high temperature and health outcomes.[11, 13, 15, 16, 18, 222] Morbidity and mortality risks start to slowly increase when ambient temperatures extend beyond a certain thermal comfort range and when they become extremely hot, poor health outcome risks increase sharply. In this study, a reversed U-shaped relationship between daily high temperatures and occupational injury claims was observed in almost all industries. This apparently contradictory finding can be probably explained by the fact that some effective heat prevention measures may be taken when temperatures become extreme. However, workers in some industries where production cannot be stopped (e.g. electricity, gas and water) or undertaking tasks with emergency nature are still at high risk of heat-related injuries and accidents.

Appropriate heat management programs and policies can reduce the risk of occupational heat exposure. Heat prevention strategies for those who are expected to or have to work in extremely hot environments may first include pre-placement health assessment screening. Screening for heat stress vulnerable individuals for some occupations (e.g. miners, firefighters, and foundry workers) and jobs susceptible to extreme heat should consider the following factors: physically demanding level of the work; and for the worker, consideration of any prior cardiovascular or pulmonary conditions; previous history of heat stress, and use of certain medications. In the increasingly warmer global climates, job specific heat vulnerability screening is of importance.[325] Other measures may include heat acclimatisation, wearing lighter and more breathable clothing (or smart clothing) that can change thermal properties dynamically,[168] and intensified training to increase workers' heat prevention knowledge and risk perceptions.

In this study, significant temperature-injury relationships were also observed in some sub-groups. The human body heat balance can be affected by environmental and non-environmental factors. The latter includes work demand, clothing, and the proximity to heat sources. Thus, exertional heat-related illnesses and injuries can still occur when the weather is not unduly hot. However, current heat prevention regulations and guidelines mainly focus on outdoor workers in extremely hot weather. Indeed, mild days occur more often than extremely hot days, and may importantly contribute to the burden of work-related injuries. Therefore, this needs to be taken into account when developing new heat prevention policies and education plans to reduce the adverse effects of environmental and process-generated heat in the workplace.[226] Additionally, heat vulnerable sub-groups can differ in different settings. For instance, in this study young workers have been shown to be at higher risk of work-related injury among all age groups when the temperature is below 38℃, while older workers are more vulnerable to heat during heatwaves, perhaps due to the extended duration of high temperature days.

9.5.2 Establishment of workplace heat alert system

After 2003 European heatwaves, the introduction of heat warning systems and some specific public health interventions have successfully contributed to the decline of heat-related mortality.[302, 326] However, it is not known if temperature-based thresholds[18, 225, 305] for the general population can be directly applied to the workplaces. Therefore, the development of locally suitable early heat warning system is needed to alert workers and relevant stakeholders in advance and then to implement effective measures to reduce the risk of harmful effects of extreme heat on workers' health and safety. The principal components of a workplace early warning system 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.[326] The system should be developed in collaboration with all relevant stakeholders to ensure that the issues of greatest concern are identified and addressed, thus increasing the likelihood of success. Relevant stakeholders may include local meteorological services, safe work departments, government health departments, and emergency response departments.

The selection of trigger temperatures for workplace heat alert levels is very important for the activation of action responses, which needs to take into account the sensitivity, reliability, and validity issues. In the present study, the threshold estimates stratified by industry ranged from

36.7℃ to 38.3℃ for Adelaide. As illustrated in Figure 9.1, the hot weather action guidelines suggested by the Construction, Forestry, Mining and Energy Union (CFMEU) South Australia Branch has three heat alert levels: <35℃, 35-37℃, and >37℃.[181] However, one threshold temperature (two-piece linear spline function with one knot) was estimated for industry-specific analysis in this study, which can only provide two heat alert levels. Nevertheless, threshold estimates in this study still provides supportive evidence for the CFMEU hot weather plan. It should be noted that different regions may need different threshold temperatures due to the differences in climatic characteristics, work environments, and public health infrastructure.[18, 327]

According to the CFMEU working procedure under hot weather conditions (Figure 9.1),[181] outdoor work continues normally but some measures should be taken to minimize heat discomfort and stress with the increase of air temperature below 35℃. This is supported by the findings in Chapter 5 as the risk of work-related injury increases among some vulnerable sub-groups even when the temperature is not extremely hot. If the temperature is between 35-37℃, the CFMEU SA Branch suggests that outdoor work ceases and indoor work continues normally but relevant actions should be taken to avoid heat strains. If the temperature is over 37°C all work ceases unless working in air conditioned area. This may explain the observed decline in injury claims reported from the construction industry when the temperature reaches the threshold. However, a low proportion (19.6%) of surveyed outdoor workers in this study answered "stopping working if the temperature exceeds 40°C", indicating there is a need to make the unenforceable CFMEU heat alert guideline mandatory to ensure its implementation in some specific heat risk industries instead of just depending on employers' self-discipline. For industries with a high proportion of casual and self-employed workers such as agriculture, enforceable implementation of the heat alert procedures may be impractical or ineffective. In this case, heat-related training and education programs should be strengthened before summer to improve workers' heat knowledge and self-protection/adaptation awareness and capacity.

Usually, daily maximum air temperature is used as the indicator of heat alert systems. However it does not take into account other heat balance affecting factors such as humidity, radiation, wind speed, work demands, clothing, heat tolerance and acclimatization. Currently, the Wet Bulb Globe Temperature (WBGT) is the most widely used heat index providing a simple method for heat stress assessment in the workplace.[54, 177] In addition, real time monitoring of occupational health data (e.g. workers' compensation claims) and weather data may be used to forecast the risk of heat-related illnesses and injuries.[327]

In addition to the temperature-based heat alert systems, the development of a locally suitable heatwave definition is needed to activate heat alerts.[223] A heatwave is generally defined using daily maximum temperature plus other meteorological factors with a specified duration ranging from one to several days. Currently, there is arguably no standard heatwave definition. The impacts of different heatwave definitions on heat outcome estimates have been investigated in the general population.[281, 328] The results of this study suggest that different heatwave definitions produced similar but slightly different outcomes (Chapter 6).[329] Currently, there is no a standardized procedure regarding how to define a standard heatwave which may vary regionally in terms of thresholds and metric but can represent the onset of physiological stress.[330, 331]

One major shortcoming for threshold-based workplace heat alert systems is that they do not consider the unique characteristics of each individual during its prediction. Even for the same individual heat vulnerability may vary in different days due to the change of work demands, acclimatization status, and clothing. The establishment of early heat alert and warning systems can be regarded as a rough defence line to protect the majority of at risk workers from heat-related illnesses and injuries.

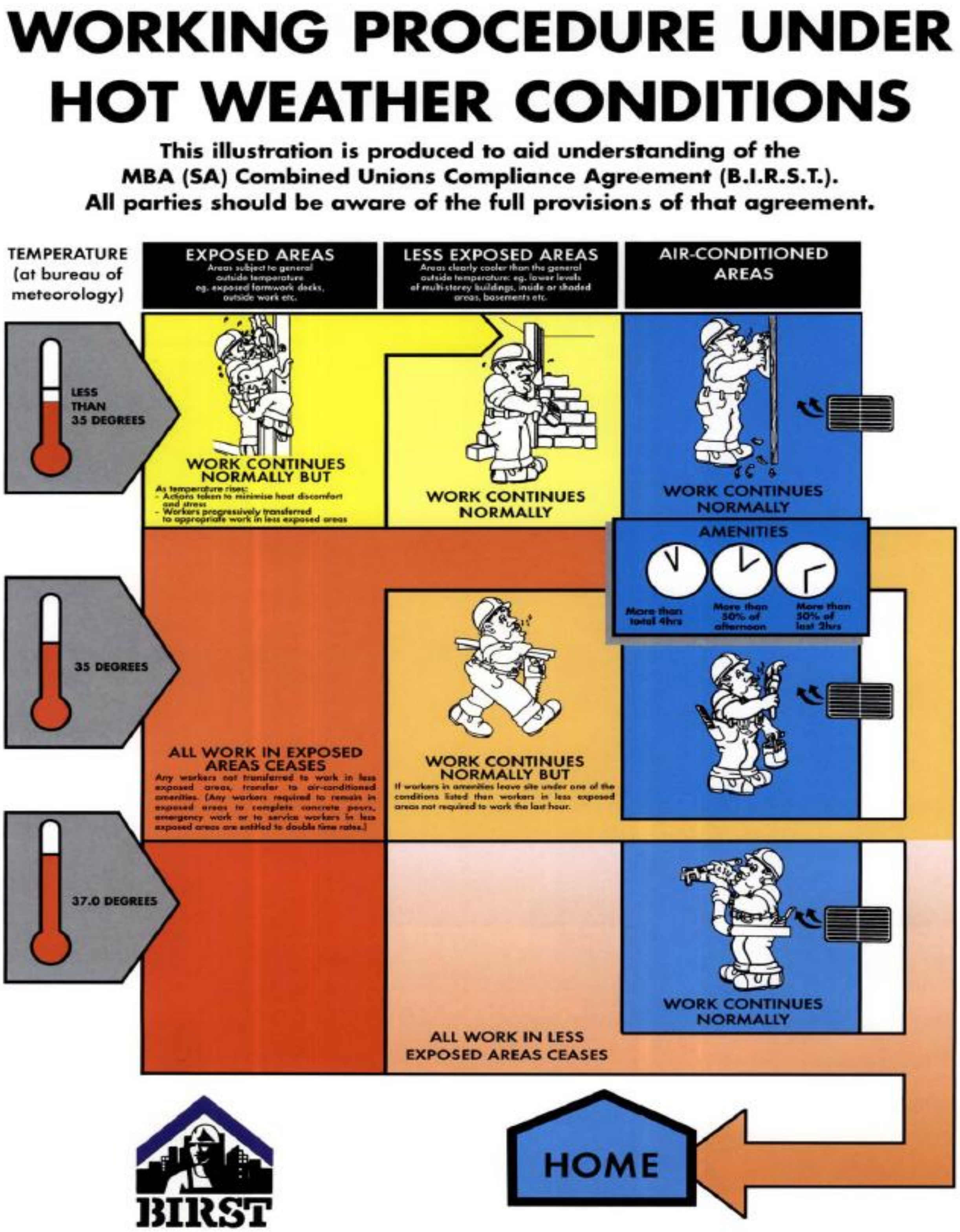

Figure 9.1 The Construction, Forestry, Mining and Energy Union (CFMEU) hot weather guideline[181]

9.5.3 Real time health surveillance

Regarding heat stress management for certain occupations or work circumstances where high heat exposure cannot be avoided, real-time physiological monitoring is a good option,[168] as it can detect early health impacts of hot weather and take timely actions to limit individual heat exposure to safe levels. In general, physiological monitoring on heat strains relies on the measure of heat rate and a surrogate of human body's internal core temperature (e.g. skin, ear, oral, and rectal temperature).[54] Validation of these monitoring systems based on heart rate and some surrogate temperatures is urgently needed.[168]

Currently, there are commercial devices to measure core temperature directly. They can report the individuals' dynamitic surveillance core temperatures to a remote central station in real time and inform decision making. Meanwhile, it enables individuals to know their heat stress status in real time and take adaptation measures (e.g. self-pacing) timely once the core temperature exceeds the exposure limits (e.g. 38°C[54]). This approach is feasible for heat stress management among those at high risk of heat exposure, whereas the costs remain high for direct core temperature measurement particularly for small or self-employed businesses.

