Understanding the Heat-Work Injury Phenomenon in Australia: An Evaluation of Risk, Susceptibility and Attributable Burden

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Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, 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 joint-award of this degree.

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I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

Signed: ……………………………………………………………………….

Blesson Mathew Varghese (Candidate)

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Attributable risk

Case-crossover design

Climate change

Distributed lag non-linear model

Environmental temperature

Health and safety

Heat stress

Heatwaves

Occupational health

Occupational injuries

Perceptions

Worker safety

Workers' compensation claims

Workplace heat exposure

Work-related injuries

Weather

List of Abbreviations and Acronyms

ABS	Australian Bureau of Statistics
ANZSCO	Australia and New Zealand Standard Classification of Occupations
ARC	Australian Research Council
AT	Apparent Temperature
BLS	Bureau of Labor Statistics
BOM	Bureau of Meteorology
CBD	Central Business District
CCO	Case-Crossover
CFMEU	Construction, Forestry, Maritime, Mining and Energy Union
CI	Confidence Interval
°C	Degrees Celsius
CSIRO	Commonwealth Scientific and Industrial Research Organisation
df	Degrees of Freedom
DLNM	Distributed Lag Non-Linear Model
EHF	Excess Heat Factor
EHIacc	Acclimatisation Index
EHIsig	Significant Excess Heat Index
GAM	Generalised Additive Model
GEE	Generalised Estimating Equations
GLM	Generalised Linear Model
HI	Heat Index
HRI	Heat-Related Illness
HSP	Health and Safety Professionals
HSR	Health and Safety Representatives
HW	Heatwave
HWS	Heatwave Warning System
HX	Humidex
ILO	International Labour Organization
IPCC	Intergovernmental Panel on Climate Change
IQR	Inter Quartile Range

IRR	Incidence Rate Ratio
NDS3	National Data Set for Compensation-based Statistics 3rd Edition
NEC	Not Elsewhere Classified
NOC	National Occupation Classification
NSW	New South Wales
OHS	Occupational Health and Safety
OR	Odds Ratio
PPE	Personal Protective Equipment
Qld	Queensland
Rh	Relative Humidity
RR	Relative Risk
SA	South Australia
SR	Global Radiation (W/m^2)
SWA	Safe Work Australia
SWSA	SafeWork SA
TLV	Threshold Limit Value
TOOCS	Type of Occurrence Classification System
TS	Time Series
UK	United Kingdom
UN	United Nations
US	United States
UTCI	Universal Thermal Climate Index
Vic	Victoria
WA	Western Australia
WBGT	Wet Bulb Globe Temperature
WC	Workers' Compensation
WHO	World Health Organization
WHS	Work Health and Safety
WRI	Work-Related Injury
WS	Wind Speed

Abstract

Problem statement

Rising global temperatures along with increased frequency of hot days, warm nights, and more frequent and severe heatwaves, are of concern to the scientific community, policy makers, and the general public. The mortality and morbidity rates in the community often rise on hot days, and during heatwave events. The most vulnerable population subgroups include the elderly and the young, those with chronic conditions, and workers.

Some workers spend a considerable amount of time in environments that are hot due to radiant heat or ambient heat. The generation of metabolic heat from physical exertion adds to the personal heat exposure. Heat-related illnesses (HRIs) arise when the thermoregulatory system is overwhelmed and the balance between heat gain and heat loss is impaired. While HRI is the well documented direct effect of heat on workers' health, research has also shown that exposure to hot environments reduces worker productivity and increases the likelihood of work-related injuries (WRIs). The phenomenon of heat-related injuries may be attributable to heat-induced physiological and behavioural factors interacting with existing workplace hazards. As an indirect effect, the link between hot conditions and WRIs may not be fully appreciated. That said, workplace injury represents a major public health burden in Australia and worldwide, and new insights into injury reduction attract considerable interest.

There exists a need to better understand the heat-work injury phenomenon and the underlying determinants, and the profile of workers at risk. This improved understanding of injuries associated with work in hot conditions will inform evidence-based adaptive strategies, practical guidelines, and tailored interventions to reduce the risk. Such research is also timely given that an increasing number of workers will be exposed to higher temperatures more often in the future, resulting in a greater burden on workers' health and safety in a warmer climate.

Research gap and opportunity

Following a systematised literature review, it was evident that hot conditions increase the risk of WRIs and HRIs in many industry sectors. However, despite Australia's generally hot climate, evidence concerning the relationship between high temperatures and WRI is limited. Furthermore, little is also known about the underlying determinants of these injuries and the prevention practices adopted by workplaces in response to heat exposure. Therefore, the body of research in this thesis is designed to provide important new data and perspectives on injury prevention in hot environments, with potential implications for workers, supervisors, industry representatives, professionals and government.

Purpose statement

The goal of this research is to obtain a better understanding of the heat-work injury phenomenon, thereby contributing to new knowledge that may be useful in reducing the frequency and incidence of workplace injuries. The project aims to achieve this goal by: (1) systematically examining the association between ambient heat and WRI in Australia; (2) exploring the underlying determinants of heat-related work injuries; and (3) exploring stakeholder perspectives regarding prevention and management.

Research questions

1. What is the epidemiology of heat-related injury and how does it vary across Australia?
2. What are the stakeholders' perceptions and experiences of occupational injuries and adaptive strategies adopted to prevent WRI from occurring during hot weather?

Methodology

There are two distinct parts to this research to address the abovementioned research questions. Part 1 consists of the analysis of workers' compensation (WC) claims data and Part 2 consists of surveys of stakeholders.

Part 1. Analysis of workers' compensation claims data

A group of four studies was conducted in Part 1 of the research to investigate the effects of heat on the occurrence of workplace injuries in four Australian cities, namely, Adelaide, Brisbane, Melbourne, and Perth using daily ambient temperature and heatwaves as exposure metrics. Workplace injuries were identified from WC claims data which were obtained from SafeWork SA for data pertaining to Adelaide (2003–2013), and from Safe Work Australia for the other three cities (2005–2016). The WC data were transformed into a daily time-series format and merged with exposure data obtained from the Bureau of Meteorology. Climate data included daily maximum temperature (T_{max}) and heatwave severity categories defined using the Excess Heat Factor (EHF_{sev}: low-intensity, moderate/high-severity). Additionally, thermal composite indices of heat stress such as humidex and apparent temperature that combine relative humidity and temperature, and wet-bulb globe temperature and universal thermal comfort index incorporating relative humidity, wind speed, solar radiation and temperature, were also used in the estimation of injury risk.

City-specific exposure-response curves summarising the relationship between ambient temperatures and WRI were generated utilising a time-stratified case-crossover design combined with a distributed lag-nonlinear model (DLNM) after adjusting for confounding factors such as day of the week and public holidays. Relative risks (RRs) of WRI at moderately hot (90th percentile) and extremely hot (99th percentile) temperatures, compared with a reference temperature were calculated. Finally, attributable fractions were derived to quantify the risk burden of WRI due to ambient temperatures.

Similarly, city-specific associations between heatwaves of varying severity and WRI (restricted to the warm season) were estimated using time-stratified case-crossover design with generalised linear models. Comparisons were made between WRI occurring on heatwave days (defined using EHF_{sev} heatwave categories) and non-heatwave days. Analyses were stratified by worker, work, work environment, and injury characteristics to identify at-risk subpopulations and types of injuries related to heat exposure (T_{max} and EHF_{sev}).

<u>Part 2. Surveys of stakeholders</u>

A group of two studies was conducted in Part 2 of the research which comprised two national online cross-sectional surveys investigating perceptions of key stakeholders (such as health and safety professionals (HSPs) and health and safety representatives (HSRs)) on heat-associated injury risks, determinants, management and prevention. Collected data included perspectives on injury experiences, current preventive measures, workplace training, policies and guidelines, barriers and suggestions for prevention, and productivity loss. Descriptive analysis and log-Poisson regression models were conducted to identify risk factors associated with the reported frequency of injury experience.

Main findings

Part 1. Ambient temperature and WRI

In Adelaide, as the daily T_{max} rose above 25 °C, the risk of WRI also increased. Compared with 25 °C, there was an 8% (RR 1.08; 95% CI: 1.05–1.12) and 30% (RR 1.30; 95% CI: 1.18–1.44) increase in WRI associated with moderately hot temperatures and extremely high temperatures (defined above), respectively. The proportion of WRI attributable to hot temperatures was 2.1% (95% CI: 1.21–2.98%) with moderately hot temperatures responsible for a higher fraction than extremely hot temperatures (1.5% vs 0.6%).

Findings varied for the other three cities. In Melbourne, there was a 5% (RR 1.05; 95% CI: 0.99–1.10) and 14% increase in WRI (RR 1.14; 95% CI: 1.03–1.25) associated with moderately and extremely hot temperatures compared with the median T_{max} of 20 °C, respectively. On the other hand, there were no observed effects in Brisbane or Perth, with the exception of traumatic injuries that increased by 17% (RR 1.17; 95% CI: 1.03–1.35) during extreme heat in Perth. Nevertheless, in all three cities there was a decreased injury risk at cooler temperatures which was greater in Brisbane resulting in a higher attributable fraction of WRI due to temperatures in Brisbane (26.5%) than in Perth (5.7%) and Melbourne (1.9%).

Who is affected?

Associations between extreme heat and WRI were observed among several groups of workers in Adelaide. These included males and females, and both young workers (15–24 years), and experienced workers. Specific occupations affected included food service and warehouse workers, workers in medium-strength (somewhat physically demanding) occupations, workers in regulated indoor climates, and industries such as 'electricity, gas and water' and 'transport and storage'. In Melbourne, young workers, female workers, workers in regulated indoor climates, and workers 'in a vehicle/cab', workers in medium-strength occupations, and those in indoor industries were identified to be at-risk of heat-related injuries.

What types of injuries occur in hot conditions?

The types of injuries that significantly increased in Adelaide during moderate and extreme heat were: burns, wounds, lacerations and amputations, along with injuries resulting from vehicle incidents, 'heat, electricity and other environmental factors' and 'chemical and other substances'. In Melbourne, the types of injuries associated with heat exposure were: traumatic injuries and injuries from 'being hit by moving objects'. Injuries attributed to 'heat, electricity and other environmental' factors and 'mental stresses' also increased at extremely high temperatures in Melbourne.

<u>Part 1. Heatwaves and WRI</u>

Uniform impacts of heatwaves were observed in Brisbane (subtropical climate) and Melbourne, Perth and Adelaide (temperate climates). For three cities (Brisbane, Melbourne and Perth), there was either a small-reduction in risk or a null effect during heatwaves of low-intensity. However, injury risk increased consistently across the four cities during moderate/high-severity heatwaves with the highest effect estimate evident in Brisbane (RR 1.45; 95% CI: 1.42–1.48), followed by Adelaide (RR 1.31; 95% CI: 1.28–1.34), Perth (RR 1.26; 95% CI: 1.24–1.29) and Melbourne (RR 1.25; 95% CI: 1.22–1.28).

Who is affected during heatwaves?