A practical obstacle limiting the popularization of direct core temperature measurement in real time is the use of an invasive sensor which is generally undesirable.[54, 168] Some attempts have been made to predict the onset of core temperature rise and generate alerts in real time,[332-334] obviating the need for ingestion of a temperature pill. Further efforts are needed to develop easy-to-use, affordable, and economical real time core temperature surveillance systems. It will have a great application prospect among industries and occupations susceptible to extreme heat,[168] especially in a warming climate.[30, 32]

9.5.4 The combination of self-regulated and mandatory heat management

The Australian Institute of Occupational Hygienists (AIOH) has adapted the ACGIH and NIOSH heat stress management programs for use in the Australian environments.[53, 54] It provides a useful guide in a staged manner for occupational health and safety professionals to design an appropriate heat prevention program taking into account their workplace context. Heat control methods can be divided into two broad categories: general and specific.[54] General controls should be implemented anytime there is a reasonable potential for heat stress on the job and applicable across all heat stress jobs. By contrast, specific controls are directed to individual jobs. A heat stress assessment follows the traditional hierarchy of hazards controls, including elimination or substitution of the hazard, engineering control (e.g. equipment for air movement, mechanical aids to reduce manual handling requirements, and a provision of cooling facilities), administrative controls (e.g. job rotation, work/rest regimes, and documented procedures for inspection), and personal protective equipment.[54] These standard traditional heat stress control protocols can be well implemented in some large businesses with institutionalized work environments, as heat regulations and guidelines can be enforced and easily regulated not only by the organizations themselves but also by the local regulators.[167] This may in part explain the findings of Chapter 5 - i.e. that a significant temperature-injury claims relationships was not found in the large businesses but in the medium-small businesses in Adelaide.[139]

Out of necessity, heat-related standards and regulations are generally conservative and are stricter than they need to be for protecting the majority of workers. This may unnecessarily constrain some individuals with high heat tolerance and reduce their work rate.[167] Subjective feelings of thermal comfort can indicate workers' heat stress level. Self-pacing is the human body's autonomous safeguards intuitively activated to manage thermally stressful conditions and reduce heat strain, which can attenuate fatigue, maximize long-term endurance and enable sustained activity over the workday.[82, 114] In this study, about 70% of participants answered that they worked at their own pace during extremely hot weather (Chapter 7). Workers' self-pacing phenomena have also been found in another two Australian studies conducted in Western Australia.[114, 115] Currently, whilst the real time core temperature surveillance method is not popularized, self-regulated management (perceptual heat awareness in conjunction with autonomous control over work conditions, work rates and work limits) may be the most valid and cheapest means of determining heat exposure limits at an individual level.[167] It is worth noting that self-regulated protection is subject to the conditions that the task has no urgent character and does not involve work rate based payment incentives.[40] Therefore, the flexible combination of mandatory regulations and self-regulated protection is a very good heat stress management pattern, especially suitable for large businesses such as the 'electricity, gas and water' and 'construction' industries.

Self-regulated heat prevention has some requirements in workers' heat risk awareness and knowledge. For large businesses, there are normally formal opportunities for educating individuals. For medium-small size businesses with a high proportion of casual and self-employed workers such as 'agriculture, forestry and fishing', specific heat campaigns before summer can be used to improve workers' heat risk awareness and knowledge.[171]

9.5.5 Heat education, training, and individual capacity building

Education and training have been proved to be a successful strategy for increasing workers' occupational hazards knowledge, building their heat prevention skills and confidence, and supporting the effective implementation of workplace health and safety requirements.[335] In this study, training is the most common way for workers to obtain heat prevention information, however less than half of the respondents have received heat-related training. Occupational hygienists surveyed in this study suggested that lack of awareness and training is the major heat prevention barriers existing in the workplace. Therefore, there is a need to launch timely heat campaigns before summer to raise heat awareness, teach workers and employers about the dangers of working in hot weather, and provide valuable resources to address these concerns. As part of heat campaigns, a 24-hour hotline or email sponsored by an alliance of government agencies and non-profit organizations could be set up during the warm season for workers to access heat-related counselling services. Meanwhile this would provide workers with a channel to report violations of local heat regulations to protect their rights and ensure the implementation of heat regulations.

Heat-related training can be mandatorily incorporated into workplace health and safety induction programs and emergency response plans. Heat-related training should be strengthened before each summer, especially among the heat vulnerable sub-groups identified such as young and older workers undertaking outdoor physically demanding work in ‘agriculture, forestry and fishing’, ‘construction’, and ‘electricity, gas and water’ industries in this study. Annual training for all employees may cover the following contents: the hazards of heat stress, recognition of predisposing heat risk factors, early signs and symptoms of heat illnesses, first aid procedures of heat stroke, increased injury risk when working in hot environments, and current heat prevention regulations and policies in place.

Specific training workshops and seminars can be extended to occupational health physicians, nurses and hygienists, as well as managers, to improve their knowledge and skills in relation to heat prevention and treatment and recent research results and recommendations. In addition, some efforts should be made to help employers realize the benefits of effective heat stress management (e.g. the reduction of productivity loss due to heat and the decreased occupational diseases burden), because employers' support is very important for the implementation of heat regulations and policies. Heat education and training can be served as software to improve workplace heat adaptive capacity.

In addition to formal heat training and education, some mass media such as newspapers, magazines, radio, TV, internet, leaflets and posters can also be used to provide heat promotion information. However, it should be noted that passive dissemination of workplace heat prevention advice may not be sufficient to reach those workers most at risk.[336] The appropriate channels of heat information promotion need to be selected according to the characteristics of the targeted vulnerable sub-groups.[337]

9.5.6 Establishment of collaborative mechanisms

The implementation and development of heat regulations and policies, the establishment of early heat alert and warning systems, the launch of heat prevention campaigns, and heat education and training need the cooperation between institutions from various sectors and administrative levels. 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 important to decide who are the overall responsible lead bodies coordinating cooperation, interventions, joint activities, and resource allocation. During extremely hot weather, the lead organization is required to trigger specific activities and interventions on the basis of the heat warning issued by the weather service.[326]

9.6 Further research directions

This study has answered defined questions related to the impact of heat exposure on workers' health and safety at the population level and the heat risk perceptions among workers and occupational hygienists. However, there is still a need for further research to be conducted in the field of occupational heat exposure in a warming climate. The following areas should be explored in the future:

9.6.1 Heat exposure and occupational disease/injury burden

As the direct health outcomes of excess heat exposure, the number of occupational heat illnesses is relatively small when compared with other occupational diseases/injuries, according to the results of this study in Chapter 4 and previous statistics from Washington DC.[72] Moreover, the average time lost and medical expenditure due to heat illnesses were relatively less than the average levels of overall occupational diseases and injuries in the present study (Chapter 4), similarly to the Washington DC study.[72] Evidence has shown that working in hot environments may increase the risk of work-related injuries and accidents,[21, 27-29] which may not be reported as a result of heat exposure.[37, 64] Estimating the occupational disease/injury burden due to heat is meaningful to better understand the possible additional disease/injury burden resulting from global warming and the predicted increase in extreme heat events.[30]

9.6.2 Heat exposure and productivity loss

Occupational heat exposure may result in productivity loss through the following two ways: (1) physical (e.g. self-pacing) and cognitive performance decrement,[20, 41, 44, 46, 233, 234, 338] and (2) the loss of afternoon outdoor work time during extremely hot weather.[36, 276] A 2% loss of body fluid can result in physical performance impairment.[339] In indoor environments, a consistent decrease in the performance of typical office work was observed when air temperature exceeded 24-26°C.[340] By contrast, in outdoor environments, two recent field studies conducted among rice harvesters and construction workers in India have found that work efficiency may reduce 2-5% per degree increase of ambient temperature exceeding certain thresholds.[42, 45]

With the predicted increase of extremely hot weather due to climate change,[30, 31] the reduction of afternoon work time may result in considerable productivity loss in some labour-intense industries involving outdoor work (e.g. agriculture and construction),[36, 46, 276] especially in some low-middle income in the tropical regions.[233, 234] The first global attempt to estimate the economic loss due to climate change and cost benefit analyses was published in the Climate Vulnerability Monitor 2012.[341] Further local and industry-specific analyses are needed to estimate the impact of climate change related extremely hot weather on productivity loss,[20, 63] taking into account not only the local climate conditions but also workforce composition.[276]

9.6.3 Heat risk perceptions among employers, policy-makers and relevant stakeholders

Multidisciplinary collaboration and comprehensive efforts from all levels of the workplaces is the key to the development and implementation of a successful heat stress control program. The team may consist of workers, employers, management, regulators, occupational physicians, nurses, hygienists, ergonomists, and toxicologists. In this study, workers and occupational hygienists' heat risk perceptions have been investigated in Chapter 7 and 8. Employers and heat policy-makers play an important role in heat stress management, implementation, and the development of heat prevention policies; Occupational medicine physicians serve several important functions in preventing heat-related illnesses and injuries, such as heat illness diagnosis and treatment, pre-placement medical screening; Occupational nurses provide care and symptom relief for patients with heat illnesses.

Thus, there remains a critical need to investigate their views on occupational heat exposure and workers' health and safety and productivity loss in a warming climate. Qualitative research such as interviews and focus group discussions is recommended, given its strength in exploring how people are thinking about an issue.[342] In particular for employers and policy-makers, it may be very difficult to recruit enough participants to meet sample size requirement if conducting a quantitative questionnaire survey among them.

9.6.4 Heat exposure and workers' reproductive health

Occupational heat exposure can be a significant risk factor for male workers' infertility.[343] Currently, there is lack of research to investigate the exposure-outcome association between high temperature and male infertility at the population level. For female workers, a recently published paper has shown that high ambient temperature may result in earlier delivery among term births.[344] More evidence is needed for better understanding of the adverse impact of extreme heat on maternal and pregnancy outcomes.[317]

9.6.5 The development of heat standards for different climatic conditions and local use

To date many heat standards have been developed to protect workers from heat-related illnesses and injuries, as summarized in Chapter 1. Most of these standards (e.g. ISO and ACGIH heat standards) are designed for the use in the temperate western settings. Whether these heat standards are suitable for the use in different geographical, cultural, socioeconomic, and climatic contexts in terms of validity and reliability deserves further investigation.[167, 345] In addition, new types of work in relation to some new technologies, climate change, accelerated urbanization, globalisation and diverse populations all provide significant heat challenges and will require continual review and development of existing standards and strategies for the future.[52]

9.7 Conclusion

Heat exposure is an invisible and silent occupational hazard, which is often overlooked and not considered as occupational health prevention priority due to the relatively small number of heat illnesses recorded compared with other occupational diseases/injuries.[72, 259, 346] In recent years, there is increasing recognition of the importance of occupational heat exposure,[19-21, 33, 37, 40, 64, 167, 168] driven by the projected increase of global average temperature and extremely hot weather events.[31, 32, 35]

The association between high temperatures and work-related injuries is confirmed in this study. For outdoor industries, one degree increase of T_{max} below the threshold of 37.7℃ was associated with 0.5% increase in work-related injuries. When the weather is not extremely hot, the following workers are at higher risk of work-related injuries: young workers aged ≤24 years; those working in the industries such as ‘agriculture, forestry and fishing’, ‘construction’, and ‘electricity, gas and water’; or employed as labourers, production and transport workers, and tradespersons in small and medium sized businesses. While during heatwave periods, vulnerable sub-groups are outdoor male labourers and tradespersons aged ≥55 years in ‘agriculture, forestry and fishing’ and ‘electricity, gas and water’ industries. Occupational burns, lacerations, amputations, and heat illnesses are found to be significantly associated with extreme heat in Adelaide, together with injuries resulting from moving objects, chemical exposures, and environmental factors. The identification of heat vulnerable workers and diseases/injuries associated with heat provides very useful information for the development of targeted heat intervention measures.

Both workers and occupational hygienists are concerned about the impacts of weather-related heat exposure. However, a high proportion of them are not satisfied with current heat regulations and guidelines, indicating the need to develop heat prevention policies and strategies. Current heat regulations are too ambiguous to effectively protect workers from heat-related illnesses and injuries,[19, 314] although an unexpected decline of work-related injuries is observed when the temperature is extremely hot.[27, 139, 226] There are some specific heat guidelines already in place,[181] whereas they are unenforceable and cannot ensure the implementation.[347] Heat prevention barriers existing in the workplace include lack of awareness, lack of training, lack of management commitment, and low compliance of heat prevention policies.

Australian workplaces are not well-prepared for the likelihood of increasing heat stress due to climate change. Regarding the suggestions for heat stress control and management, in the short term it may include the establishment of workplace heat alert systems, real time health surveillance for workers undertaking tasks with emergency nature, the flexible combination of self-regulated and mandatory heat management pattern, specific and clear enforceable heat regulations, and heat awareness campaign and promotion. In the long-term, it may include 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. Inter-disciplinary and multi-sectorial efforts are required to minimize the negative impacts of a changing and warming climate on workers' health and safety.

APPENDICES

Appendix A: Overseas heat-related regulations and standards

1. The United States

1.1 Legal requirements

To date there are no specific national regulatory standards available in the United States to protect workers from excessive environmental heat exposure[37], although heat-related illness has been a well-recognized occupational hazard in outdoor work environments. Under the General Duty Clause of the Occupational Safety and Health Act (OSH Act) of 1970[348], in Title 29 USC 654, employers are required to provide their employees with a place of employment that "is free from recognized hazards that are causing or likely to cause death or serious harm to his employees." Hence, an employer has a legal obligation to provide a workplace free of heat-related hazards that are likely to cause death or injury. Twenty-five states plus Puerto Rico and the Virgin Islands have OSHA-approved State Plans and are required to adopt standards that are at least as effective as those adopted by the Federal OSHA. Most of the remaining State Plans have standards and enforcement policies beyond what is required by the Federal OSHA. No federal occupational standards specifically address heat stress prevention, although three state-based regulations that have been adopted in California, Washington, and Minnesota.

In 2005, the California Occupational Safety and Health Administration implemented the nation's first heat stress regulation[49]. Under the Title 8 California Code of Regulations, Section 3395, employers in agriculture, construction, landscaping, oil/gas extraction, and transportation or delivery of agricultural products, construction materials or other heavy materials are explicitly required to provide shade when the temperature exceeds 85 degrees Fahrenheit (29.4℃). They also need to provide drinking water, access to regular breaks, and training to workers and supervisors regarding heat stress prevention. When the temperature equals or exceeds 95 degrees

Fahrenheit (35.0°C), employers are required to implement high-heat procedures including ensuring effective communication, observing early signs and symptoms of heat illness, reminding employees throughout the work shift to consume small quantities of water regularly, and close supervision of new employees.

In 2007, Washington State issued a similar heat regulation (WAC 296-62-095) for workplace outdoor heat exposure[50] which has been updated in 2009. To my knowledge, it is the first official definition regarding outdoor work environment: an environment where work activities are conducted outside. Employees inside transportation road vehicles are not considered to be "working outdoors" while driving or occupying the vehicles if the vehicles are able to maintain airflow throughout the vehicle by use of fans, vents, or open windows. Construction activity is considered to be work in an indoor environment when performed inside a structure after the inside walls and roof are erected. Work performed within outdoor containment areas such as lead removal projects on bridges, or where an employee must enter a manhole, tunnel, or outdoor vault are considered outdoor work activities. The Washington heat regulation operates between 1 May and 30 September of each calendar year, only when outdoor heat at or above an applicable temperature listed in Table A1 of WAC 296-62-09510 or WAC 296-307-09710. To ensure effective and meaningful application of the rules, all violations are cited as serious with appropriate penalty. This may be one of the strictest mandatory heat management regulations in place.

Appendix A

Table A1 Outdoor temperature action levels

Clothing	WBGT*, °F
Non-breathing clothes including vapor barrier clothing or PPE such as chemical resistant suits	52
Double-layer woven clothes including coveralls, jackets and sweatshirts	77
All other clothing	89

*WBGT: wet bulb globe temperature.

In 2008, Minnesota issued a standard for indoor heat exposure [349]. It requires employees shall not be exposed to indoor environmental heat conditions in excess of the values listed in Table A2, where the values apply to fully clothed and acclimatized workers. In addition, a minimum air temperature of 60 degrees Fahrenheit (15.6°C) shall be maintained in all indoor workrooms where work of a strenuous nature is performed, and a minimum air temperature of 65 degrees Fahrenheit (18.3°C) shall be maintained in all other workrooms unless prohibited by process requirements.

Table A2 Two-hour time-weighted average permissible heat exposure limits

Work activity	WBGT*, °F
Heavy work	77
Moderate work	80
Light work	86

*WBGT: wet bulb globe temperature.

Note: "Heavy work" means 350-500 kcal/hour, for example: heavy lifting and pushing, shove work; "Moderate work" means 200-350 kcal/hour, for example: walking about with moderate lifting and pushing; "Light work" means up to 200 kcal/hour, for example: sitting or standing performing light hand or arm work.

Appendix A

In 2011, Occupational Safety and Health Administration (OSHA) launched a heat illness prevention campaign in order to raise awareness and teach employers and outdoor workers about the risk of working in hot weather,[171] with the support of the California OSHA, NIOSH, and the National Oceanic and Atmospheric Administration (NOAA). Apart from developing a heat-themed webpage to provide educational resources on risk, prevention, signs and symptoms, and first aid for heat illnesses, the OSHA also provides a free on-site consultation about occupational heat exposure for small businesses with fewer than 250 workers.[350] Moreover, on-site consultations services are separate from enforcement and do not result in penalties and citations. In addition, the US Mine Safety & Health Administration (MSHA) also has voluntary guidelines and recommendations for heat stress prevention in miners.

1.2 Heat standards and guidelines

The American Conference of Governmental Industrial Hygienists (ACGIH) is a membership-based professional association of industrial hygienists and practitioners of related professions. In 1956, ACGIH established the concept of threshold limit value (TLV). Its major purpose is to provide guidelines to assist in the control of occupational hazards such as heat stress. The TLVs for heat stress and strain were introduced in 1974, with the goal of maintaining core body temperature within +1℃ of normal (37℃). It should be realized that TLVs for the assessment of heat stress and strain are only recommendations by ACGIH with a guideline or suggestion status. ACGIH TLVs do not have a legal force. Therefore, it should not be confused with heat exposure limits having a regulatory status, like those published and enforced by the OHSA.

A five-step easy-to-use decision making process has been first suggested by ACGIH in 2001 for evaluating the risk to workers health and safety due to heat stress and strains, taking clothing and work demands factors into account, as shown in Figure A1. The decision process should be stated when (1) a qualitative exposure assessment indicates the possibility of heat stress, (2) there are reports of discomfort due to heat stress, or (3) professional judgement indicates heat stress conditions. The guidance provided in the Figure 1 should be used together with the accompanying Documentation, including WBGT-based “screening criteria for TLV and Action Limit for heat stress exposure”, “clothing adjustment factors for some clothing ensembles”, “metabolic rate categories and the representative metabolic rate with example activities”, “guidelines for limiting heat strain”, and “elements to consider in establishing a heat stress management program”. It must be recognized that the ACIGH guidelines provide means for determining conditions under which it is believed that an acceptable percentage of healthy workers can be repeatedly exposed without adverse heat effects[54]. Therefore, the level of heat exposure to be permitted by the management, or by regulatory requirements, is subject to a socio-economic decision on the proportion of the exposed population for whom safeguarding is to assured.

The American National Institute for Occupational Safety and Health (NIOSH) is another federal agency, conducting research and making recommendations for the control of occupational hazards including heat exposure. NIOSH recommended a heat exposure standard to the US OSHA in 1972 and updated that recommendation (recommended heat stress alarm limits, RAL; recommended heat stress exposure limits, REL) in 1986.[179] Similar to the ACGIH standards in terms of authority, NIOSH standards are not mandatory and enforceable. The NIOSH website provides information relating to heat stress. The ACGIH and NIOSH heat standards provide a useful template for other countries to develop their own locally suitable heat guidelines or/and regulations.

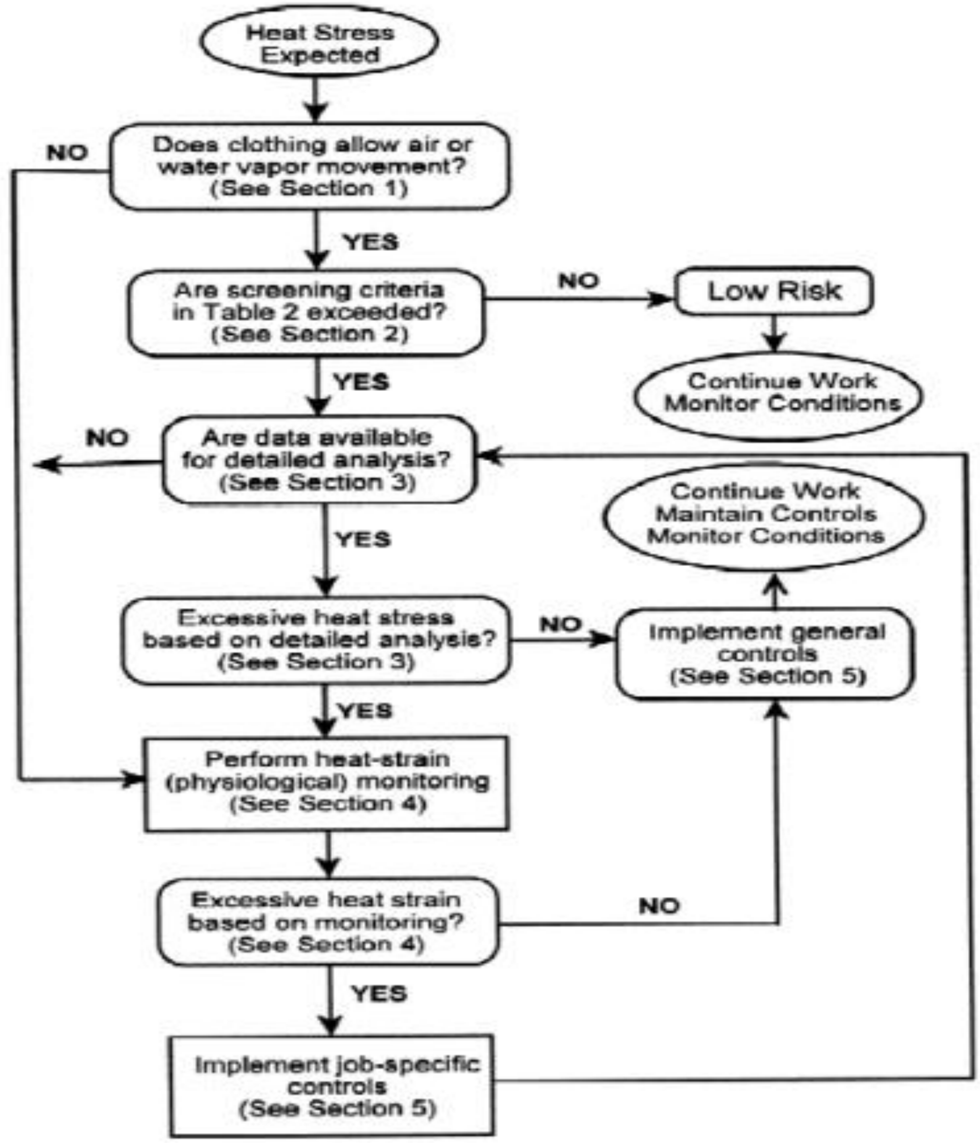

Figure A1 Evaluating heat stress and strain[180]

2. Canada

Currently, almost all Canadian provinces and territories employ the ACGIH TLVs standard as either guidelines or legal regulations for all or particular working environments such as construction and underground mines. However, under the Canadian Occupational Health and

Safety Regulations of 2014, heat stress related clauses do not exist. In 2003 the Occupational Health Clinics for Ontario Workers (OHCOW) developed a new heat stress measurement method called "Humidx". However, it is only used by the Treasury Board Secretariat (TBS) as basis for a legal health and safety regulation to determine the indoor thermal conditions.

3. Europe

3.1 Legal requirements

As summarized in Table A3, there are no specific regulations regarding heat stress control and prevention in the EU member countries.

3.2 Heat standards and guidelines

The European Committee for Standardization has developed two heat stress standards: EN 27243:1993 and EN ISO 7933:2004. On the basis of the two standards, every EU member country's standardization committee developed the equivalent or identical standards. Basically, all European countries use the ISO heat standards.