Stratified analysis by worker characteristics identified highest associations between heatwaves of moderate/high-severity and the risk of WRI among male workers, workers aged up to 24 years, apprentice/trainee workers, new workers, and workers working through labour hire firms. When physical demands of the occupation were taken into account, workers employed in the medium-strength and heavy-strength (physically demanding) occupations were at increased risk of WRI during moderate/high-severity heatwaves. Workers in regulated indoor climates and 'in a vehicle or cab' environments were also at risk of WRI. Stratified analyses according to industrial sectors identified positive associations in both outdoor and indoor industries.

What types of injuries occur during heatwaves?

Injury claims that significantly increased across the four cities during moderate/high-severity heatwaves included those for traumatic injuries, 'mental health' and injuries from 'body stressing', 'chemicals and other substances' and 'falls, trips, and slips of a person'.

<u>Part 2. Stakeholder perceptions</u>

In total there were 307 HSPs who completed the first survey, the majority (74%) of whom acknowledged the potential for increased risk of occupational injuries in hot weather. A variety of injury types and mechanisms were reported, including manual

handling injuries, hand injuries, wounds or lacerations, loss of control of power tools, fatigue, and dehydration.

Work factors significantly associated with reported injuries included problems with heat-retentive personal protective equipment (PPE); lack of shade for workers; inadequate hydration and rest breaks, and problems with supervision. Whereas ceasing outdoor work when temperatures are extreme can be a preventive measure, only 54% of HSPs reported this occurring in workplaces they visited or managed. Furthermore, less than half (42%) stated the availability of adequate heat training for staff. Reported barriers for prevention included: lack of awareness by workers and supervisors of injury risks, and management concerns about productivity loss and/or deadlines.

A second survey was conducted among workplace HSRs. In total, 222 HSRs completed the survey. Overall, 43% of respondent reported that injuries or incidents caused by hot/very humid weather occur sometimes/often in their workplace. Factors found to be associated with these injuries included 'the wearing of PPE', 'inadequate resources and facilities' and being a new worker. For outdoor workers, the most frequently adopted preventive measures were provision of PPE, sunscreen and access to cool drinking water. HSRs reported more injuries if certain preventive measures (i.e. rescheduling work to cooler times and shaded rest/work areas) were adopted never/rarely/sometimes. Access to cool drinking water and provision of PPE were the most frequently adopted preventive measures for indoor workers. HSRs reported that more injuries occurred if self-pacing, shielding of heat sources and adequate ventilation were adopted never/rarely/sometimes.

Implications of findings

Part 1. Ambient temperature and WRI

The findings from this research show that WRI do not only occur in extreme temperatures but also during moderate temperatures and that the risks apply to both outdoor and some indoor workers. Interestingly, in Adelaide which had the greatest risks, the burden of WRI was substantially higher during moderate hot temperatures than extremes. This finding suggests that while extremely hot temperatures that rarely occur are dangerous for workers, the risks during the more common hot days should not be ignored. On the other hand, a higher burden of WRI was seen in Brisbane than in Melbourne and Perth. This finding has implications for the future as extreme hot days become more frequent. This study clearly indicates that increasing exposure to higher temperatures poses a risk for workers' health and safety.

Part 1. Heatwaves and WRI

The consistency in the impacts of moderate/high-severity heatwaves on WRI across study sites suggest that it is not only severe heatwaves (during which work may cease) that are cause for concern. Forecasts for moderate-severity heatwaves, based on EHF, should also signal the need for heightened heat awareness and preventive measures, to minimise the risks to workers in Australian workplaces.

Part 2. Stakeholder perceptions

The stakeholder evidence suggest that the burden of heat-related work injuries could be reduced by wider adoption of prevention measures such as work rescheduling, self-pacing, provision of shade and adequate ventilation. There

should also be an increased awareness of heat as an occupational hazard, particularly with regard to injury occurrence and modifiable risk factors.

The integration of multiple lines of evidence (Parts 1 and 2) suggests that underlying mechanisms of injuries in hot weather are complex and multi-factorial.

Strengths and weaknesses

There are a number of strengths of this research. Firstly, the research has evaluated the risk and susceptibility of workers and quantified the associated attributable burden of heat and WRI across four Australian cities with diverse climate and worker profiles. This is the first time such an extensive multi-city study has been conducted in Australia on heat-related work injuries and their determinants. A unique multiple data source approach was used to address the research questions, combining both complex statistical models incorporating administrative data, and surveys of key stakeholders. A novel standard heatwave definition across the study sites, and classifications of indoor/outdoor workers by occupation, were incorporated in the estimation of injury risk, adding to the rigour of the study methods. The multiple data source approach yielded a triangulation of findings with the outcomes of surveys supporting and supplementing the major findings of the analysis of the WC data.

This research also has a number of limitations. The WC data have inherent limitations in the identification of WRI, as not all workers who are injured lodge a claim. Therefore these data can underestimate the true burden of WRI due to under-reporting. Weather data were assessed at an aggregate level using data from only one monitoring station per study site. Additionally, being an ecological study, personal exposures could not be ascertained. These factors can therefore introduce exposure misclassification. Similarly, surveys may produce biased results if only

certain sections of stakeholders (such as those particularly interested in the topic) respond. Furthermore, self-reported responses may introduce recall or reporting bias. Nevertheless, this study has added considerably to the body of knowledge of heat and WRI and may provide valuable evidence for policymakers and workplaces moving forward as heat exposure becomes a greater hazard for exposed workers.

Novelty

This is the first Australian investigation to utilise a multiple data source approach to systematically examine the epidemiology and specific determinants of heat-related work-injury occurrence.

Conclusions

The findings showed while the highest extreme temperatures have the greatest risk, WRI can also occur on moderate-hot days which are more common and therefore have the greatest burden. The findings also identified a range of modifiable risk factors for injuries. These can be associated with the work (e.g. PPE, no shade), the worker (e.g. lack of awareness) and organisational issues (e.g. poor supervision and lack of training).

Recommendations

Based on the findings from this body of research, it is evident that a holistic approach is needed to address the risks of injuries associated with work in hot conditions. The following recommendations are made for jurisdictional safety regulators and policy makers, employers, and manufacturers of PPE.

- It is recommended that there be awareness raising at both the employer and the worker levels, that the health risks of working in hot environments includes injuries as well as HRIs.
- It is recommended that workplaces be aware of forecasted heatwaves (moderate or severe) so that plans, policies and preventive measures can be enacted in advance to minimise risks to the health and safety of workers.
- It is recommended that workplaces examine the potential interaction between existing hazards and heat induced physiological and behavioural effects.
- As some PPE can impair heat loss, and alter behaviour, it is recommended that that research is done on improving PPE comfort and suitability for hot conditions.

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Dedication

This thesis is dedicated to my loving family in Australia and India.

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Publications During Candidature

Publications contributing to this thesis

Published

1. **Varghese BM**, Hansen AL, Bi P, Pisaniello DL. Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review. *Safety Sci* (Impact factor: 3.619). 2018, 110 (A), 380–392.
2. **Varghese BM**, Barnett AG, Hansen AL, Bi P, et al. The effects of ambient temperatures on the risk of work-related injuries and illnesses: Evidence from Adelaide, Australia 2003–2013. *Environ Res* (Impact factor: 5.026). 2019, 170, 101-109.
3. **Varghese BM**, Hansen AL, Nitschke MN, Nairn J, et al. Heatwave and work-related injuries in Adelaide, Australia: using the Excess Heat Factor (EHF) as a universal heatwave index. *Int Arch Occup Environ Health* (Impact factor: 2.025). 2019, 92 (2), 263-272.
4. **Varghese BM**, Barnett AG, Hansen AL, Bi P, et al. Characterising the impact of heatwaves on work-related injuries and illnesses in three Australian cities using a standard heatwave definition—Excess Heat Factor (EHF). *J Expo Sci Environ Epidemiol* (Impact factor: 3.025), 2019
5. **Varghese BM**, Barnett AG, Hansen AL, Bi P, et al. Geographical variation in risk of work-related injuries and illnesses associated with ambient temperatures: A multi-city case-crossover study in Australia, 2005–2016. *Sci Total Environ* (Impact factor: 5.589). 2019, 687, 898-906.

Manuscripts in draft

6. **Varghese BM**, Hansen AL, Williams S, Bi P, et al. Determinants of heat-related injuries in Australian workplaces: perceptions of health and safety professionals. (Revisions Submitted).
7. **Varghese BM**, Hansen AL, Williams S, Bi P, et al. Heat-related injuries in Australian workplaces: perspectives from health and safety representatives.(Revisions Submitted).

Other relevant manuscripts

1. Hansen AL, Pisaniello DL, **Varghese BM**, Rowett S, et al. What Can We Learn about Workplace Heat Stress Management from a Safety Regulator Complaints Database? *Int J Environ Res Public Health* (Impact factor: 2.468). 2018; 15(3), 459.
2. Hansen AL, Williams S, Hanson-Easey S, **Varghese BM**, et al. Using a qualitative phenomenological approach to inform aetiology and prevention of workplace heat-related injuries: Lessons learned from Australia. (Revisions Submitted).
3. Williams S, **Varghese BM**, Hansen AL, Hanson-Easey S, et al. Workers' health and safety in the heat: current practice in Australian workplaces. (Revisions Submitted).

Presentations Arising from This Thesis

International conferences

1. **Varghese BM**, Barnett AG, Hansen AL, Bi P, Pisaniello DL. The effects of ambient temperature on work-related injuries in Adelaide, Australia—workers' compensation claims increase with high temperatures *(Oral presentation)*. The 32nd International Congress on Occupational Health (ICOH), Dublin, Ireland, 2018.
2. **Varghese BM**, Hansen AL, Bi P, Pisaniello DL. The impact of Heatwaves on workers' health and safety in Australia: A multi-city study *(Poster presentation)*. The 2018 Joint Annual Meeting of the International Society of Exposure Science (ISES) and International Society for Environmental Epidemiology (ISEE), ISES-ISEE Conference, Ottawa, Canada, 2018.
3. **Varghese BM**, Hansen AL, Williams S, Bi P, Pisaniello DL. Heat and Injury in the Workplace: Perspectives from Health and Safety Representatives *(Oral presentation)*. The 27th International Epidemiology in Occupational Health (EPICOH) Conference, Wellington, New Zealand, 2019.
4. **Varghese BM**, Pisaniello DL, Hansen AL, Williams S, Bi P. Exploring Occupational Injury Experiences during Hot Weather: A National Survey of Health and Safety Professionals *(Oral presentation)*. The 27th International Epidemiology in Occupational Health (EPICOH) Conference, Wellington, New Zealand, 2019.
5. **Varghese BM**, Pisaniello DL, Hansen AL, Barnett AG, et al. Insights into the epidemiology of heat-related work injuries: a mixed-methods analysis of workers' compensation claims and stakeholder perspectives *(Thematic*

Poster presentation). The 31st conference of the International Society for Environmental Epidemiology (ISEE), Utrecht, Netherlands, 2019.