4. Japan

Japan is one of the participating countries involved in the production of ISO heat standards.[52] In Japan, the heat and cold stress threshold limit values (TLVs) are established by the Society for Occupational Health and the thermal standard for offices is set up by the Ministry of Health, Labour and Welfare.[351] The criteria for the occupational heat stress limits are described for healthy male workers who are acclimatized and wear normal working clothes, which is similar with the ACGIH TLVs. These criteria are mainly set up for working in mines and factories.[352]

Appendix A

Table A3 Legal requirements relating to workplace heat exposure in some European Union countries

Country	Key legislation	Requirement
Austria	Occupational Safety and Health at Work Act	“Employees may only be employed after suitability tests (before starting work) and follow-up tests (on a regular basis if the work continues) are carried out in the case of heat which places a particular strain on the body”; “Workplaces and work processes must additionally be designed in such a way that vibrations and other physical effects and other stress factors (such as heat …) are kept as low as possible”
Germany	EU directives and German OSH Strategy	None required
United Kingdom	The Workplace (Health, Safety and Welfare) Regulations, 1992	"7(1) During working hours, the temperature in all workplaces inside buildings shall be reasonable."; "7(3) A sufficient number of thermometers shall be provided to enable persons at work to determine the temperature in any workplace inside a building."; "22(1) An adequate supply of wholesome drinking water shall be provided for all persons at work in the workplace.(2) Every supply of drinking water required by paragraph (1) shall - (a) be readily accessible at suitable places; and (b) be conspicuously marked by an appropriate sign where necessary for reasons of health or safety..."
	The Management of Health and Safety at Work Regulations 1999	"19(2) no employer shall employ a young person for work in which there is a risk to health from (i) extreme cold or heat."
France	Labour Code No.262/2006	None required
Belgium	Royal Decree of 3 May 1999 on the assignments and operation of the Committees for prevention and protection at work	None required

The Netherlands	Working Conditions Act, 1999	"Chapter 6.1 Temperature: (1) the temperature at the workplace should not cause damage to the health of the employees. (2) If because of the temperature in the workplace or by unfavourable weather conditions damage can still be caused to the health of the employees, personal protective equipment should be made available..."; "Article 7.9 High and low temperatures. Employees should be prevented as much as possible from coming into the direct surroundings of work equipment or its parts which are at very high or very low temperatures..."; "Article 3.27 General requirements: Sufficient drinking water or other soft drinks should be available on the construction site."
Bulgaria	Law on health and safety at work 1997	None required
Croatia	Act on safety and health protection at the workplace	None required
Czech Republic	Labour Code	None required
Denmark	Working Environment Act	"39(1) The Minister for Employment may lay down more detailed regulations on the requirements which shall be complied with in order that the work may be regarded as planned, organised and performed in such a way as to ensure health and safety, including regulations on heat..."
Estonia	Occupational Health and Safety Act	"6(2) An employer shall implement measures to prevent a health risk arising from physical hazards or reduce it as much as possible."; "6(4) The indoor climate at a workplace – air temperature and humidity and air velocity – shall be appropriate for the performance of official duties..."
Finland	Act on Occupational Safety and Health Enforcement and Cooperation on Occupational Safety and Health at Workplaces No 44/2006	None required

Appendix A

Hungary	Act No. 93 of 1993 on Occupational Safety and Health	"13(a) Any factor present during or in connection with the performance of work that might endanger or harm employees or persons present in the area in which the work is being carried out, including the pressure, temperature, humidity and ionization level of air..."; "Section 24 (a): All employees shall be entitled to have access to appropriate amounts of drinking water..."
Ireland	Safety, Health and Welfare at Work Act 2005	None required
Poland	Labour Code: Section X Work safety and hygiene Law on Social Labour Inspection, 1983	None required
Portugal	Law No. 102/2009 the legal arrangements for the promotion of occupational safety and health 10 September 2009	"Article 69. Preventive measures should be taken if the temperature below 0℃ or higher than 42℃..."
Romania	Law No. 319, 14 July 2006 – Law on Safety and Health at Work	None required
Spain	Law 31/1995: Prevention of Occupational risks, 8 November 1995	None required
Sweden	The Swedish Work Environment Act	"2. Occupational exposure limit values are a useful aid to practical work environment policy. Limit values can also be specified for temperature..."
	The Work Environment Ordinance	None required

5. Selected major developing countries

5.1 China

Due to the increased heat-related deaths that have occurred among outdoor labourers during hot summer days in recent years, the State Administration of Work Safety, the Ministry of Health, the Ministry of Human Resources and Social Security, and the all-China Federation of Trade Unions issued a notice on 29 June 2012 to promulgate the "Administrative Measures on Preventing Heat Stroke and Lowering Temperature" [51]. Employers are required to take appropriate measures to ensure workers' health and safety according to the local hot weather warning or alert.

Apart from some general requirements such as rescheduling work time, increasing rest times, reducing work intensity, the provision of drinking water and other cooling facilities, heat stress training and education, heat vulnerability screening among some special occupations, the Administrative Measures explicitly require that "(1) All outdoor work should be ceased when the maximum air temperature (T_{max}) exceeds 40℃; (2) When the T_{max} is between 37-40℃, the accumulative work time should not exceed 6 hour, and employers should not arrange outdoor work during the hottest 3 hours of a day unless otherwise inevitable; (3) When the T_{max} is between 35-37℃, requirements include the use of a work rotation pattern, reducing continuous work time, and avoid working overtime for outdoor workers; (4) Employers should not arrange pregnant workers and young workers to undertake outdoor work when the temperature over 35℃". Moreover, employers are required to pay workers for the time lost due to heat exposure.

In addition, employers are required to provide high temperature allowance for employees working outdoors in temperatures above 35℃ and when indoor temperatures are above 33℃.

The high temperature allowance is part of an employee's salary, and payment is mandatory. A selection of the high temperature allowance standards in China's major cities and provinces was summarized in Table A4. Problems appeared during the implementation of this requirement. Many employers are too concerned about their costs to pay the high temperature allowance and some of them have taken advantage of the loopholes in laws and regulations to avoid the payment. Although relevant rules stipulate that employees can file a complaint with competent authorities if their employers fail to provide the allowances, they seldom do so due to fears of being fired. Therefore, it has been suggested that labour unions should shoulder the responsibility to protects workers' rights and interests, and ensure they receive the relevant benefits and allowances when working in hot environments.

China is one of the participating countries involved in the production of ISO heat standards. Technical standards for the evaluation of heat stress include 'Classified Standards of Working in the Hot Environment (GBZ/T229.3)', 'Limit Values of Allowable Continuous Heat Exposure Time in Hot Environment (GBZ2.2)', and the 'Measurement of physical agents in workplace. Part 7: Heat stress (GBZ/T 189.7-2007)'. They are similar with the ISO standards in terms of heat measurement methods and prevention strategy.

5.2 Other developing countries

In India, the measurements of heat stress comply with the US ACGIH TLVs.[180] Currently, there are no specific regulations and codes for the prevention of heat stress. In South Africa legislation requires that workers be provided with a safe work environment, but there is no specific heat regulations for outdoor workers in terms of minimizing exposure to hazards including extreme heat.[116] A similar situation exists in Costa Rica.[97]

Appendix A

Table A4 High temperature allowance standards in major municipalities/provinces, China[353]

Municipality /Province	Operation requirement	Operation period	Allowance standard on a monthly basis in 2013
Beijing	Work outdoors or indoors in temperature above 33℃	Jun - Aug	RMB 120 (≈AUD 22) for outdoor workplaces; RMB 90 (≈AUD 18) for indoor workplaces in 2010
Shanghai	Work outdoors or indoors in temperature above 33℃	Jun - Sept	RMB 200 (≈AUD 37) per person for all workplaces
Tianjin	Work outdoors in temperature above 35℃or indoors in temperature above 33℃	Jun - Aug	RMB 120 (≈AUD 22) per person for all workplaces
Zhejiang	Work outdoors in temperature above 35℃ or indoors in temperature above 33℃	Jun - Sept	RMB 200 (≈AUD 37) per person for all workplaces
Jiangsu	Work outdoors or indoors in temperature above 33℃	Jun - Sept	RMB 160 (≈AUD 29) for outdoor workplaces; RMB 130 (≈AUD 24) for indoor workplaces
Guangdong	Work outdoors or indoors in temperature above 33℃	Jun - Oct	RMB 150 (≈AUD 27) per person per month or RMB 10 (≈AUD 1.8) per day for all workplaces
Shaanxi	Work outdoors in temperature above 35℃ or indoors in temperature above 33℃	Jun - Sept	RMB 10 (≈AUD 1.8) per day for all workplaces
Shandong	Work outdoors or indoors in temperature above 33℃	Jun - Sept	RMB 120 (≈AUD 22) per person for all workplaces
Hubei	Work outdoors in temperature above 35℃ or indoors in temperature above 33℃	Jul - Sept	RMB 8 (≈AUD 1.5) per day for all workplaces
Sichuan	Work outdoors in temperature above 35℃ or indoors in temperature above 33℃	Jun - Sept	RMB 12 (≈AUD 2.1) per day for all workplaces

Appendix B1

Appendix B1: Ethical approval letter for the analysis of workers' compensation claim data

THE UNIVERSITY *of* ADELAIDE

RESEARCH BRANCH
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CRICOS Provider Number 00123M

26 May 2011

Associate Professor P Bi
Public Health

Dear Associate Professor Bi

PROJECT NO: H-111-2011
Extreme heat exposure and workers' health in South Australia

I write to advise you that on behalf of the Human Research Ethics Committee I have approved the above project. Please refer to the enclosed endorsement sheet for further details and conditions that may be applicable to this approval.

The ethics expiry date for this project is: 31 May 2012

Where possible, participants taking part in the study should be given a copy of the Information Sheet and the signed Consent Form to retain.

Please note that any changes to the project which might affect its continued ethical acceptability will invalidate the project's approval. In such cases an amended protocol must be submitted to the Committee for further approval. It is a condition of approval that you immediately report anything which might warrant review of ethical approval including (a) serious or unexpected adverse effects on participants (b) proposed changes in the protocol; and (c) unforeseen events that might affect continued ethical acceptability of the project. It is also a condition of approval that you inform the Committee, giving reasons, if the project is discontinued before the expected date of completion.

A reporting form is available from the Committee's website. This may be used to renew ethical approval or report on project status including completion.

Yours sincerely

for **PROFESSOR GARRETT CULLITY**
Convenor
Human Research Ethics Committee

Appendix B2

Appendix B2: Renewal of the ethical approval for the workers' compensation claim data

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
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CRICOS Provider Number 00123M

07 May 2012

Professor P Bi
Public Health

Dear Professor Bi

PROJECT NO: H-111-2011
Extreme heat exposure and workers' health in South Australia

Thank you for your report on the above project. I write to advise you that I have endorsed renewal of ethical approval for the study on behalf of the Human Research Ethics Committee.

The expiry date for this project is: 31 May 2015

Where possible, participants taking part in the study should be given a copy of the Information Sheet and the signed Consent Form to retain.

Please note that any changes to the project which might affect its continued ethical acceptability will invalidate the project's approval. In such cases an amended protocol must be submitted to the Committee for further approval. It is a condition of approval that you immediately report anything which might warrant review of ethical approval including (a) serious or unexpected adverse effects on participants (b) proposed changes in the protocol; and (c) unforeseen events that might affect continued ethical acceptability of the project. It is also a condition of approval that you inform the Committee, giving reasons, if the project is discontinued before the expected date of completion.

A reporting form is available from the Committee's website. This may be used to renew ethical approval or report on project status including completion.

Yours sincerely

Pro **PROFESSOR GARRETT CULLITY**
Convenor
Human Research Ethics Committee

Appendix C: SafeWork SA Research Dataset Confidentiality Agreement

SAFEWORK SA
WORK HEALTH AND SAFETY

RESEARCH DATASET CONFIDENTIALITY AGREEMENT

BACKGROUND

Workplace injury/illness compensation claims data is sourced from WorkCoverSA by SafeWork SA for the purpose of developing and implementing strategies to improve the Work Health and Safety (WHS) performance of industry, with the aim of reducing the incidence and costs of work-related injury and illness in South Australia.

This Research Dataset Confidentiality Agreement (the Agreement) is to be completed by single researchers or research teams applying for the de-identified unit-record workplace injury/illness compensation claims dataset (the Dataset) that will be analyzed in the context of a single specified WHS research project.

The Dataset will normally be provided as an Excel 2007 spreadsheet with a purpose-built Pivot Table. Because it is provided in such a way that tabulated data summaries can readily be produced, the Dataset is colloquially known as the 'WHS Tabulator'.

PART 1 **DEFINITIONS**

PART 2 **THE APPROVED RESEARCH**

PART 3 **CONDITIONS UNDER WHICH THE DATASET WILL BE PROVIDED**

PART 4 **SECURITY AUDIT SELF-ASSESSMENT TOOL**

PART 5 **IDENTITIES OF SIGNATORIES**

PART 6 **EXECUTION**

PART 1 DEFINITIONS

Approved Research means the research project in relation to which the SafeWork SA Data Custodian has approved the use of the Dataset under this Agreement. The Approved Research is described in Part 2 of this Agreement. The Dataset must only be used for the purposes of undertaking the Approved Research.

An **Authorised Researcher** means a person who has been given permission by SafeWork SA to use the Dataset for the Approved Research. The Research Project Data Custodian is an Authorised Researcher. All Authorised Researchers are listed in Part 5 of this Agreement. All Authorised Researchers are signatories to this Agreement.

Authorised Researcher Rights: SafeWork SA grants to the Authorised Researchers non-exclusive, non-transferable rights to use, copy, adapt and modify the Dataset for the purposes of undertaking Approved Research for the Term of the Agreement.

The **Commencement Date** means the date of execution of this Agreement by all parties.

Confidential Business Information means the full Dataset, or subsets, from which individual businesses can potentially be identified. It is information that any Authorised Researcher knows, or ought to know, is confidential.

Confidential Personal Information means the full Dataset, or subsets, from which individuals can potentially be identified. It is information that any Authorised Researcher knows, or ought to know, is confidential.

Confidential Information includes Confidential Business Information and Confidential Personal Information.

The **Dataset** means any Release by SafeWork SA of the de-identified unit-record workplace compensation claims dataset. This is data from which people's names, addresses and date of birth have been removed and other identifying information has been modified by various methods such as top coding and the application of classification codes at a more general level. The term 'Dataset' should be taken to apply to any subset of the full Dataset, and to any Unit-Record derived variables.

Intellectual Property means copyright (and all associated rights, including moral rights), and all rights in relation to inventions, registered and unregistered trade marks (including service marks), registered and unregistered designs, and circuit layouts, and any other rights resulting from intellectual activity in the industrial, scientific, literary or artistic fields.

Organisation means the organisation with which an Authorised Researcher is associated for the purposes of conducting the Approved Research.

A **Portable Storage Device** is a device external to a computer that can be used to transport digitised information. Examples are USB flash drives, CDs, DVDs and external hard drives.

A **Release** means a dataset that differs from another dataset from the same data collection in that it contains additional information based on new records. For the purposes of this Agreement, a Release does not include a new version of the data in which changes have been made based on the same set of records. There will be a new release of the Dataset in January each year.

Research Material means any final research publications based on analyses of the Dataset.

The **Research Project Data Custodian** for the Approved Research has the primary responsibility for ensuring adherence to the conditions prescribed in this Agreement. The Research Project Data Custodian is an Authorised Researcher.

The **Research Project Finalisation Date** is the date provided in Part 2 of this Agreement. It is the date by when the Termination Procedures will have been carried out.

The **SafeWork SA Data Custodian** is the representative of SafeWork SA for the purposes of this Agreement. The SafeWork SA Data Custodian or delegate is the final signatory to this Agreement.

A **Secure Room** is a lockable room, to which only the Authorised Researchers have access and keys. A Secure Room is locked when there is no Authorised Researcher in it.

Security Audit: Before the SafeWork SA Data Custodian or delegate signs this Agreement, the Research Project Data Custodian will have conducted a pre-installation Security Audit using the Self-Assessment Tool provided in Part 4 to ensure that the computing facilities and premises are capable of dealing securely with the Dataset to be provided. The SafeWork SA Data Custodian or delegate will verify the results of the security audit before installing the Dataset. Additionally, the SafeWork SA Data Custodian or delegate may conduct a post-installation Security Audit at any time during the Term of the Agreement.

The **Term of the Agreement** starts from the Commencement Date and, unless terminated in accordance with the Agreement, will continue in force until the Research Project Data Custodian complies with the conditions set out in the Termination Procedures clause (see below).

The **Termination Procedures** are the procedures by which all Unit-Record Data (whether electronically stored or in the form of paper output) will be deleted or destroyed. The Termination Procedures are described in Part 3 of this Agreement.

An **Unauthorised Person** means a person who is not authorised under this Agreement to use the Dataset. An Unauthorised Person is anyone other than an Authorised Researcher or the SafeWork SA Data Custodian or delegate. An Unauthorised Person is not a signatory to this Agreement.

Unit-Record Data means individual records from the Dataset; that is, unaggregated data. Each record is stored as a row in a spreadsheet.

PART 2 THE APPROVED RESEARCH

This Part of the Agreement describes the research context in which the Dataset will be used.

TITLE OF THE RESEARCH PROJECT:
[The research project could involve exploratory analyses, with no clear hypotheses being tested.]

Extreme Heat Exposure and Workers' Health in South Australia

SUMMARY OF THE RESEARCH PROJECT
[In **200 words or less** provide a clear summary of the project's aims, methodology, and expected benefits.]

Occupational exposure to extreme heat, especially for outdoor physical workers, may lead to adverse health effects and contribute to work-related injury. With global warming and the predicted increase in frequency and intensity of extreme heat, however, currently the implications are poorly understood. This project aims to: (a) explore the relationships between extreme heat exposure and heat-related illness and injury (HRII); (b) identify the pre-disposing factors related to the occurrence of HRII; (c) explore the perspectives among stakeholders; (d) investigate the knowledge, attitudes and behaviors among high risk worker subpopulations; and utilize the findings to make evidence-based recommendations for mitigation and adaptation strategies.

Using both qualitative and quantitative methods, this research will be conducted in Adelaide including three parts: (1) analysis of historical data using workers compensation databases, to examine the association between extreme heat and occupational injury notifications, (2) focus group discussions and interviews to seek for views and opinions about extreme heat and occupational injuries and prevention from various stakeholders, and (3) a questionnaire survey about knowledge of above issue among workers. The findings will provide policy implications, heat-related adaption, guidelines and occupational protection strategies to relevant governmental organizations, unions, workers associations, employers and workers in South Australia, nationally and internationally.

NAME AND AFFILIATION OF THE RESEARCH PROJECT DATA CUSTODIAN

Name: Peng Bi
Organisation:
The University of Adelaide

KEY VARIABLES
[List the key variables from the Dataset that will be analyzed.]

The key variables include WHS_TABULATOR_2011, RDG_CODE, RDG_DESC, Date of Injury, and all available claim related comments. All variables will be de-indentified.

RESEARCH PROJECT FINALISATION DATE

16 September 2014

EXPECTED PUBLICATION AND DISSEMINATION OF FINDINGS
[Describe how the findings from the research project will be published and disseminated, including departmental presentations, industry workshops, academic conferences, commissioned reports, and peer-reviewed publications in the international journal literature. Indicate if the output includes a thesis. Where possible, identify the journals that will be targeted for publication.]

The primary publication will be Jianjun Xiang's PhD thesis on Extreme Heat Exposure and Workers' Health in South Australia.

The authors will seek to publish the research findings in appropriate print and online journals, and present on relevant academic conferences.

SPONSORSHIP
[If the research project is being sponsored or commissioned by an agency other than Organisation to which the Research Project Data Custodian is affiliated, the agency should be identified below. In particular, it should be noted if the project is funded from a SafeWork SA grant.]

Not applicable.

PART 3 CONDITIONS UNDER WHICH THE DATASET WILL BE PROVIDED

ALLOWABLE USE OF THE DATASET

SafeWork SA grants to the Authorised Researchers non-exclusive, non-transferable rights to use, adapt and modify the Dataset for the purposes of undertaking the Approved Research for the Term of this Agreement. Authorised Researchers may create new derived data items, aggregate and manipulate the data. Authorised Researchers may copy/reproduce the Dataset for any permitted purpose, such as backup on a computer's hard-drive.

RESTRICTIONS ON THE USE OF THE DATASET

The names of the Research Project Data Custodian and all other Authorised Researchers are provided in Part 5 of this Agreement, along with their contact information, including the Organisations with which they are affiliated.

The Dataset must be used only by the Authorised Researchers.

If a new researcher joins the research team and wants to become an Authorised Researcher, the Research Project Data Custodian must apply in writing to the SafeWork SA Data Custodian for the necessary permission.

If an Authorised Researcher ceases to be part of the research team, the Research Project Data Custodian must ensure that he/she no longer has access to the Dataset. The Research Project Data Custodian must inform the SafeWork SA Data Custodian that the researcher no longer has Authorised Researcher status, and that access to the Dataset has been removed.

The Dataset will be provided on the basis of the Authorised Researchers' associations with the Organisation(s) as identified in Part 5 of this Agreement. If any Authorised Researcher ceases association with his/her Organisation, but wishes to keep involved with the Approved Research, the Research Project Data Custodian must obtain written approval from the SafeWork SA Data Custodian.

The Dataset must be used only for the purpose of undertaking the Approved Research.

The Dataset must not be used after the Term of the Agreement.

If any Authorised Researcher wants to use the Dataset for research other than the Approved Research, he/she must complete a new Agreement and have it approved.

ENSURING THE SECURITY OF THE DATASET

The SafeWork SA Data Custodian or delegate is the only person authorised to possess a copy of the Dataset on a Portable Storage Device. The SafeWork SA Data Custodian or delegate will oversee the installation of the Dataset for use by the Authorised Researchers.

The storage location of the Dataset on any hard drive where it is stored must be password protected. The password must be at least seven characters long, and contain a mix of upper and lower case characters, and numerics or symbols. The password must be known only to the Authorised Researchers.

If any storage device where the Dataset is located has network or Internet connectivity, there must be an adequate network security system operating that incorporates virus protection to prevent possible hacking of the Dataset.

Any computer on which the Dataset is stored or analysed must have a password-protected screen saver set to be activated after no more than 15 minutes.

The Authorised Researchers may use the Dataset only on their Organisation's premises. The locations of all servers and any computers that will be used to store or analyse the Dataset will be recorded in the Security Audit Self-Assessment Tool (see Part 4).

Any computer on which the Dataset is stored must be protected from removal or theft by being firmly secured to the workstation, or be located in a Secure Room.

The Authorised Researchers will never copy, or be involved in copying, or allow copying of, the Dataset onto a Portable Storage Device, or onto a portable (i.e., not firmly secured to the workstation) laptop computer.

The Authorised Researchers must not:

- Perform any matching, merging or linkage of any of the Dataset with any other dataset
- Attempt to identify any individuals or businesses in the Dataset
- Publish, in any form, any part of the Dataset
- Publish, in any form, aggregated data with a cell count of only 1 or 2

Authorised Researchers must not allow any Unit-Record Data to be viewed by an Unauthorised Person.

When not being used, any Unit-Record Data in the form of paper output must be stored in a locked container. The locked container must be accessible only to the Authorised Researchers. Alternatively, the paper output could be kept in a Secure Room.

Any Unit-Record Data in the form of paper output must be disposed of using a shredder when no longer required. Alternatively, the paper output could be given to the SafeWork SA Data Custodian for secure disposal through SafeWork SA.

Before the installation of the Dataset by the SafeWork SA Data Custodian, the Research Project Data Custodian will conduct Security Audit of the relevant computers and related facilities using the Security Audit Self-Assessment Tool provided in Part 4. At the time of installation, the SafeWork SA Data Custodian or delegate will verify the findings of the Self-Assessment Security Audit.

The SafeWork SA Data Custodian, or a delegate, may, with at least three business days notice, and during normal business hours, conduct a Security Audit of the premises in which the Dataset is stored or used, the hard-drives involved, and any Unit-Record output, to ensure that all specified security measures are in place.

Authorised Researchers must immediately notify the SafeWork SA Data Custodian if they become aware of any unauthorised access to, or use or disclosure of, any Confidential Information.

If required at any time by the SafeWork SA Data Custodian to do so, Authorised Researchers will deliver up to the SafeWork SA Data Custodian, or at the option of the SafeWork SA Data Custodian destroy, any Unit-Record paper output in their possession.

TERMINATION PROCEDURES

On, or before, the Project Finalisation Date (provided in Part 1), the Research Project Data Custodian will:

- Ensure the deletion of the Dataset from any hard drive on which it has been installed

- Ensure the destruction of all paper copies of Unit-Record data and any subsets or derived Unit-Records
- Provide written confirmation to the SafeWork SA Data Custodian that the two above procedures have been undertaken

The Research Project Data Custodian has the primary responsibility for all copies of the Dataset until the Termination Procedures have been undertaken.

If the Dataset is still required after the originally nominated Project Finalisation Date, the Research Project Data Custodian will apply in writing to the SafeWork SA Data Custodian for an extension to the Project Finalisation Date.

INTELLECTUAL PROPERTY

The Authorised Researchers acknowledge that the State of South Australia as represented by SafeWork SA owns all Intellectual Property rights in the Dataset.

The Authorised Researchers and any co-authors will own all Intellectual Property rights in any Research Material created using the Dataset.

ACKNOWLEDGEMENT AND DISCLAIMER TO BE USED BY AUTHORISED RESEARCHERS

The Authorised Researchers agree to acknowledge SafeWork SA for the provision of the Dataset (and any assistance provided in using the Dataset) in any Research Material.