National conferences

1. **Varghese BM**, Barnett AG, Hansen AL, Bi P, Pisaniello DL. Do temperature extremes pose risk to workers' injury risk? (*Oral presentation)*. The 30th Annual Scientific Meeting of the Australasian Epidemiological Association (AEA), Sydney, Australia, 2017.
2. **Varghese BM**, Barnett AG, Hansen AL, Nitschke M, et al. Are moderate heatwaves more important than severe heatwaves for worker injury risks? *(Poster presentation)*. National Climate Change Adaptation Research Facility (NCCARF) Climate Adaptation Conference, Melbourne, Australia, 2018.
3. **Varghese BM**, Barnett AG, Hansen AL, Bi P, Pisaniello DL. The impact of ambient temperatures on work-related injuries in three Australian cities *(Mini oral presentation)*. The 31st Annual Scientific Meeting of the Australasian Epidemiological Association (AEA), Fremantle, WA, Australia, 2018.
4. **Varghese BM**, Hansen AL, Nairn J, Bi P, Pisaniello DL. Heatwaves and work-related injuries in Australia: A multi-city study *(Oral presentation)*. The 31st Annual Scientific Meeting of the Australasian Epidemiological Association (AEA), Fremantle, WA, Australia, 2018.

Local conferences

1. **Varghese BM**, Barnett AG, Hansen AL, Nitschke M, Nairn J, Bi P, Pisaniello DL. Are moderate heatwaves more important than severe heatwaves for worker injury risks? *(Poster presentation)*. The Florey Postgraduate Research Conference, The University of Adelaide, Australia, 2017.
2. **Varghese BM**, Barnett AG, Hansen AL, Bi P, Pisaniello DL. Both low and high temperature may increase the risk of work-related injuries—an assessment using case-crossover analysis in Adelaide, Australia *(Oral presentation)*. The Public Health Association of Australia (PHAA) SA State Population Health Conference, Adelaide, Australia, 2017.
3. **Varghese BM**, Barnett AG, Hansen AL, Nitschke M, Nairn J, Bi P, Pisaniello DL. Are moderate heatwaves more important than severe heatwaves for worker injury risks? *(Oral presentation).* The Public Health Association of Australia (PHAA) SA State Population Health Conference, Adelaide, Australia, 2017.
4. **Varghese BM**, Hansen AL, Nairn J, Bi P, Pisaniello DL. Characterising the impact of heatwaves on work-related injuries in three Australian cities: When is it unsafe to work? *(Poster presentation)*. The Florey Postgraduate Research Conference, The University of Adelaide, Australia, 2018.
5. **Varghese BM**, Hansen AL, Williams S, Bi P, Pisaniello DL. Occupational injuries during hot weather: perspectives from health and safety representatives *(Oral presentation)*. The Public Health Association of Australia (PHAA) SA State Population Health Conference, Adelaide, Australia, 2018.

6. **Varghese BM**, Hansen AL, Williams S, Bi P, Pisaniello DL. Risk factors for heat-related injuries: survey of work health and safety professionals *(Poster presentation)*. The Public Health Association of Australia (PHAA) SA State Population Health Conference, Adelaide, Australia, 2018.
7. **Varghese BM**, Pisaniello DL, Hansen AL, Barnett AG, et al. Insights into the epidemiology of heat-related work injuries: a mixed-methods analysis of workers' compensation claims and stakeholder perspectives *(Poster presentation)*. The Florey Postgraduate Research Conference, The University of Adelaide, Australia, 2019.

Stakeholder engagement

A National Heat and Work Injury Workshop was held in Adelaide (Oct 17th 2018) as the final stage of the Heat and Work Injury Project led by Professor Dino Pisaniello, and funded by the Australian Research Council (ARC). Presentations of key research findings were given (see below) followed by discussions with a wide stakeholder group (workers, industry, unions and employers, safety professionals, researchers and regulatory bodies) on the implications of the research for policy, training, risk assessment, and to develop a set of evidence-based recommendations for the prevention of work-related injuries in hot conditions.

Presentation: **Varghese BM**. The effects of daily maximum temperature and heatwaves on worker injury risks and perspectives from workplace health and safety representatives and professionals. Heat and Work Injury National Workshop, Adelaide, Australia, 2018.

The resulting outcome from the workshop was summarised in the Workshop Proceedings document circulated to all attendees.

Output: Pisaniello DL, Hansen AL, **Varghese BM** & Williams S. Understanding and preventing injuries in hot working conditions. Proceedings of a National Workshop on Heat and Work Injury, Adelaide, Australia, 2018. https://figshare.com/articles/Proceedings_of_National_Heat_and_Work_Injury_Workshop_Adelaide_October_17_2018/7451387

Media coverage

Research findings from two of my studies (Chapters 4 and 6) were covered in this media story by the Advertiser, a daily tabloid format newspaper published in Adelaide, South Australia, 2019. https://www.adelaidenow.com.au/news/south-australia/university-of-adelaide-research-to-help-authorities-get-the-heatwave-message-across/news-story/6500d8af51dacaf86d4873b839da87fb

Other invited presentations

1. **Varghese BM**. The effects of daily maximum temperature and heatwaves on worker injury risks in Adelaide.
    a. Presentation to the Bachelor of Health and Medical Science third year students, The University of Adelaide, Australia, 2017.
    b. Presented at the Heat and Injury Seminar, National Safe Work Month, Safe Work SA, Adelaide, Australia, 2017.
    c. Presented at the SA Health Data Analysis Group (DAG) Meeting, Adelaide, Australia, 2018.
2. **Varghese BM**. Heat and work injury research.
    a. Presentation to the Master of Public Health students. The University of Adelaide, Australia, 2019.
    b. Presented to the study group at the Department of Public Health, University of Helsinki, Helsinki, Finland, 2019.

Awards and Achievements

Date	Type	Title	Institution Name
2019	Scholarship	Phil Ryan Travelling Scholarship	Phil Ryan
2019	Scholarship	Walter and Dorothy Trust Scholarship	Walter and Dorothy Trust
2018	Award	2018 Graduate Women SA Centenary Bursaries Award	The Australian Federation of University Women—SA Inc. Trust
2018	Award	2018 Florey Postgraduate Research Conference School of Public Health Poster Prize	The University of Adelaide
2018	Award	2018 AEA Student Award	Australasian Epidemiological Association (AEA)
2018	Award	People’s Choice Award for oral presentation at the Annual Meeting of AEA	Australasian Epidemiological Association (AEA)
2018	Scholarship	Global Learning Travel Grant	The University of Adelaide
2018	Scholarship	Climate Adaptation 2018 Post-Graduate Student Travel and Registration Scholarship	National Climate Change Adaptation Research Facility (NCCARF)
2017	Award	2017 Florey Postgraduate Research Conference School of Public Health Poster Prize	The University of Adelaide
2016–2019	Scholarship	Faculty of Health and Medical Sciences Divisional Scholarship	The University of Adelaide

Other achievements

- Shortlisted for ‘Research and Business Partnerships prize for Impact, Engagement and Translation’—The University of Adelaide
- Special mention on oral presentation at the State Population Health Conference 2018— Public Health Association of Australia (PHAA)

01

Chapter 1: Introduction

1.1 PREFACE

It has long been recognised that excessive heat exposure can cause harm to workers. Work in hot conditions can lead to heat-related illnesses (HRIs) and in severe cases, deaths. Besides these direct effects, there is now increasing evidence that occupational heat stress is strongly associated with injuries. As an indirect effect of heat exposure, the occurrence of occupational injuries in hot weather conditions may not be fully recognised. That said, workplace injury represents a major public health burden in Australia and worldwide, and new insights into injury reduction attract considerable interest. Therefore, understanding this important phenomenon and developing relevant preventive/adaptive strategies represents the basis of this research.

This chapter outlines the background to the body of research underpinning this thesis and summarises the health impacts of heat exposure in the community and on workers. Furthermore, this chapter discusses the need to investigate heat-associated occupational injuries in the context of a changing climate and global warming. The chapter concludes by outlining the overarching aims and the structure of the thesis.

1.2 BACKGROUND

'Whoever would study medicine aright must learn of the following subjects. First, he must consider the effect of each of the seasons of the year and the differences between them. Secondly, he must study the warm and the cold winds, both those which are common to every country and those peculiar to a particular locality....'

Hippocrates, '*Airs, Waters, Places*', 400 BC[1]

These words written by Hippocrates, the father of modern medicine, more than 2500 years ago which, even then highlighted the need to understand the influence of environmental factors on the health of populations in a locality.[2] Some 24 centuries later there is still great interest among scientists, health professionals, public policymakers and the general public, in unpacking the impacts of temperature on health.[2] This interest is continually growing with concerns associated with increasing global average temperatures and temperature extremes due to climate change (discussed in Section 1.5). The next section provides a summary of health impacts experienced due to heat exposure, both at a population and at an occupational level.

1.2.1 Heat impacts on health

Humans are homeothermic, meaning that their internal core body temperature is regulated to keep it nearly stable within a very narrow range around 37 °C. Changes in body temperature can occur from hour to hour and even day-to-day due to the impact of heat produced as a result of work performed or that gained from external environmental conditions. However, these fluctuations are usually not more than 1 °C as under normal circumstances, the increase in core body temperature is managed by the body up to a limit through a process called thermoregulation (elaborated on more detail in Chapter 2).[3] Briefly, this process involves the exchange of heat input and output between the body and the environment, ensuring a balance. This can be described mathematically using the heat balance equation:

$$M – W = E + R + C + K + S$$

On one side of the equation are factors contributing to heat gain (M: metabolic rate and W: mechanical work). On the other side of the equation are factors related to heat loss (E: evaporation, C: convection, K: conduction, R: radiation) and the rate of heat storage (S). When balance is achieved between heat gained and heat lost, the rate of heat storage becomes zero and body temperature remains stable.[3]

Generally, the health impacts of extreme heat arise when the body fails to regulate its temperature and when the heat balance is impaired.[3] HRIs such as heat cramps, syncope, fatigue, heat exhaustion, and heat stroke are well-known and documented direct adverse effects of heat exposure.[4] Some of these outcomes may initially manifest as feeling of discomfort and may progress further with the intensity of exposure. Besides HRIs, exposure to high temperatures can exacerbate chronic conditions and diseases such as, diabetes-related conditions, cardiovascular, renal, respiratory, and cerebrovascular diseases, as well as mental health conditions. Epidemiological studies have shown that mortality/morbidity rates in the community rise progressively with temperature and decrease at temperatures within a ‘comfort zone' (i.e. between 15 °C and 25 °C).[5-7] This relationship between ambient temperature and risk of health outcomes is often described as a U, V, or J-shaped curve. However, the nadir of the curve or ‘comfort zone’ is place-specific and varies geographically with a greater heat effect in cooler locations and a greater cold effect in warmer locations.[8-10] This variation depends on the climate and the local population's adaptation to the typical range of temperatures through physiological, behavioural, cultural, and technological responses.

While everyone in the population is vulnerable to extreme heat, some are more so than others, depending on the level of exposure, individual susceptibility, and levels of resilience.[11] People at both ends of the age spectrum, those of lower socio-economic status and from culturally and linguistically diverse groups, those with disability, pre-existing and chronic morbidities (respiratory, cardiovascular, renal, and mental), and residents of cities have a higher risk of heat-related morbidity and mortality.[5, 12-15] Furthermore, research has also shown that mortality and morbidity rates increase during extended periods of hot weather or heatwave events.[16, 17] Several heatwaves have attracted public interest due to the adverse impacts they imposed on health. Examples include major heatwaves in Chicago (1995), across Europe (2003), Australia (2009, 2014), and Russia (2010).[18-23] These heatwave events have led to the development of interventions and strategies targeted at the previously mentioned vulnerable sub-populations.