The Authorised Researchers agree to insert the following disclaimer in any Research Material: "The findings from this research and any opinions expressed or recommendations made, are not necessarily endorsed by SafeWork SA or the Government of South Australia."

SAFEWORK SA DISCLAIMER

The Dataset is provided to the Authorised Researchers on an 'as is' basis, and SafeWork SA is not responsible for its accuracy, quality or fitness for purpose.

CONFLICT OF INTEREST

All Authorised Researchers warrant that no conflict of interest exists or is likely to arise while in receipt of the Dataset.

INDEMNITY (This clause will survive the termination of this Agreement)

All Authorised Researchers agree to indemnify SafeWork SA against any:
- cost or liability incurred by SafeWork SA
- loss or expense incurred by SafeWork SA in dealing with any claim against it including reasonable legal costs

arising from:
- any negligent act or omission by the Authorised Researchers in connection with the use of the Dataset
- any breach by the Authorised Researchers of their obligations under this Agreement
- any use or disclosure by the Authorised Researchers of Confidential Information held in connection with this Agreement

PART 4 SECURITY AUDIT SELF-ASSESSMENT TOOL

This self-assessment audit tool is to be completed by the Research Project Data Custodian, and verified by the SafeWork SA Data Custodian or delegate before the SafeWork SA Data Custodian or delegate installs the Dataset.

Where an item is not relevant, the Research Project Data Custodian will insert 'N/A'. The SafeWork SA Data Custodian will verify all responses by initialing: [...YB...].

The Dataset will normally be provided as an Excel 2007 spreadsheet with a purpose-built Pivot Table. However, it can be provided in other formats if required. The SafeWork SA Data Custodian has been contacted and has agreed to provide the Dataset in the format given below:

Agreed alternative Dataset format: Excel 2007 [...............]

The location and name of any server on which the Dataset is to be installed is provided below:

Server location: \\uofa\users$\users4\a1207894
Server name: a1207894 [......✓......]

The locations and asset numbers (or serial numbers) of all computers on which the Dataset will be installed or analysed are provided below:

Computer asset/serial number: L3AAP7R
Computer location: Room 9-22, The Tower Building Level 9, 10 Pulteney Street [......✓......]

All storage locations where the Dataset will be installed or analysed are able to be password protected. [Y] [......✓......]

Any storage location where the Dataset will be installed or analysed that has local network or Internet connectivity has a network security system in place that incorporates adequate virus protection to prevent possible hacking. [Y] [......✓......]

Any computer on which the Dataset will be stored or analysed has a password-protected screen saver set to be activated after no more than 15 minutes. [Y] [......✓......]

All computers on which the Dataset will be installed or analysed are firmly attached to their workstations [Y], or located in a Secure Room [Y]. [......✓......] only on network drive

A lockable container is available for the storage of Unit-Record paper output from the Dataset when it is not being used. All Authorised Researchers, and only the Authorised Researchers, have keys to the container. [Y]. Alternatively, the Unit-Record paper output from the Dataset will be used only in a Secure Room. [Y]. [......✓......]

A shedder is available for the destruction of Unit-Record paper output from the Dataset when it is no longer required. [Y]. Alternatively, the SafeWork SA Data Custodian or delegate has agreed to securely destroy it through the services of SafeWork SA. [Y] [......✓......]

If the Research Project Data Custodian has alternative means of achieving any of the security arrangements described above, which provide equal or superior levels of security, those means are described here: [N/A]. These means are approved by the SafeWork SA Data Custodian or delegate. [......✓......]

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Appendix C

PART 6 EXECUTION

Peng Bi		06-07-2011
Name of Research Project Data Custodian (Print)		Date
Dino Pisaniello		6/7/11
Name of Authorised Researcher (Print)	Signature	Date
Alana Hansen		6/7/11
Name of Authorised Researcher (Print)	Signature	Date
Jianjun Xiang		06-07-2011
Name of Authorised Researcher (Print)		Date
		13-7-2011
Name of SafeWork SA Data Custodian Or delegate (Print)	Signature	Date of Execution

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Appendix D: Research invitation letter for employers

Government of South Australia
SafeWork SA

Department of the Premier and Cabinet

Performance and Data

Level 4, World Park A,
33 Richmond Road
Keswick SA 5035

GPO Box 465
Adelaide SA 5001

DX 715 Adelaide

Contact John Horrocks
Phone 0401 125 689
Fax
Email john.horrocks2@sa.gov.au

ABN 50-560-588-327

www.safework.sa.gov.au

Our ref: SAFE11/0548

10 August 2012

Dear Manager / OHS Manager

IMPACT OF EXTREME HEAT EXPOSURE IN SOUTH AUSTRALIAN WORKPLACES

The University of Adelaide is conducting research into the impact of extreme heat exposure on occupational health and safety in South Australian workplaces.

The study is being conducted by a PhD candidate, Mr Jianjun Xiang, who will explore perceptions of extreme heat exposure and adaptation strategies, in particularly with **workers undertaking manual work outdoors or working in hot environments.**

Employer contribution to the research would comprise the distribution of a questionnaire to appropriate workers for completion and return to the University. A stamped addressed return envelope will be provided to enable this. Alternatively, there is an option for a workplace visit to be conducted to undertake face-to-face surveys, which would take about 5-10 minutes to complete.

All responses will be kept strictly confidential and no worker or employer will be identifiable in the final research report.

An information sheet giving a brief outline of the study is enclosed and additional information can be sought from Mr Xiang at the University of Adelaide.

Your assistance in this research will be greatly appreciated and participation can be organised by contacting Mr Jianjun Xiang, telephone number 8303 8147, or by email at jianjun.xiang@adelaide.edu.au

Yours sincerely

Kim Tolotta
DIRECTOR
STRATEGIC ALLIANCES AND PERFORMANCE
SAFEWORK SA (DPC)

Appendix E: Information sheet for workers

THE UNIVERSITY OF ADELAIDE AUSTRALIA

DISCIPLINE OF PUBLIC HEALTH
Level 8, Hughes Building
North Terrace Campus

INFORMATION SHEET

Extreme Heat Exposure and Workers' Health & Safety in South Australia

Research Background

Occupational exposure to extreme heat may lead to adverse health effects and contribute to work-related injury. Those at risk of heat stress include outdoor workers and workers in hot environments such as those working outdoors in the building and construction trades, firefighters, agricultural workers, miners, boiler room workers and factory workers. With the predicted increase in the frequency and intensity of extremely hot weather in South Australia, workplace heat exposure is presenting a growing challenge to occupational health and safety.

Aims of the research

This project aims to: (a) explore the extent to which manual workers are affected by or adapt to extreme heat exposure in South Australia; (b) identify which industrial sectors and occupations are most vulnerable to heat-related illness and injury in SA; (c) investigate how stakeholders and manual workers perceive the impact of workplace extreme heat exposure on OH&S and productivity loss; and (d) utilize the findings to inform policy implications and guidelines.

Study Design

Using both qualitative and quantitative methods, this research will be conducted in Adelaide in three stages:

- Stage I is the analysis of historical OH&S data to explore the association of heat exposure and occupational compensation claims in SA.
- Stage II will ascertain views and experiences of various stakeholders and key informants regarding extreme heat in the workplace.
- Stage III is a questionnaire survey of workers to explore perceptions of workplace heat exposure, behavioural responses and adaptation barriers in South Australian workplaces.

How do I participate?

If you are interested in this project and would like to participate, please email: jianjun.xiang@aedelaide.edu.au. We are currently seeking workers to complete a questionnaire. Target workers are those mainly undertaking manual work outdoors or in hot environments. For this we require the permission and support of their employers. Questionnaires could be provided to employers for distribution to workers. Stamped and addressed envelopes will be provided for the return of completed questionnaire. Alternatively we could visit workplaces and conduct face-to-face surveys which would take about 5-10 minutes to complete. Participation is voluntary and people can withdraw from the study at any time without any reasons given.

Confidentiality would be assured

The questionnaire is anonymous and neither worker nor workplace will be identifiable in the final analysis. Only members of the research team will have access to data. The study findings will be published in a completely attributable format in order to ensure that no participants will be identified.

What if I have a complaint or any concerns?

If you wish to raise concerns about the conduct of the project with an independent person or discuss matters related to the University policy on research involving human participants or your rights as a participant, contact: The Human Research Ethics Committee's Secretary, Ph.: 08 8303 6028 or visit:http://www.adelaide.edu.au/ethics/human/guidelines/applications/#complaint.

For further information, please contact:

Jianjun Xiang, Discipline of Public Health, the University of Adelaide,
jianjun.xiang@adelaide.edu.au

John Horrocks, Principal Data Analyst and Statistician, SafeWork SA,
Horrocks.John@dpc.sa.gov.au

Your contribution to this survey is very greatly appreciated.

Appendix F: Survey questionnaires for workers

THE UNIVERSITY OF ADELAIDE AUSTRALIA

Questionnaire Number: ___________

Discipline of Public Health
School of Population Health & Clinical Practice

Extreme Heat Exposure and Worker Health & Safety

A South Australian Survey

General Instructions

- This survey, which is being conducted by The University of Adelaide, is investigating workplace heat exposure and occupational health & safety.
- Please answer each question as best you can by placing a (✓) in the box next to your preferred answer.
- For each question, please select one response unless otherwise instructed.
- Please follow any arrows or instructions that direct you to the next question.
- This survey is anonymous to maintain confidentiality.
- A reply paid envelope is enclosed for the return of completed questionnaire.

Thank you very much for taking the time to complete this questionnaire

Contact person: Jianjun Xiang; Email: jianjun.xiang@adelaide.edu.au
Phone: 8313 6875

1. **What is your gender?**
   - Male ☐1
   - Female ☐2

2. **What is your age?** __________ (years)

3. **What is your level of formal education?**
   - High school ☐1
   - Trade certificate ☐2
   - University degree ☐3
   - Other (specify) ☐4

   ____

4. **What is your current main occupation?**
   - Technician and/or trades worker ☐1
   - Health and/or community services worker ☐2
   - Clerical & administrative worker ☐3
   - Retail/Sales worker ☐4
   - Machinery operator and/or driver ☐5
   - Labourer ☐6
   - Other (specify)__________________ ☐7

5. **What is the industry of your current employment?**
   - Agriculture, forestry & fishing ☐1
   - Mining ☐2
   - Manufacturing ☐3
   - Construction ☐4
   - Wholesale Trade & Retail Trade ☐5
   - Transport & Storage ☐6
   - Other (specify)__________________ ☐7

6. **In which type of workplace environment do you currently work?**
   - Completely indoors ☐1
   - Mainly indoors ☐2
   - Completely outdoors ☐3
   - Mainly outdoors ☐4
   - Other (specify below) ☐5

   ____

7. **Would you consider your job to be physically demanding (e.g. lifting or moving heavy or awkward objects)**

   (Please tick one box)

Not at all	*A little*	*Moderately*	*Very much*
1	*2*	*3*	*4*
☐	☐	☐	☐

8. **Do you work around heat sources like ovens, furnaces, or welding etc?**
   - Yes ☐1 →How often?
     - Seldom ☐1
     - Sometimes ☐2
     - Often ☐3
     - Always ☐4
   - No ☐2

9. **Does your job require the use of protective clothing such as overalls?**
   - Yes ☐1 →Types? __________________
     →How often?
     - Seldom ☐1
     - Sometimes ☐2
     - Often ☐3
     - Always ☐4
   - No ☐2

10. Which of the following applies when you are working during very hot weather?

- I drink plenty of fluids before starting work ☐ 1
- I drink fluids regularly while at work......... ☐ 2
- I only drink when thirsty........................ ☐ 3
- All of the above.................................. ☐ 4
- Other, please specify below.................. ☐ 5

____

11. What have been your main sources of information about preventing heat illnesses in the workplace? *(You can choose more than one)*

- Training.................... ☐ 1
- Internet..................... ☐ 2
- TV and Radio............ ☐ 3
- Newspaper................ ☐ 4
- Friends and families.... ☐ 5
- Colleagues................ ☐ 6
- Workplace................ ☐ 7
- SafeWork SA............ ☐ 8
- None....................... ☐ 9
- Others (specify below) ☐ 10

____

12. Have you ever experienced a heat illness (such as heat rashes, heat exhaustion or heat stroke etc) at work?

- Yes......... ☐ 1 →Types?
- No.......... ☐ 2
- Not sure... ☐ 3

Types:
- Heat rashes......... ☐
- Heat cramps........ ☐
- Heat exhaustion... ☐
- Heat stroke......... ☐
- Other................. ☐