As many workers can be exposed to high environmental temperatures as part of their job, they are a subgroup who can also be impacted by increasing temperatures and heatwaves.[24-26] The heat-related injury risk to these workers is the central focus of this thesis. Concomitant with the importance of studying the impact of heat exposure on population health, research around the impacts on occupational health is gaining in importance.

1.2.2 Impacts of heat on occupational health

As mentioned previously, the recognition that heat can harm workers' health is not new, and for many occupations, it remains a clear and significant safety hazard.[4, 26-

[32] Unlike the general population, some workers are more vulnerable to the impacts of rising heat due to the considerable amount of time they spend in hot environments and the nature of their jobs.[26] These hot environments can be due to ambient heat, or the heat generated from machinery, or a combination of both.[33] The generation of metabolic heat from physical exertion further adds to personal heat exposure. Additionally, poorly designed workplaces and the clothing requirements for certain occupations also pose risks for some workers.[29] The nature of work carried out may influence whether or not the individual worker is able to adopt behavioural protective measures such as taking rest, self-pace, seeking shade, or drinking water.[32] Industrial sectors such as agriculture, forestry, fisheries, utility, transportation, and construction are places where workers are exposed to a combination of higher outside temperatures, radiant heat, humidity, and heavy physical labour, making them particularly vulnerable.[33-36] Furthermore, those working in hot indoor environments without air-conditioning such as manufacturing, smelting plants, bakeries, laundries, and restaurant kitchens can also be affected.[25, 33]

The potential health effects arising from environmental heat exposure can be classified as direct and indirect and may be acute or chronic in nature.[24] Examples of direct impacts include renal diseases in workers manifesting as acute kidney injury[37, 38] or chronic kidney disease [39] which have been identified among agricultural workers and manual labourers in Central America. Research has also shown that exposure to high ambient temperatures reduces worker productivity,[40] mental task capacity,[41] and increases the risk of occupational injuries,[42-45] which are examples of indirect effects of workplace heat exposure.

1.3 WORK-RELATED INJURIES

Injuries that arise during employment, known as work-related injuries (WRIs), are a substantial public health burden in Australia and worldwide. According to the International Labour Organization (ILO), WRI is experienced by 153 workers worldwide, every 15 seconds.[46] This equates to about 6400 deaths from WRI and 860,000 being injured on the job every day amounting to over 2.3 million lives lost. In Australia, it was estimated that the total economic cost of WRIs was 4.1% of the GDP ($61.8 billion) for the 2012–2013 financial year.[47]

Several factors including the nature of work, workplace hazards (i.e. physical, work organisation, and psychosocial) along with individual factors such as age, gender, and health status, contribute to the risk of WRI.[48] However, WRI are often preventable if safety control measures are in place. Therefore, identification of hazards and assessment of associated risks and vulnerable workers remains crucial so that appropriate prevention strategies can be adopted.

1.4 HOW DO WORK-RELATED INJURIES OCCUR IN HOT WEATHER?

As physical workplace hazards are a risk factor for WRI, it is plausible that exposure to hot weather may lead to increased risk. Although a direct biological mechanism is not present, it is possible that WRI can occur in hot weather as a part of the progression of health effects along a continuum. Figure 1.1 shows that there are many cases of initial signs of heat stress due to heat exposure and progressively fewer incidences of more serious consequences such as heat stroke and ultimately death. When a worker is heat stressed, they can become fatigued and lethargic resulting in a reduction in fine motor skills, coordination, alertness and general productivity. These effects can lead to a loss of concentration, alter behaviour, and increase the rate of mistakes resulting in injuries, such as, falls and traffic accidents.[49] Workers may also reduce their use of personal protective equipment (PPE) because of discomfort, and there may be changed work practices due to hot surfaces/equipment, and grip loss or visibility problems due to perspiration.[50] In hot conditions WRI can occur in addition to, secondary to, or even before, HRI.[50] However, more information is needed to better understand the heat-WRI phenomenon which can inform evidence-based adaptive strategies and interventions to reduce the risk.

Figure 1.1 Progression of health effects of heat-related illness and work-related injuries from minor symptoms to death.

Source: Adapted and redrawn from Corletto RD.[51]

1.4.1 Extent of the work-related injury problem in hot weather

Reports from three countries (United States [US], Canada, and Australia) provide some indication of the extent of the issue of injury associated with work in hot conditions.

Firstly, according to the US Bureau of Labor Statistics (BLS), there have been 1,113 worker deaths in the US between 1992 and 2017 associated with 'contact with temperature extremes', a category encompassing exposure to environmental heat and cold, and contact with hot objects and cold objects.[52-67] However, the majority of the deaths (815 deaths) were due to exposure to environmental heat (Figure 1.2A). The corresponding figures in Canada and Australia were 69 deaths (1996–2017)[68] and 53 deaths (2003–2016),[69] respectively, with the majority due to 'contact with hot objects'.

Besides fatalities, non-fatal occupational injuries and illnesses that involved lost days of work associated with temperature extremes have also been documented, ranging from 41,374 in Australia (1996–2017)[70-72] to over 600,000 in the US (1992–2017) [52-67, 73-98]. The majority of these non-fatal injuries in these three countries were due to 'contact with hot objects' (Figure 1.2B). Combined, these deaths and injuries represent less than 2% of total fatalities and claims associated with temperature extremes, with the proportion attributed to 'exposure to environmental heat' constituting less than 1%.

However, it is possible that the issue of WRI related to heat is under-recognised. This is because of the multi-factorial aetiology whereby the phenomenon of heat-related injuries may be attributable to heat-induced physiological and behavioural factors interacting with existing workplace hazards as discussed earlier in Section 1.4.[50] For example, if a heat-stressed worker has a fall on a hot day the cause will most likely to be recorded as a slip with no mention of the underlying symptoms of heat stress that may have contributed to the fall. As a result, the relative incidence or attributable burden of heat-related WRI is unknown.

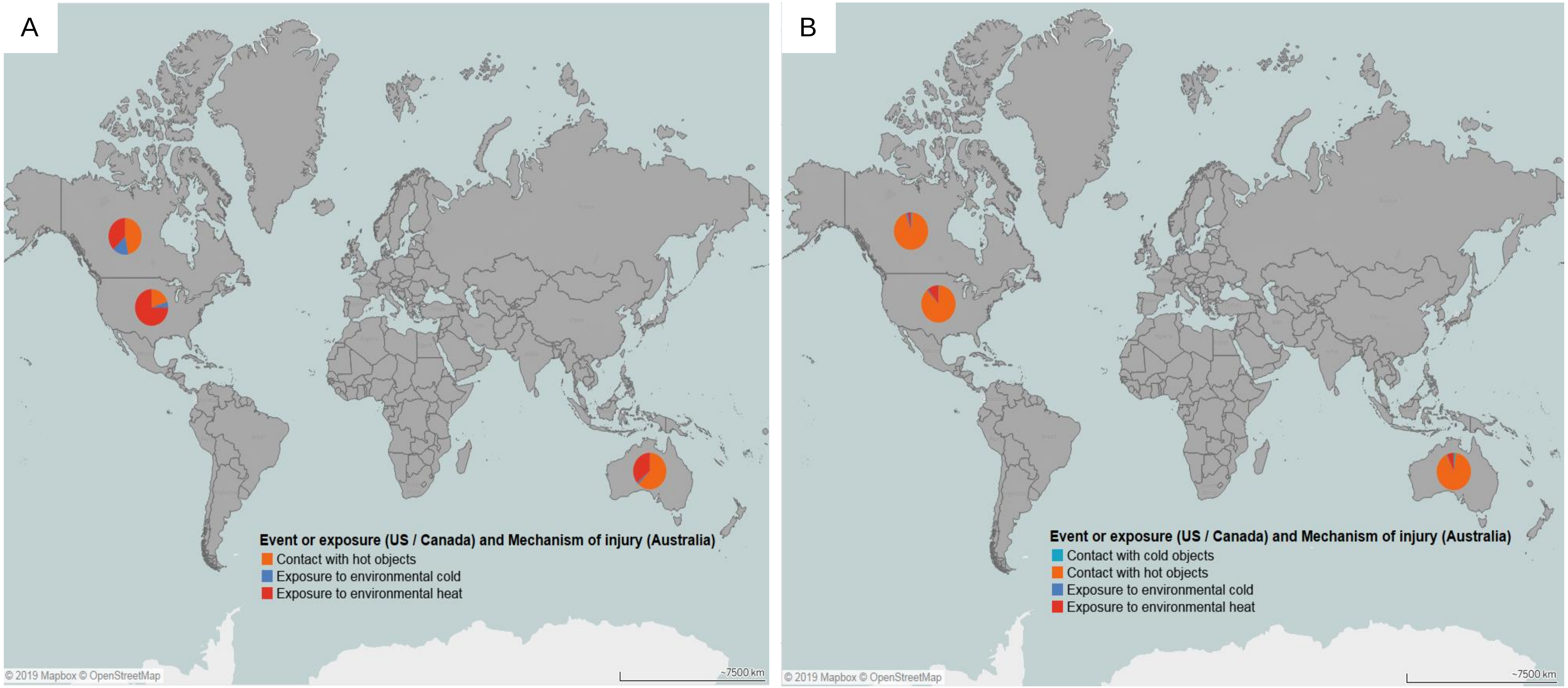


Figure 1.2 Fatal (A) and non-fatal (B) cases of occupational injuries and illnesses by event or exposure (temperature extremes—US and Canada) and mechanism of injury ('heat, electricity and other environmental factors'—Australia).

Sources: Data were extracted and drawn from US BLS (1992–2017);[52-67, 73-98] Canada AWCB (1996–2017);[68] Safe Work Australia (SWA, fatal data: 2003–2016; non-fatal data: 1996–2017).[69-71, 99]

1.5 INFLUENCE OF GLOBAL WARMING ON OCCUPATIONAL HEALTH

The previous sections have shown that workers' health and safety can be affected by hot weather conditions. Given that the climate is warming it is now of growing importance to understand the influences of heat on occupational health.

1.5.1 Global assessment of a changing climate

The World Health Organization (WHO) has recognised 'climate change as one of the leading global health threats of the 21st century'.[100] According to the Intergovernmental Panel on Climate change (IPCC) report, the occurrence of extreme weather events (e.g. heat, floods, cyclone, and droughts) has increased in frequency, intensity, duration and timing in recent decades.[101] Among all the intense weather events, the most robust observed evidence is regarding extreme heat events which have increased since the 1950s.[102]

Human actions such as deforestation and the burning of fossil fuels have increased the proportion of greenhouse gases in the atmosphere resulting in heat being trapped in the lower atmosphere.[103] As a result the global average temperatures have risen about 0.85 °C over the last 100 years (Figure 1.3) and projections based on a trajectories of greenhouse gas concentrations (i.e. representative concentration pathways) suggest that this temperature rise will reach 1.8 °C–4 °C by 2100.[104] With a greater than 90% probability, the IPCC notes that there has been an increase in the overall number of warm days and nights and a decrease in the number of cold days and nights observed globally since the 1950s.[101] At a continental scale, most of these impacts have occurred in North America, Europe, and Australia.