13. Have you been given instructions on first aid procedures for serious heat illnesses?

- Yes.......... ☐ 1
- No.......... ☐ 2
- Not sure... ☐ 3

14. How concerned are you about the risk of heat illness at work during very hot weather?

(Please tick one box)

Not at all	*A little*	*Moderately*	*Very much*
1	*2*	*3*	*4*
☐	☐	☐	☐

15. Have you ever injured yourself at work during very hot weather?

- Yes....... ☐ 1 →If yes, please tick the type of injury?
- No...... ☐ 2
- Not sure ☐ 3

Type of injury:
- Falls, trips and slips.......... ☐
- Hitting objects................. ☐
- Being hit by moving objects ☐
- Burn.............................. ☐
- Other injuries.................. ☐

16. Have you witnessed an injury to another person during very hot weather?

- Yes....... ☐ 1 → If yes, please tick the type of injury?
- No........ ☐ 2
- Not sure ☐ 3

Type of injury:
- Falls, trips and slips.......... ☐
- Hitting objects................. ☐
- Being hit by moving objects ☐
- Burn.............................. ☐
- Other injuries.................. ☐

17. Have you attended a training course which covers the prevention of heat illnesses?

Yes............... ☐1
No................ ☐2
Not sure........ ☐3

18. Do you think there is a need for more training about working in very hot weather?

Yes.............. ☐1
No............... ☐2
Don't know.... ☐3

19. Are there any guidelines in your workplace for working during very hot weather?

Yes.............. ☐1
No............... ☐2
Don't know.... ☐3

20. Do you think there should be more legal requirements or restrictions for working during very hot weather?

Yes ☐1

No ☐2→Because? (You can choose more than one)

- There are enough regulations...... ☐1
- I don't think it is a serious problem ☐2
- I haven't thought about it............ ☐3
- Other(specify)________________ ☐4

____

Don't know ☐3

21. What measures are adopted in your workplace during very hot weather?

(You can choose more than one)

- Provision of cool drinking water................. ☐1
- Electric fan... ☐2
- Broad brimmed hats supplied..................... ☐3
- Shady rest area... ☐4
- Stopping work if the temperature exceeds 40℃ ☐5
- Central cooling system or air conditioning...... ☐6
- Rescheduling work time, e.g., start work early, extend break time, etc........................ ☐7
- Others (specify)________________________ ☐8

____

____

____

____

22. Are you satisfied or dissatisfied with the measures currently adopted in your workplace for reducing the risk of heat illnesses in very hot weather? (Please tick one box)

Strongly dissatisfied	*Dissatisfied*	*Undecided*	*Satisfied*	*Strongly satisfied*
1	*2*	*3*	*4*	*5*
☐	☐	☐	☐	☐

23. Do you generally work at your own pace during very hot weather?

Yes ☐ 1

No ☐ 2 → Because? *(You can choose more than one)*

- ▶ Enough has been done to cool the workplace ☐ 1
- ▶ Pressure from co-workers............ ☐ 2
- ▶ Pressure from supervisors........... ☐ 3
- ▶ Pressure from work demand......... ☐ 4
- ▶ Other (specify)________________ ☐ 5

____

24. Do you think you should adjust your work habits personally to reduce the risk of heat illnesses when working during very hot weather?

Yes ☐ 1

No ☐ 2 → Because? *(You can choose more than one)*

- ▶ I don't think it is a serious problem ☐ 1
- ▶ I don't think I am at risk................ ☐ 2
- ▶ Enough has been done already..... ☐ 3
- ▶ I haven't thought about it.............. ☐ 4
- ▶ Other (specify)________________ ☐ 5

____

Don't know ☐ 3

25. If you have any comments you would like to make about workplace heat exposure and Occupational Health & Safety, please write them below.

____

____

____

____

____

THE END

Thank you for participation. Your contribution to this survey is very greatly appreciated.

Please return your questionnaire in the reply paid envelope provided.

If the envelope has been mislaid, please forward to:

Jianjun Xiang

Discipline of Public Health, The University of Adelaide, Level 8, Hughes Building, Mail Drop DX 650 207, Adelaide, SA 5005

Appendix G: Survey questionnaires for TAFE students

THE UNIVERSITY OF ADELAIDE
AUSTRALIA

Discipline of Public Health
School of Population Health and Clinical Practice

Questionnaire Number: ___________

Extreme Heat Exposure and Worker Health & Safety

A South Australian Survey

General Instructions

- This survey, which is being conducted by The University of Adelaide, is investigating workplace heat exposure and occupational health & safety.
- Please answer each question as best you can by placing a (✓) in the box next to your preferred answer.
- For each question, please select one response unless otherwise instructed.
- Please follow any arrows or instructions that direct you to the next question.
- This survey is anonymous to maintain confidentiality.
- A reply paid envelope is enclosed for the return of the completed questionnaire.

Thank you very much for taking the time to complete this questionnaire

Contact person: Jianjun Xiang; Email: jianjun.xiang@adelaide.edu.au
Phone: 8313 6875

1. What is your gender?

Male ☐ 1

Female ☐ 2

2. What is your age? __________ (years)

3. What is your level of formal education?

High school .... ☐ 1

Trade certificate.......................... ☐ 2

University degree .... ☐ 3

Other (specify)...... .... ☐ 4

____

4. What is your current main occupation?

Full-time student.................................. ☐ 1

Technician and/or trades worker............. ☐ 2

Health and/or community services worker.. ☐ 3

Clerical & administrative worker............. ☐ 4

Retail/Sales worker............................ ☐ 5

Machinery operator and/or driver........... ☐ 6

Labourer.. ☐ 7

Other (specify)____________________ ☐ 8

5. What is your current study area?

Agriculture and Biology.................. ☐ 1

Building and Furnishing................. ☐ 2

Community and Health................... ☐ 3

Engineering and Transport............. ☐ 4

Electrical and Electronics............... ☐ 5

Food and Wine............................... ☐ 6

Other (specify)________________ ☐ 7

6. In which type of workplace environment do you currently work?

Completely indoors............ ☐ 1

Mainly indoors.................. ☐ 2

Completely outdoors.......... ☐ 3

Mainly outdoors................. ☐ 4

Not applicable................... ☐ 5

7. If you are currently employed, would you consider your job to be physically demanding (e.g. lifting or moving heavy or awkward objects)?

(Please tick one box)

Not at all	*A little*	*Moderately*	*Very much*
1	*2*	*3*	*4*
☐	☐	☐	☐

8. Do you work around heat sources like ovens, furnaces, or welding etc?

Yes ☐ 1 →How often?

- Seldom......... ☐ 1
- Sometimes.... ☐ 2
- Often........... ☐ 3
- Always......... ☐ 4

No ☐ 2

N/A ☐ 3

9. Does your job require the use of protective clothing such as overalls?

Yes ☐ 1 →Types? ________________

→How often?

- Seldom...... ☐ 1
- Sometimes... ☐ 2
- Often.......... ☐ 3
- Always...... ☐ 4

No ☐ 2

N/A ☐ 3

10. Which of the following applies when you are working during very hot weather?

- I drink plenty of fluids before starting work ☐ 1
- I drink fluids regularly while at work......... ☐ 2
- I only drink when thirsty....................... ☐ 3
- All of the above................................. ☐ 4
- Not applicable.................................... ☐ 5
- Other, please specify below.................. ☐ 6

____

11. What have been your main sources of information about preventing heat illnesses?
(Select all that apply)

- Training.................. ☐ 1
- Internet.................. ☐ 2
- TV and Radio............ ☐ 3
- Newspaper............... ☐ 4
- Friends and families.... ☐ 5
- Colleagues............... ☐ 6
- Workplace................ ☐ 7
- SafeWork SA............ ☐ 8
- None...................... ☐ 9
- Others (specify below) ☐ 10

____

12. Have you ever experienced a heat illness (such as heat rashes, heat exhaustion or heat stroke etc) at work?

- Yes......... ☐ 1 →Types?
- No.......... ☐ 2
- Not sure... ☐ 3
- N/A......... ☐ 4

Types:
- Heat rashes......... ☐
- Heat cramps........ ☐
- Heat exhaustion... ☐
- Heat stroke......... ☐
- Other................ ☐

13. Have you been given instructions on first aid procedures for serious heat illnesses?

- Yes.......... ☐ 1
- No.......... ☐ 2
- Not sure... ☐ 3

14. How concerned are you about the risk of heat illness at work during very hot weather?

(Please tick one box)

Not at all	*A little*	*Moderately*	*Very much*
1	*2*	*3*	*4*
☐	☐	☐	☐

15. Have you ever injured yourself at work during very hot weather?

- Yes....... ☐ 1 →If yes, please tick the type of injury?
- No...... ☐ 2
- Not sure ☐ 3
- N/A....... ☐ 4

Type of injury:
- Falls, trips and slips.......... ☐
- Hitting objects.................. ☐
- Being hit by moving objects ☐
- Burn.............................. ☐
- Other injuries.................. ☐

16. Have you witnessed an injury at work to another person during very hot weather?

- Yes....... ☐ 1 →If yes, please tick the type of injury?
- No...... ☐ 2
- Not sure ☐ 3
- N/A....... ☐ 4

Type of injury:
- Falls, trips and slips.......... ☐
- Hitting objects.................. ☐
- Being hit by moving objects ☐
- Burn.............................. ☐
- Other injuries.................. ☐

17. Have you attended a training course which covers the prevention of heat illnesses?

Yes.............. ☐1

No............... ☐2

Not sure........ ☐3

18. Do you think there is a need for more training about working in very hot weather?

Yes.............. ☐1

No............... ☐2

Don't know.... ☐3

19. Are there any guidelines in your workplace for working during very hot weather?

Yes.............. ☐1

No............... ☐2

Don't know.... ☐3

N/A............... ☐4

20. Do you think there should be more legal requirements or restrictions for working during very hot weather?

Yes ☐1

No ☐2 →Because? (Select all that apply)

- There are enough regulations...... ☐1
- I don't think it is a serious problem ☐2
- I haven't thought about it............ ☐3
- Other(specify)________________ ☐4

____

Don't know ☐3

21. What measures are adopted in your workplace during very hot weather?

(Select all that apply)

- Provision of cool drinking water................. ☐1
- Electric fan.. ☐2
- Broad brimmed hats supplied..................... ☐3
- Shady rest area.. ☐4
- Stopping work if the temperature exceeds 40℃ ☐5
- Central cooling system or air conditioning...... ☐6
- Rescheduling work time, e.g., start work early, extend break time, etc.......................... ☐7
- Not applicable... ☐8
- Others (specify)______________________ ☐9

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22. Are you satisfied or dissatisfied with the measures currently adopted in your workplace for reducing the risk of heat illnesses in very hot weather? (Please tick one box)

Strongly dissatisfied	*Dissatisfied*	*Undecided*	*Satisfied*	*Strongly satisfied*
1	*2*	*3*	*4*	*5*
☐	☐	☐	☐	☐

23. Do you generally work at your own pace during very hot weather?

Yes ☐ 1

No ☐ 2 → Because? *(Select all that apply)*

- ▶ Enough has been done to cool the workplace ☐ 1
- ▶ Pressure from co-workers………… ☐ 2
- ▶ Pressure from supervisors………… ☐ 3
- ▶ Pressure from work demand……… ☐ 4
- ▶ Other (specify)________________ ☐ 5

____

24. Do you think you should adjust your work habits personally to reduce the risk of heat illnesses when working during very hot weather?

Yes ☐ 1

No ☐ 2 → Because? *(Select all that apply)*

- ▶ I don't think it is a serious problem ☐ 1
- ▶ I don't think I am at risk…………… ☐ 2
- ▶ Enough has been done already….. ☐ 3
- ▶ I haven't thought about it…………. ☐ 4
- ▶ Other (specify)________________ ☐ 5

____

Don't know ☐ 3

25. If you have any comments you would like to make about workplace heat exposure and Occupational Health & Safety, please write them below.