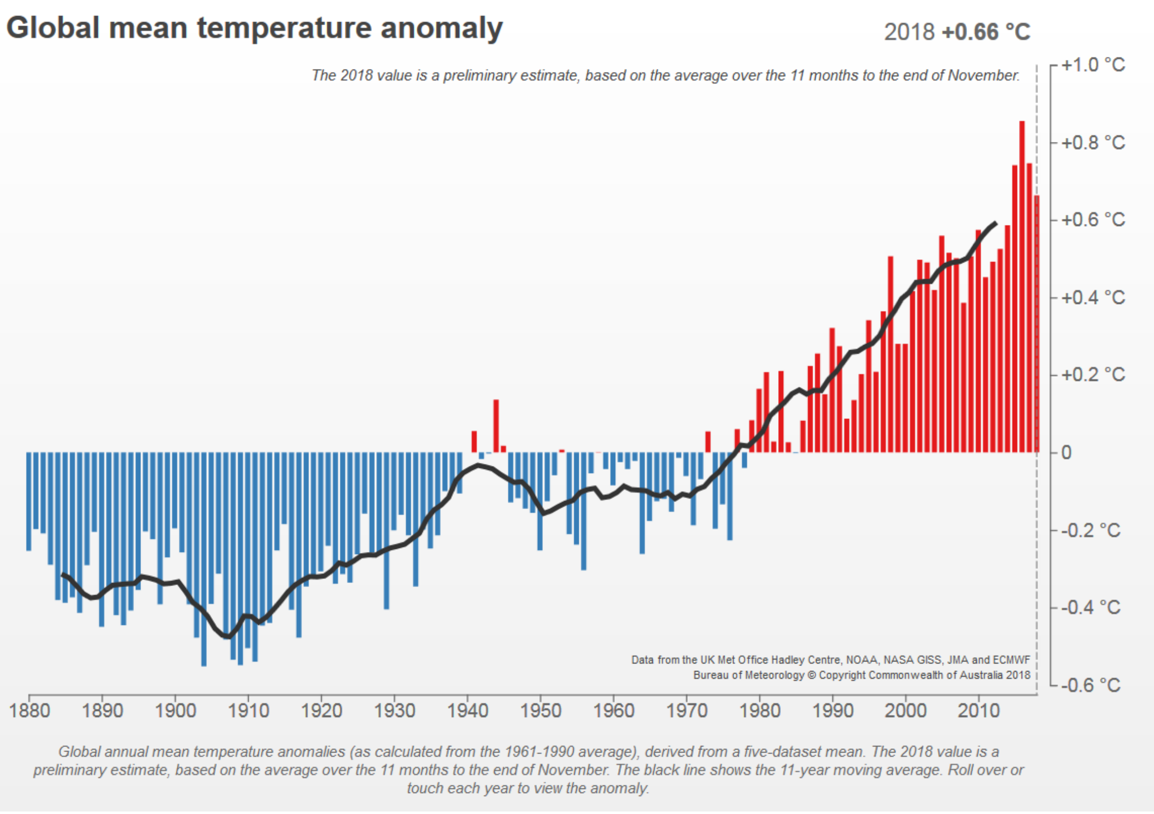


Figure 1.3 Global annual mean temperature anomaly (1880–2018).

Source: Australian BOM[105] (used under Creative Commons Attribution Australia Licence).

1.5.2 Australian assessment of a changing climate

Consistent with the global trend, the mean surface air temperature across Australia has warmed by over 1.1 °C since 1910 and this trend has become more evident since the 1970s (Figure 1.4). As future temperatures depend on greenhouse gas emissions, projections by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology (BOM) indicate that by 2030, Australian temperatures could rise by 0.6 °C–1.5 °C compared to the climate of 1980–1999. Temperatures are projected to be 1.0 °C–2.5 °C under low greenhouse gas emissions scenarios and 2.2 °C–5 °C for high greenhouse gas emissions by 2070.[106]

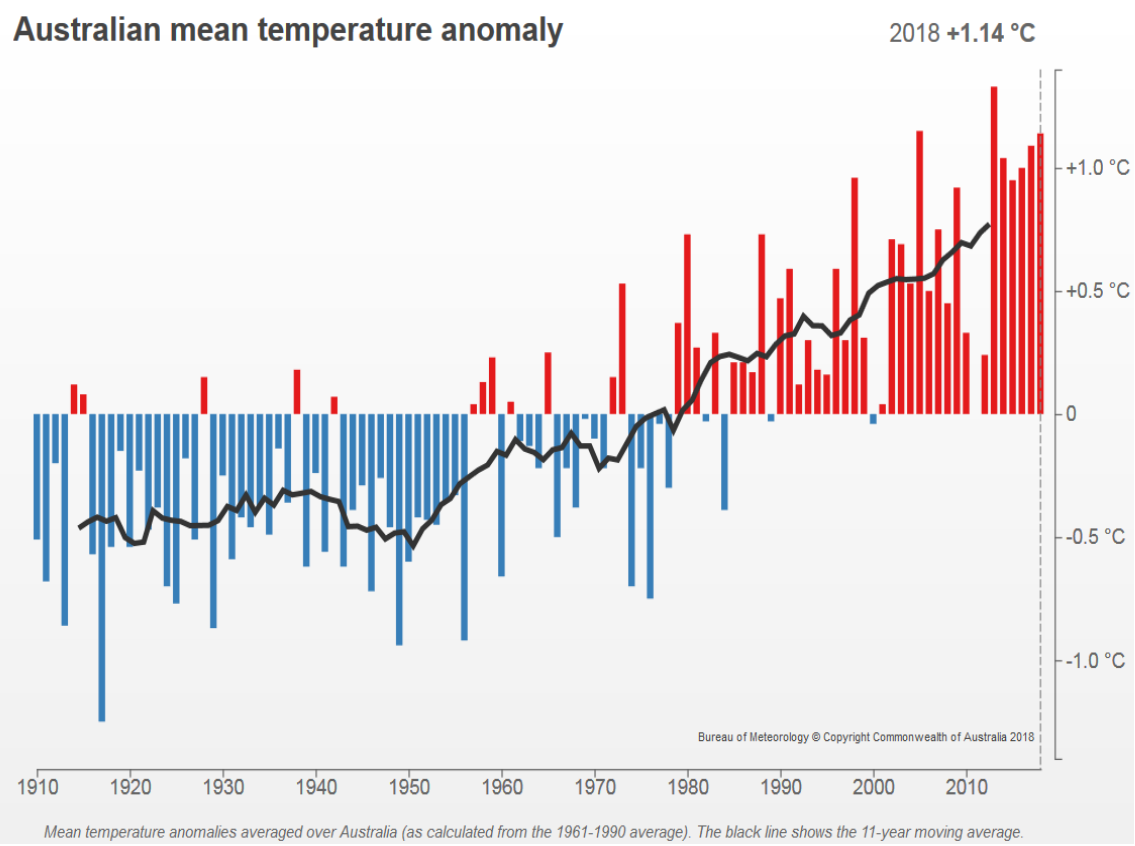
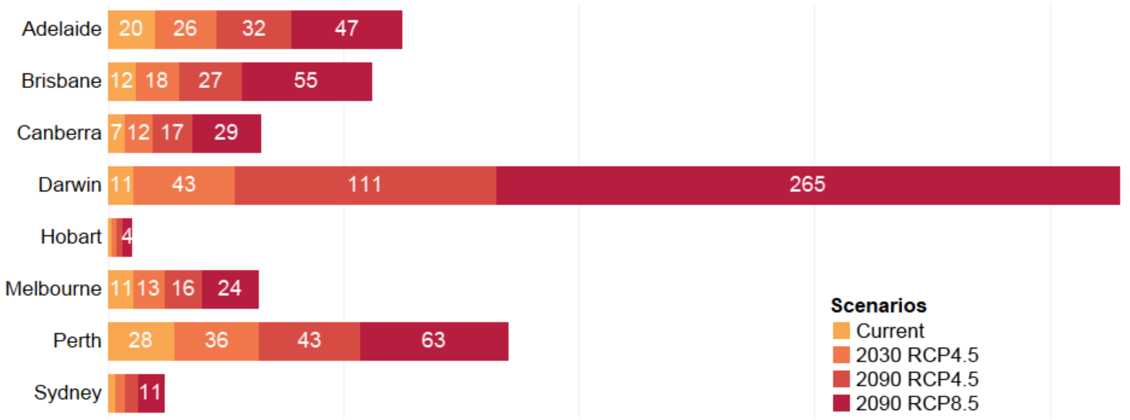


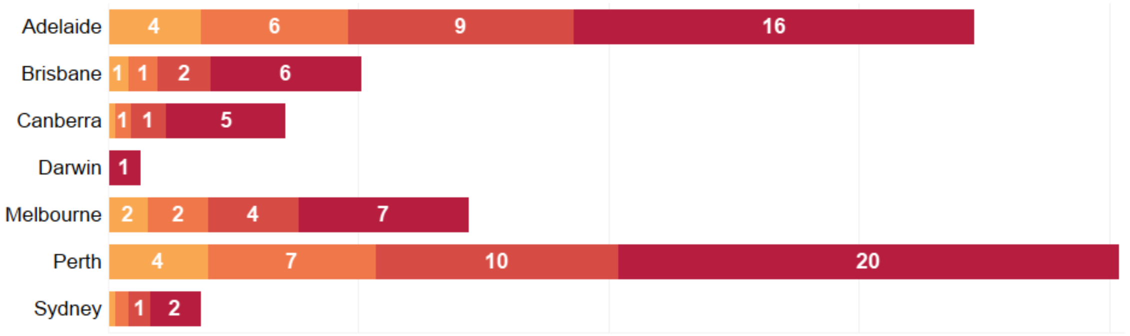
Figure 1.4 Australian annual mean temperature anomaly (1910–2018).

Source: Australian BOM[107, 108] (used under Creative Commons Attribution Australia Licence).

Consistent with the global trend, there has been a decline in the frequency of cooler months (cooler days and cold nights) and increase in hot days and warm nights in Australia since the 1980s. Indications suggest that this trend of increasing numbers of hot days will continue into the future. For example, Figure 1.5 shows the projections of the average number of days per year (>35 °C and >40 °C) by 2030 and 2090 for each of Australia's capital cities.



Number of days over 35 °C for each Australian capital city.



Number of days over 40 °C for each Australian capital city.

Figure 1.5 Current and future projections of number of days above 35 °C (A) and 40 °C (B) for each Australian capital city by 2030–2090 under different representative concentration pathways (RCP) scenarios.

Source: Based on data from Webb LB and Hennessy K.[109]

Summer temperatures are now continuing into autumn, with the recent BOM climate statement indicating the increasingly widespread warmth throughout the year.[108] Notably, nine out of ten of Australia's warmest years on record have occurred since 2005 with January 2019 recorded as the hottest month on record with mean temperatures exceeding 30 °C. Several all-time temperature records were also broken in the 2019 summer. For example, temperatures reached 47.7 °C on 24 January 2019 in Adelaide making it the hottest Australian capital city, topping the previous record of 46.4 °C in Melbourne in 2009.