____

____

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THE END

Thank you for participation. Your contribution to this survey is very greatly appreciated.
Please return your questionnaire in the reply paid envelope provided.
If the envelope has been mislaid, please forward to:

Jianjun Xiang
Discipline of Public Health, The University of Adelaide, Level 8, Hughes Building, Mail Drop DX 650 207, Adelaide, SA 5005

Appendix H

Appendix H: Ethical approval for questionnaire surveys

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
RESEARCH ETHICS AND COMPLIANCE UNIT

SABINE SCHREIBER
SECRETARY
HUMAN RESEARCH ETHICS COMMITTEE
THE UNIVERSITY OF ADELAIDE
SA 5005
AUSTRALIA

TELEPHONE +61 8 8303 6028
FACSIMILE +61 8 8303 7325
email: sabine.schreiber@adelaide.edu.au
CRICOS Provider Number 00123M

23 August 2011

Associate Professor P Bi
Discipline of Public Health, University of Adelaide

Dear Associate Professor Bi

PROJECT NO: H-200-2011
Extreme heat exposure and workers' health and safety in South Australia

I write to advise you that on behalf of the Human Research Ethics Committee I have approved the above project. Please refer to the enclosed endorsement sheet for further details and conditions that may be applicable to this approval.

The ethics expiry date for this project is: 31 August 2012

Where possible, participants taking part in the study should be given a copy of the Information Sheet and the signed Consent Form to retain.

Please note that any changes to the project which might affect its continued ethical acceptability will invalidate the project's approval. In such cases an amended protocol must be submitted to the Committee for further approval. It is a condition of approval that you immediately report anything which might warrant review of ethical approval including (a) serious or unexpected adverse effects on participants (b) proposed changes in the protocol; and (c) unforeseen events that might affect continued ethical acceptability of the project. It is also a condition of approval that you inform the Committee, giving reasons, if the project is discontinued before the expected date of completion.

A reporting form is available from the Committee's website. This may be used to renew ethical approval or report on project status including completion.

Yours sincerely

p.p. **PROFESSOR GARRETT CULLITY**
Convenor
Human Research Ethics Committee

Appendix I

Appendix **I:** Survey questionnaires for hygienists

Questionnaire Number: _________

THE UNIVERSITY OF ADELAIDE AUSTRALIA

Take 5 minutes to win a $100 prize and $200 to charity

Professional Hygienist Perspectives on Extreme Heat Management in the Workplace

Note: This survey, which is being conducted by The University of Adelaide, is investigating workplace heat exposure and health & safety. Please answer each question by placing a (✓) in the box next to your preferred answer. Return the completed questionnaire to the box on the reception desk, and you will be in the draw to win a $100 Coles-Myer gift voucher and a $200 Christmas donation to an AIOH-sponsored charity. This survey is anonymous to maintain confidentiality. Your contribution to this survey is very greatly appreciated.

Part A: Your circumstances

1. Job Position:

☐ Consultant ☐ General Industry Hygienist ☐ Mining Hygienist

☐ Government Hygienist ☐ University Hygienist ☐ Military Hygienist

☐ Health and Safety Manager ☐ Other ______________

2. Years of OH&S experience: __________

3. Which state are you from?

☐ ACT ☐ NSW ☐ NT ☐ QLD

☐ SA ☐ TAS ☐ VIC ☐ WA

Given predictions of increased hot weather and the likelihood of more frequent extreme heat events in Australia we would like to ascertain your thoughts on heat stress in the workplace

Part B: Your perspectives

4. On a scale of 1-5 with 5 being the most concerned, how concerned are you about extreme heat resulting in increased hazards in the workplace?

1	2	3	4	5
☐	☐	☐	☐	☐

Page 1

5. **Do you agree or disagree that extremely hot weather due to changing climate presents a future challenge for workplace heat management?**

☐ Strongly agree ☐ Agree ☐ Neither agree nor disagree ☐ Disagree ☐ Strongly disagree

6. **Do you know of any organizations planning for increased frequency of extremely hot weather events?**

☐ Yes ☐ No

7. **In your experience have workers ever expressed concern about heat in your workplace (or workplaces you consult in) during very hot weather?**

☐ Yes ☐ No

If yes, how often?

☐ Seldom ☐ Sometimes ☐ Often ☐ Always

8. **In the last five years, have you had to investigate the circumstances around injuries or illnesses that could be attributed to extreme heat (air temperature greater than 38℃)?**

☐ Yes ☐ No

If yes, how many times?

☐ Once ☐ Two to five times ☐ More than five times ☐ Not sure

9. **What measures are adopted in the workplace or workplaces that you consult in during very hot weather?**

(Select all that apply)

☐ Provision of cool drinking water ☐ Electric fan

☐ Broad brimmed hats supplied ☐ Shady rest area

☐ Stop outdoor work if the temperature is extreme ☐ Central cooling system or air conditioning

☐ Rescheduling work time ☐ Heat stress related training

☐ Other (specify)______________________________

10. Overall, are you satisfied or dissatisfied with the measures currently adopted for reducing the risk of heat illnesses and injuries in the workplace or workplaces that you consult in during very hot weather?

☐	☐	☐	☐	☐
Strongly satisfied	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied	Strongly dissatisfied

11. Do you think there is a need for more training about working in very hot weather in your workplace or workplaces that you consult in?

☐ Yes → Which aspects should be strengthened? ______________________________

____

☐ No → Because? (Select all that apply)
- ▶ Training is generally adequate......... ☐
- ▶ I don't think it is a serious problem.... ☐
- ▶ Other(specify)__________________ ☐

☐ Not sure

12. Is there a hot weather plan or heat stress policy in your workplace or any workplaces that you consult in?

☐ Yes → which industrial sectors? ______________________________

☐ No

☐ Not sure

13. Do you think there should be more guidelines or regulations for reducing the risk of heat-related illnesses and injuries in very hot weather applicable to your workplace or workplaces that you consult in?

☐ Yes

☐ No → Because? (Select all that apply)
- ▶ There are enough regulations......... ☐
- ▶ I don't think it is a serious problem... ☐
- ▶ I haven't thought about it................ ☐
- ▶ Other __________________________ ☐

☐ Don't know

14. Do you know of companies that have recently made changes to maintain OHS in work environments where extreme heat may become more common?

☐ Yes ☐ No

If yes, what changes have been made? ______________________________

____

____

Page 3

15. Do you intend to alter your recommendations to management or companies due to the likelihood of increased hot weather?

☐ Yes

☐ No → Because? (Select all that apply)

- ▶ I don't think it is a serious problem....... ☐
- ▶ The timescale is too long.................. ☐
- ▶ I haven't thought about it.................. ☐
- ▶ Other ______________________ ☐

☐ Not sure

16. What do you foresee as potential barriers for the prevention of heat stress in workplaces?

(Select all that apply)

☐ Lack of awareness

☐ Lack of training

☐ Lack of management commitment

☐ Lack of financial resources to bring in engineering controls

☐ Lack of specific heat-related guidelines and regulations

☐ Low compliance and implementation of heat stress prevention programs

☐ None

☐ Other ____

17. Do you have any further recommendations or suggestions for the prevention of heat-related illnesses and injuries in Australian workplaces?

____

____

____

____

Thank you very much for taking time to complete the questionnaire.

Please return the completed questionnaire to the box on the reception desk by 3:00 pm on Tuesday (4th December), you will be in the draw to win a $100 prize and $200 for an AIOH sponsored charity.

If you have any queries or interest in this research, please contact me at jianjun.xiang@adelaide.edu.au

Page 4

Appendix J: Information sheets for hygienists

AUSTRALIAN INSTITUTE OF OCCUPATIONAL HYGIENISTS INC
30th ANNUAL CONFERENCE & EXHIBITION

THE UNIVERSITY OF ADELAIDE AUSTRALIA

INFORMATION SHEET

Professional Hygienist Perspectives on Extreme Heat Management in the Workplace

Global warming is likely to lead to more extreme climatic events. The potential impact of climate change has received international attention, and there is a growing body of occupational and environmental hygiene literature on the topic. However, there is a gap in knowledge on the current perspectives and opinions of professional hygienists who provide advice, and particularly in a country where extreme heat episodes are likely to be more common.

Please take 5 minutes to complete the anonymous questionnaire that covers current and future concerns and return in the box at the registration desk by **3:00 pm on Tuesday** (4th December) to be in the draw to **win a $100 Coles-Myer gift voucher and a $200 Christmas donation to an AIOH-sponsored charity**. The findings of the survey will be provided in a forthcoming AIOH Newsletter.

Ethics approval: University of Adelaide (H-111-2011)

Eligibility: AIOH members attending the AIOH 2012 conference

Your participation is greatly appreciated.

For further information, please contact: Jianjun Xiang, Discipline of Public Health, School of Population Health, the University of Adelaide, jianjun.xiang@adelaide.edu.au

Thanks for your contribution to this survey

Appendix K: Abstracts of published manuscripts

Industrial Health 2014, **52**, 91–101

Review Article

Health Impacts of Workplace Heat Exposure: An Epidemiological Review

Jianjun XIANG[1], Peng BI[1]*, Dino PISANIELLO[1] and Alana HANSEN[1]

[1] Discipline of Public Health, School of Population Health, The University of Adelaide, Australia

Received August 31, 2012 and accepted December 11, 2013
Published online in J-STAGE December 21, 2013

Abstract: With predicted increasing frequency and intensity of extremely hot weather due to changing climate, workplace heat exposure is presenting an increasing challenge to occupational health and safety. This article aims to review the characteristics of workplace heat exposure in selected relatively high risk occupations, to summarize findings from published studies, and ultimately to provide suggestions for workplace heat exposure reduction, adaptations, and further research directions. All published epidemiological studies in the field of health impacts of workplace heat exposure for the period of January 1997 to April 2012 were reviewed. Finally, 55 original articles were identified. Manual workers who are exposed to extreme heat or work in hot environments may be at risk of heat stress, especially those in low-middle income countries in tropical regions. At risk workers include farmers, construction workers, fire-fighters, miners, soldiers, and manufacturing workers working around process-generated heat. The potential impacts of workplace heat exposure are to some extent underestimated due to the underreporting of heat illnesses. More studies are needed to quantify the extent to which high-risk manual workers are physiologically and psychologically affected by or behaviourally adapt to workplace heat exposure exacerbated by climate change.

Key words: Climate change, Heat stress, Workplace heat exposure, Health and safety, Work-related injury

Introduction

Many ecological studies have revealed that extremely hot weather contributes to excess morbidity and mortality in the community[1]. Most of the extreme heat-related research has traditionally focused on vulnerable populations including the elderly, children and patients with chronic diseases and those on certain medications[2]. Extremely hot weather also places many types of indoor and outdoor manual workers at increasing risk of heat-related illnesses and injuries[3, 4]. Increased concerns about the environmental heat-related impacts of climate change on population health have been raised since the late 1990s.

Heat gain can be a combination of external heat from the environment and internal body heat generated from metabolic processes. There are two types of external heat exposure sources in the workplace: weather-related and man-made heat exposure. With predicted increasing frequency and intensity of heatwaves, weather-related heat exposure is presenting a growing challenge to occupational health and safety. This article is intended to comprehensively review the characteristics of workplace heat exposure in selected relatively high risk occupations, to summarize findings of published studies, and ultimately to provide suggestions for heat exposure reduction, adaptations, and further research directions.

*To whom correspondence should be addressed.
E-mail: peng.bi@adelaide.edu.au

Appendix K

Xiang, J., Bi, P., Pisaniello, D., Hansen, A. & Sullivan, T. (2013) Association between high temperature and work-related injuries in Adelaide, South Australia, 2001-2010. *Occupational and Environmental Medicine, v. 71(4), pp. 246-252*

NOTE:
This publication is included on page 254 in the print copy of the thesis held in the University of Adelaide Library.

It is also available online to authorised users at:

http://doi.org/10.1136/oemed-2013-101584

Appendix K

Xiang, J., Bi, P., Pisaniello, D. & Hansen, A. (2014) The impact of heatwaves on workers' health and safety in Adelaide, South Australia.
Environmental Research, v. 133, pp. 90-95

NOTE:
This publication is included on page 255 in the print copy of the thesis held in the University of Adelaide Library.

It is also available online to authorised users at:

http://doi.org/10.1016/j.envres.2014.04.042

Appendix L: Journal commentary on a published manuscript based on Chapter 5

Basagana, X. (2014) High ambient temperatures and work-related injuries. *Occupational and Environmental Medicine, v. 71(4), pp. 231*

NOTE:
This publication is included on page 256 in the print copy of the thesis held in the University of Adelaide Library.

It is also available online to authorised users at:

http://doi.org/10.1136/oemed-2013-102031

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