Besides rising temperatures and increased frequency of hot days, heatwaves have become more frequent, intense, and longer in duration.[103] With adverse effects on human health, heatwaves can be 'silent killers' as they have taken more lives than any other natural disasters combined.[110]

The increasing number of hot days associated with climate change and heatwaves could pose a serious threat to Australia and the health of vulnerable populations. In particular, workers will be exposed to more hot days affecting not only their health and safety, but also work capacity and productivity. Indeed, a Western Australian study predicts that by 2070 it will be dangerous to perform manual labour tasks on 15–26 days per year compared to 1 day per year at present, even for those acclimatised to the conditions; whereas for the unacclimatised this figure approximately doubles.[111] This highlights the need to better understand the impacts of heat on workers and the development of prevention and adaptation strategies to reduce the risk to health and safety in the face of a warming climate.

1.6 THESIS AIM

The overall purpose of this research was to obtain a better understanding of the heat-work injury phenomenon in Australia, thereby contributing to new knowledge that may be useful in reducing the frequency and incidence of WRI. The goal of this thesis is to present the findings of the research which was conducted in six studies. Studies 1–4 systematically examined the association between ambient heat and WRI in Australia using statistical reviews of workers' compensation (WC) claims data. Studies 5 and 6 investigated a range of stakeholder perceptions towards heat-related injury, its prevention, and management using survey data collected de novo.

The main research questions, and aims and objectives of the research, are detailed in Chapter 3.

1.7 THESIS OUTLINE

This thesis is presented as a ‘thesis by publication’ and is formulated in five sections. A concept map illustrating the thesis structure is shown in Figure 1.6.

Section A consists of two chapters: a literature review (Chapter 2) and the study design and methodology (Chapter 3). Chapter 2 presents a comprehensive systematised review of the current state of knowledge about the effects of heat exposure on WRI. The published review is supplemented by a review of relevant literature on stakeholder perceptions, followed by gaps in the existing literature that this thesis aims to address. Chapter 3 outlines the aims and objectives of the study, research questions extrapolated from the knowledge gaps summarised in Chapter 2, and the conceptual framework underpinning the studies that constitute this thesis. Furthermore, Chapter 3 also discusses the study design, study population, data collection and management, and the overall analytical approach used.

Section B comprises two chapters (Chapters 4 and 5) covering the first two studies (Studies 1 and 2, respectively), investigating the effects of ambient temperatures on WRI in four Australian cities: namely, Adelaide (Study 1), and Brisbane, Melbourne, and Perth (Study 2). Accordingly, both these chapters have been published in peer-reviewed journals.

Section C consists of two chapters (Chapters 6 and 7) which specifically focus on the details of two studies examining the effects of heatwaves on WRI in the previously mentioned four cities. Chapters 6 (Study 3) and 7 (Study 4) have also been published as articles in peer-reviewed journals.

Section D focusses on injury experiences, management, and prevention from stakeholders' points of view, and consists of two chapters (Chapters 8 and 9). The details of the final two studies are presented in this section. Chapter 8 (Study 5) explores the perceptions of health and safety professionals (HSPs), whereas Chapter 9 (Study 6) presents perceptions from health and safety representatives (HSRs). Both these chapters prepared in manuscript form have been submitted for publication.

Section E brings together the multiple lines of evidence arising from the six studies presented in Sections B through D. This section consists of two chapters (Chapters 10 and 11). Chapter 10 summarises and discusses the key findings from Chapters 4–9, along with the strengths, limitations and overall significance of the work undertaken. The public health implications of this research and suggestions for research areas warranting attention and further investigation are also articulated in Chapter 10. Chapter 11 draws an overall conclusion for the study and concludes the thesis with recommendations based on the research findings.

As mentioned previously, the format of this thesis is by publication, and as such to aid the reader, clear navigation links have been included across sections and chapters. Each section begins with an overview that outlines the chapters in that respective section and ends with a section summary. Similarly, each chapter begins with a preface and ends with a chapter synopsis. The published articles and manuscripts are formatted such as that, subsections, figures and table numbers are consecutive throughout the thesis to align with those in other chapters. The list of references at the end of the thesis includes those cited in all chapters and papers included in the thesis.

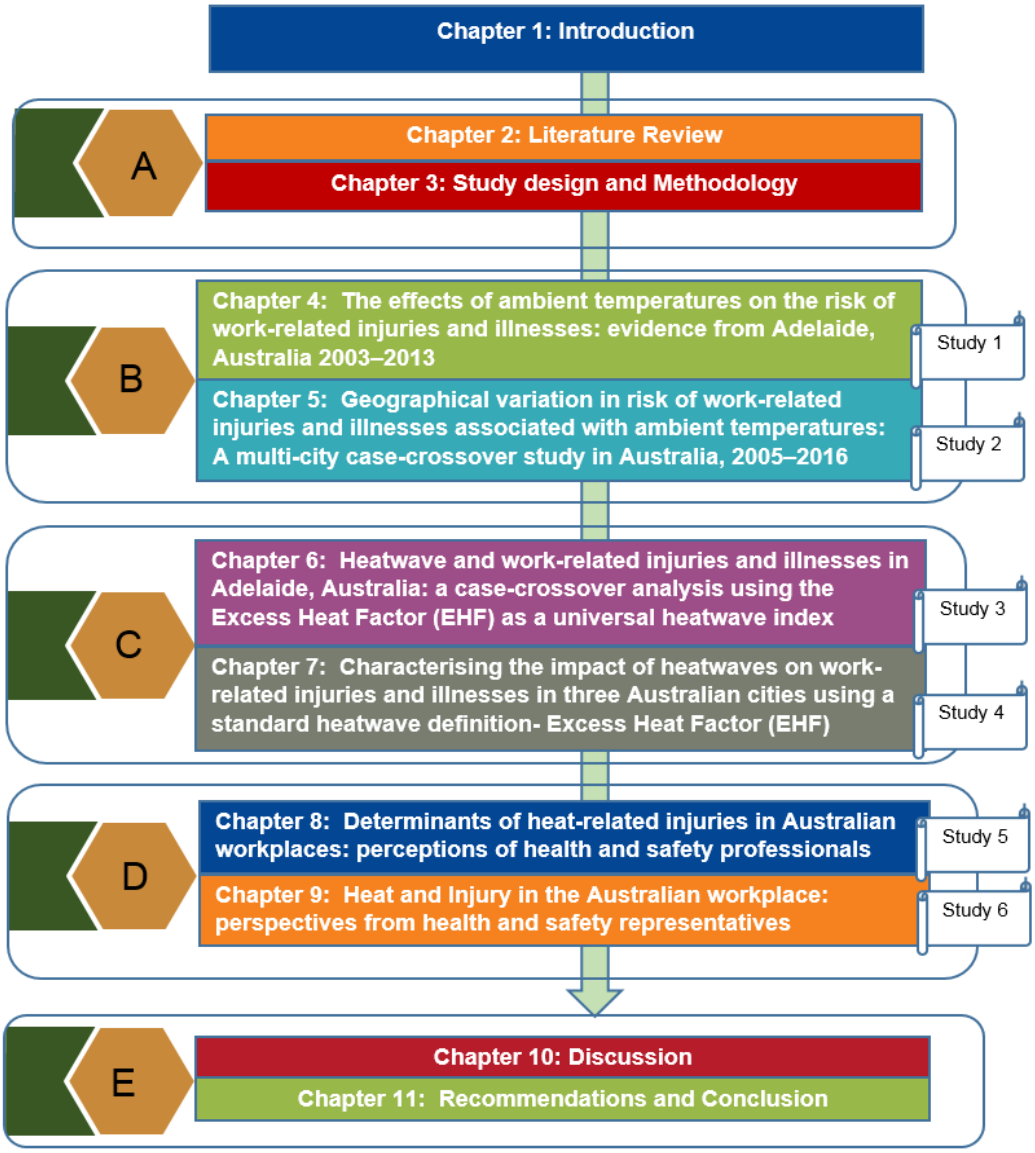


Figure 1.6 Flowchart illustrating the thesis structure.

Notes: Sections are denoted as A, B, C, D, and E. Published papers and manuscripts prepared for publication were drawn from Chapters 4 to 9.

SECTION A: LITERATURE REVIEW AND STUDY DESIGN

Overview of Section A

Section A of the thesis consists of two chapters, Chapters 2 and 3, which provide the basis, background, and design for the research conducted in this thesis.

Chapter 2 presents a literature review that ascertains the current state of knowledge regarding the effects of high temperatures and heatwaves on the risk of occupational injuries, and covers the major aspects of this research. Literature covering epidemiological evidence and stakeholder perceptions is also reviewed. This chapter also presents the research gap leading to the studies conducted and presented in this thesis.

Chapter 3 presents the aims and objectives, research questions, and conceptual framework of the study. A broad outline of the study design, description of the data sources used, and the overall methodological framework and analytical approach used in this research is also provided in Chapter 3.

02

Chapter 2: Literature Review

2.1 PREFACE

This chapter is divided into five sections. Section 2.3 presents a comprehensive epidemiological review of published studies up to 2017, examining the relationship between heat exposure and WRI. This review was published in April 2018 (Varghese et al. *Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review*. Safety Science. 2018. 110, Part A: 380–92. doi:10.1016/j.ssci.2018.04.027) and provides the foundation upon which this research was conducted. The published review article is presented in the form accepted for publication, with the exception of minor differences in formatting, such as the referencing style, section, figure, and table numbering.

Section 2.4 provides an update of relevant epidemiological studies published from February 2017 to April 2019. Section 2.5 provides an additional review of the literature pertaining to stakeholder perceptions of heat-related work injuries. Finally, Section 2.6 discusses research gaps in the existing literature, and Section 2.7 is a summary of the information covered in this chapter.

2.2 STATEMENT OF AUTHORSHIP

Title of Paper	Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review
Publication Status	☑ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Varghese B, Hansen A, Bi P, Pisaniello, D. Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review. Safety Science. 2018; 110: 380-392. https://doi.org/10.1016/J.SSCI.2018.04.027

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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Available at: https://www.sciencedirect.com/science/article/pii/S0925753517313437

The accepted version of the published review is reproduced as follows.

2.3 PUBLICATION

2.3.1 Abstract

Rationale: There is increasing concern about occupational illness, injury and productivity losses due to hot weather in a changing climate. Most of the current understanding appears to relate to heat-induced illness, and relatively little regarding injuries.

Objectives: This paper sought to summarise the evidence on the relationship between heat exposure and injuries, to describe aetiological mechanisms and to provide policy suggestions and further research directions.

Methods: A literature review was conducted using a systematic search for published and grey-literature using Embase, PubMed, Scopus, CINAHL, Science Direct and Web of Science databases as well as relevant websites.

Results and Conclusions: There was a diversity of studies in terms of occupations, industries and methods utilised. The evidence suggests an imprecise but positive relationship between hot weather and occupational injuries, and the most likely mechanism involves fatigue, reduced psychomotor performance, loss of concentration and reduced alertness. The findings reflect an increased awareness of injury risk during hot weather and the economic benefits associated with averting injury, poor health outcomes and lost productivity.

Implications: More work is required to characterise specific injuries and the workers at risk. Policymakers and employers should be aware that heat exposure can lead to occupational injuries with information and training resources developed to aid prevention.

2.3.2 Introduction

Global average temperatures have risen about 0.85 °C over the last 100 years with temperatures further projected to increase by an estimated average of 3 °C by 2100 to reach 1.8 °C–4 °C above pre-industrial times.[104] As a result, extremely hot days and warm nights have increased in number over recent decades and indications suggest that this trend will continue.[104, 112]

In addition to the adverse effects of heat exposure on the general population, occupational health and safety (OHS) is also affected.[5, 12, 13] Workers in industrial sectors such as agriculture, forestry, fisheries and construction are exposed to outside temperatures and solar heat load making them vulnerable to the adverse health effects of heat exposure in hot weather.[34, 36] Furthermore, those working in hot indoor environments without air-conditioning—such as manufacturing, smelting plants, bakeries, laundries, and restaurant kitchens—can also be affected.[34-36] Heat-related illnesses (HRIs) such as heat cramps, heat syncope, fatigue, heat exhaustion, heat stroke and heat shock are often the well-known and documented adverse direct effects of heat on health.[113] These outcomes have been reported in the occupational setting among, for example, surface mine workers,[114, 115] construction workers,[116] agricultural workers[117-120] and radiation decontamination workers.[121]

There is now increasing evidence that occupational heat stress is strongly associated with injuries, as an indirect effect of heat exposure.[7, 42, 43, 122-125] Work-related injuries (WRIs)/accidents in hot conditions can be caused by physical discomfort and altered behaviour, fatigue, declining psychomotor performance, loss of concentration and reduced alertness.[113] However, the extent of injury occurrence in hot weather is poorly characterised and understood, and may represent a notable human and economic cost when combined with HRI.

In the United States (US), the National Institute for Occupational Safety and Health (NIOSH) estimated in 1986 that around 5–10 million workers worked in hot weather conditions for at least part of the year.[32] According to the US Bureau of Labor Statistics (BLS) Census of Fatal occupational injuries report, 144 worker deaths and around 14,022 non-fatal work injuries and illnesses involving lost days of work were reported between 2011 and 2014 due to environmental heat exposure.[126] These figures provide little information about the scale of the problem and are also unlikely to include statistics on injuries that could be attributed to heat such as falls or traffic accidents. As a result, the relative incidence of heat-related occupational injuries is unknown.

In order to summarise current literature on hot weather and occupational injuries, a comprehensive literature search was conducted. Initially, we present a systematised review of studies on heat exposure and injuries, followed by a discussion of the potential pathways to injuries.

2.3.3 Methods

Search strategy

Published literature on heat exposure and injuries were obtained by systematically searching PubMed, Embase, Scopus, CINAHL, Science Direct and Web of Science databases. A search strategy using a combination of controlled vocabulary [Mesh, EMTREE] and key words was developed for each of the above databases (see Table B1, Appendix B1-supplementary file for detailed search strategy). The following keywords along with their synonyms and closely related words were used:

‘heat’, ‘heat stress’, ‘hot weather’, ‘high temperature’, ‘climate change’; combined with ‘injury’, ‘occupation’, ‘workers’, ‘work-related’ and ‘epidemiology’. Searches were not limited to year of publication and references cited in identified papers were used as a further source of literature. Additionally, unpublished studies (articles/reports/academic-theses/conference presentations) were searched in internet search engines and web-based searches for ‘grey literature’.

Inclusion and exclusion criteria

The published studies included in the review met the following criteria:

- Original research articles in English published until 31 January 2017.
- Studies which investigated the association between heat exposures and WRIs/accidents.

Excluded were studies not focussing on injuries occurring in workplaces due to heat exposure, and literature reviews investigating the general population health impacts of heat. All titles and abstracts from the literature search were evaluated against the inclusion criteria for possible relevance and those references judged to be relevant were included as part of the review.

2.3.4 Results

Twenty-six studies (22 published and 4 unpublished) from 1922 to 2017 were selected as part of this review. Figure 2.1 illustrates the study selection process for this review.

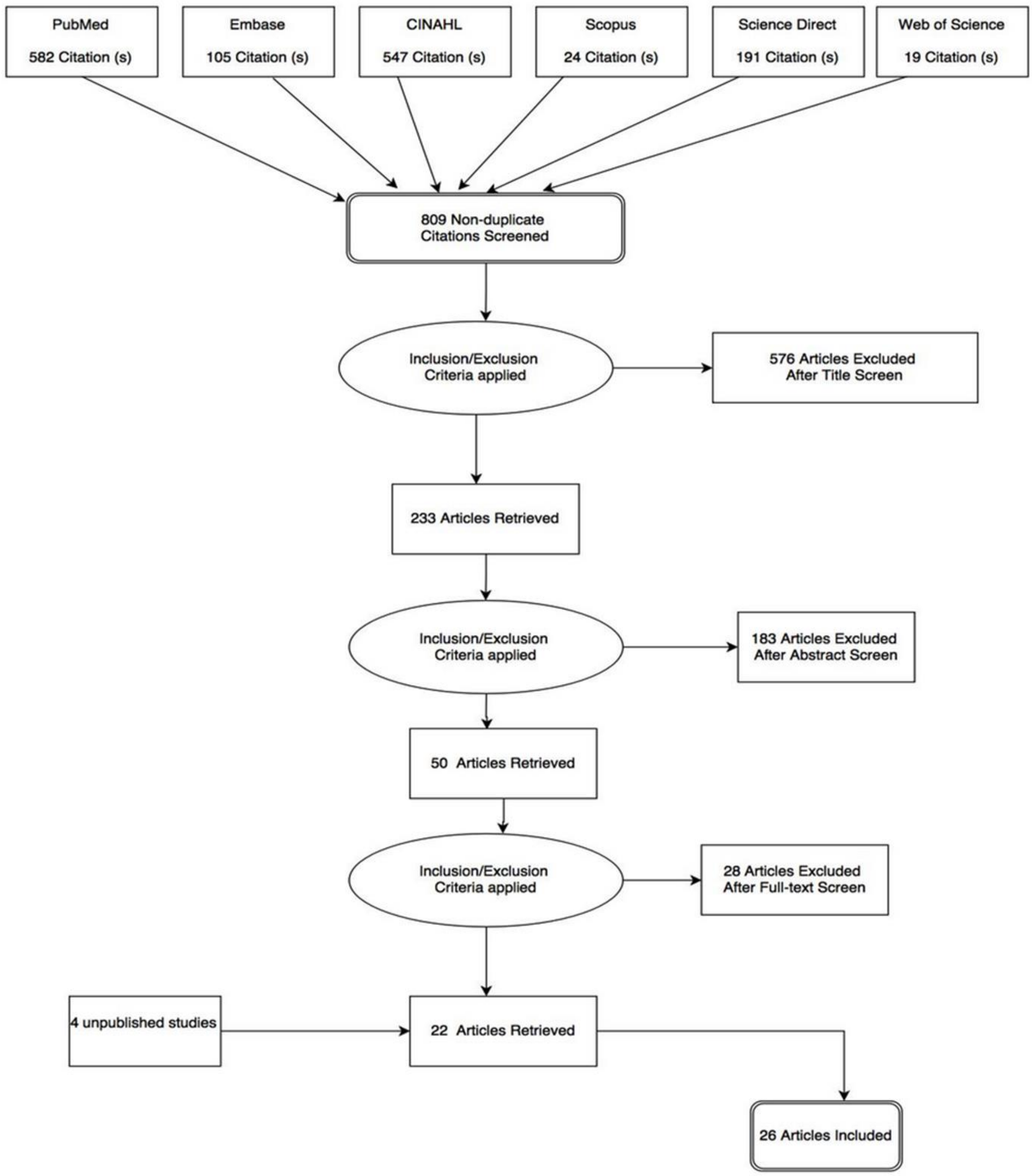

Figure 2.1 Flowchart of selection process for published studies.

Figure 2.2 shows the study location and design employed by the included studies. Most studies have been undertaken in developed countries such as North America and Australia, with fewer in developing and tropical parts of India and Thailand. The study populations were from general and specific occupational settings (n=24) and the military (n=2). The weather variables used in the studies included maximum temperature (T_{max}, n=7), minimum temperature (T_{min}, n=1), and indexes combining relative humidity and temperature, such as Apparent Temperature (AT, n=1), Heat Index (HI, n=1), Humidex (HX, n=1) and Wet Bulb Globe Temperature (WBGT, n=2).

The methods to evaluate the association between heat exposure variables and the risk of occupational injury used in the studies were ecological time-series studies (TS, n=5), case-crossover studies (CCO, n=3) correlational studies (n=10) and cross-sectional questionnaire surveys (n=8). The TS/CCO and correlational studies involved both non-parametric regression models such as generalised estimating equations (GEEs), generalised additive models (GAMs) and negative binomial regression (NBR) and parametric regression models. The models of the TS and CCO studies were adjusted for key potential confounders such as relative humidity (n=2), seasonal and long-term trends (day of week, year, month, n=4), weekends and public holidays (n=5) and used labour force estimates as offset (n=1). However, none of the TS or CCO studies included effects of air-pollution, a variable normally included in the temperature-health relationship analysis models.[(27)] The summary of the included studies (study description, methods and key findings) is provided in Table 2.1.

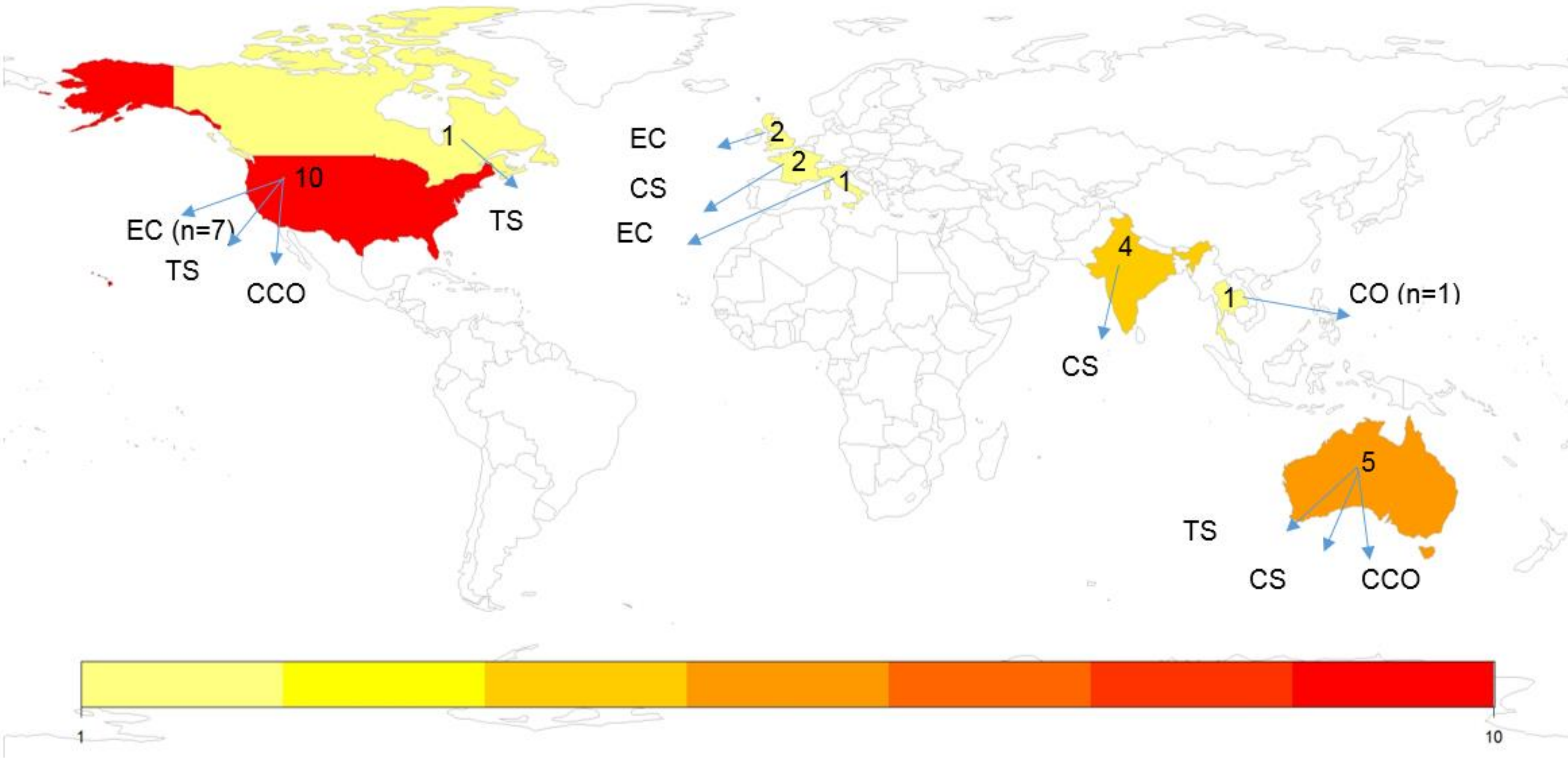

Figure 2.2 Distribution of studies assessing heat exposure and occupational injuries by study country and study design.

Notes: TS: time series; EC: ecological correlation; CS: cross-sectional; CCO: case-crossover; CO: cohort study. Colour indicates the number of publications per country.

Risk of accidents/injuries

The relationships between temperature and occurrence of workplace injuries/accidents have been examined by several studies. Consistent with the literature on heat effects on morbidity and mortality, this association between heat exposure and occurrence of injury/accidents is typically described as a U-, V-, or J-shaped curve whereby injuries increase up to a certain threshold (e.g. around 30 °C depending on each individual study) following which they decline, possibly due to workers modifying work practices at extreme temperatures.[42, 43, 45, 122, 127, 128] The associations between heat and injuries among different occupational categories are discussed below.

Heat-associated injuries in the workforce

A relationship between heat exposure and occurrence of injury/accidents was first established by Osborne et al. in 1922.[129] They found that fewer accidents occurred in three British munitions factories when temperatures were around 19 °C–20 °C, while higher frequencies of accidents occurred at both higher and lower temperatures.[129] However, in 1971, a study of 2,367 accidents in four industrial workshops in the United Kingdom (UK) found no significant increase in accidents at higher temperatures while in half the workshops more accidents occurred at temperatures below 20 °C.[130]

In a 2005 study by Fogleman et al.[43] conducted at a US aluminium smelter, a significant increase in acute injury rates was observed (Odds Ratio (OR)=2.3) when the HI was above 32 °C. Bernard and Fogleman[131] categorised ‘heat stress levels’ (HSL) as being ‘low’ when the WGBT was 0 °C–3 °C above the threshold limit value (TLV) of 29 °C WBGT and ‘high’ when the HSL was 3 °C WGBT above TLV. They reported an increase in the rate of acute musculoskeletal disorders at both low and high HSL with corresponding ORs of 1.8 (95% CI: 1.1–2.9) and 2.4 (95% CI: 1.4–4.3) respectively.[131] Significantly increased rates of acute injuries were found at high TLV (OR=1.7 95% CI: 1–2.9) compared to low TLV (OR=1.4 95% CI: 0.9–2.2).[131]

Moreover, in a study of hospital admissions in Tuscany, Italy, Morabito and co-workers[122] found that the peak occupational accident rate occurred on days characterised by high, but not extreme thermal conditions. No association was found for outdoor workers such as those employed in construction, land and forestry occupations but a significant increase in injuries occurred between the 10th and 90th percentile of temperature range.[122] Similarly, Xiang et al.[45] conducted a study assessing the association between high temperature and WRIs in Adelaide, South Australia, during 2001–2010, and found that injuries occur in moderately hot conditions when workers can suffer from impaired mental judgment and concentration. The authors found a reversed U-shaped relationship between T_{max} and total workers' injury claims. This divergence in the shape of the relationship was attributed to adaptive behaviours at extreme temperatures resulting in the decline of WRIs.[45] The absence of denominator data for calculating WRI rates was noted. The study reported that a 1 °C increase in T_{max} was associated with 0.2% increase in injury claims up to 37 °C, after which injury risk significantly dropped.[45] A log-linear relationship was reported between outdoor temperatures and injury claims in Quebec, Canada.[127] The findings were similar to those of Xiang et al.[45] in that a 0.2% increase in daily injury claims was observed with each 1 °C increase in daily T_{max}.[127] Both the Adelaide and Quebec studies identified key vulnerable groups that included: males, younger workers (<24 years), outdoor, physical occupations and industries, tradespersons, and workers in small- and medium-sized businesses.[45, 127]

Another study in Melbourne, Australia also reported positive associations between temperature and injuries using a CCO approach.[132] The authors did not find any evidence of non-linearity in the relationship between T_{max} and injuries which contrasts with the studies in Adelaide[45] and Italy.[122] Compared to other studies mentioned previously, the authors used daily T_{min} as the exposure metric and found a stronger curvi-linear relationship with injuries—a finding unique in this literature.[132] Female workers, young workers (aged 25–35 years) and older workers (>55 years), those engaged in light and limited physical demand work, and those working in regulated indoor climates, vehicle or cabs, were found to be at risk when daily T_{min} was high.[132] The key vulnerable groups identified using daily T_{max} were similar to those reported by Xiang et al.[45] and Adam-Poupart et al.[127] but also included workers engaged in heavy physical work.[132]

Higher estimates of work-related occupational accidents and injuries associated with ambient temperatures were reported in a 20-year US (unpublished) study of 71,218 occupational injuries and fatalities from 1990 to 2010 targeted at 'temperature-sensitive industries' such as construction, agriculture, forestry and utilities servicing industries.[133, 134] It was reported that on days with T_{max} between 32 °C and 37 °C, accident rates increased by 8.2%, and by 30% on days with T_{max} above 37 °C. Injuries were associated with a 4% increase on days with T_{max} between 21 °C and 27 °C, and 30% for days above 37 °C.[133, 134] Relative to days of T_{max} between 15 °C and 21 °C, rates were higher when temperatures were extremely high or low.[133, 134] Several recent studies by Spector et al.[135], Hiles[136] and

Garzon-Villalba et al.[44] using other meteorological indices such as HX and WBGT have also shown that increases in injuries occur at higher temperatures.

Two studies were also conducted amongst military personnel. A study of US army combat trainees found that the incidence of injuries was higher in summer than in fall, with a dose-response relationship observed between incidence and average daily T_{max}.[137] In a study of national guard troops involved in disaster relief work (sandbagging), days with highest T_{max} translated into higher HRI rates with higher rates observed in females (relative risk, RR=3.1) than in males.[138] The authors concluded that high ambient temperature, high humidity and prolonged exertion can be the determinants of injuries.[138]

Apart from the evidence from ecological studies, eight cross-sectional studies that investigated heat exposure as a risk factor for occupational injuries were also identified. These studies relying on self-reported injury data obtained through surveys, covered a range of workers from general (all workers) to workers in specific industries (both outdoors and indoors) where heat exposure was a known risk factor (e.g. miners, construction, iron and steel and textile industry workers). One study of textile industry workers in India showed a higher prevalence of injuries during summer months when outdoor ambient temperatures ranged between 42 °C and 48 °C.[139] Similar findings were also reported in other cross-sectional studies conducted in India, France and Australia where injury prevalence among workers exposed to high temperatures ranged from 9.2% to 49%.[116, 140-144] Additionally, a large national cohort study of 58,495 workers in Thailand provided substantial and statistically significant evidence of the relationship between heat stress and occupational injuries.[42] In this study, occupational heat stress was prevalent in 20%

of the surveyed workers who also had a greater odds of serious occupational injuries. Interestingly, this study adjusted for several important covariates such as age, income, education, account of existing illness, alcohol consumption, smoking status, sleeping hours, job location and nature of the work.[42]

Effects of heatwaves

Heatwaves are prolonged periods of excessively hot weather with impacts that can differ from those of single high temperature days. In a study from Adelaide, South Australia, Xiang et al.[145] found no significant difference in overall workers' compensation (WC) claims during heatwaves compared to non-heatwaves but noted that wounds, lacerations, amputations and burns were the types of injuries strongly associated with heatwaves.[145] In a CCO study of construction worker claims in Adelaide, Rameezdeen and Elmualim[146] found that the severity of work-related accidents/injuries is governed by worker characteristics, type of work, work environment and the direct cause of the injury (i.e. agency of accident).They reported that during heatwaves, workers in the civil engineering sub-sector, older workers and those employed in small-sized companies were at higher risk of severe accidents.[146]

Types of occupational injuries associated with heat exposure

Most of the reviewed studies have reported on total occupational injuries (both acute and serious), while some ecological and cross-sectional studies[42, 116, 127, 135, 140, 145] have focussed on specific types of injuries sustained in hot conditions. Notwithstanding, some studies have mentioned increased risks for injuries arising from 'slips, trips and falls', 'exposure to harmful substances', 'contact with objects/equipment', 'by hitting objects', 'blunt forces', 'wounds, lacerations and amputations', 'burns', 'minor cuts', 'scrapes', 'being hit by moving objects', 'contusions' and 'fractures' in association with heat exposure.[42, 145]

Table 2.1 Characteristics of studies on the association between heat exposure and work-related injuries (WRI).

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
Ramsay et al. (1983)[147]	Manufacturing plant and foundry workers	WBGT	Unsafe behaviour index (UBI) n=17,841 n=1,734 as UBI	ANOVA, quadratic model controlled for workers' metabolic workload, job risk group, time of day and day of week	U-shaped relationship minimum UBI occurred between 17 °C–23 °C WBGT. Metabolic workload is also significantly related to UBI.
Dellinger AM et al. (1996)[138]	National guard troops	T_{max}	Medical claims of illness and injuries (HRI) Illness (n=95) Injuries (n=119)	Fisher exact tests	Overall 19.3% injuries; males: 16% and females: 42%. Women greater risk for HRI than men. (RR=3.07; 95% CI: 1.09–8.68). Days with T_{max} coincided with highest HRI rates and higher HRI rates at the beginning of the relief work declining over time.
Knapik JJ et al. (2001)[137]	US army subjects attending basic combat training	Average T_{max} and minimal dry bulb	Retrospective injury data post training Injury categories: –All injuries –Overuse injury –Traumatic injuries –Time-loss injuries	Pearson chi-square test, logistic regression and Pearson product moment correlation coefficients	Higher incidence of injury during summer (30.8 °C–36.1 °C) than fall (14.5 °C–26.1 °C). Men had twice higher risk of all injuries and time-loss injuries in summer than women. Dose-response relationship identified between injury incidence and average T_{max} (between 16.2 °C and 34.2 °C) with correlations ranging from 0.92 to 0.97 for time-loss injuries and all injuries respectively.
Nag PK and Nag A (2001)[139]	Textile industry workers	Heat exposure as risk factor	Questionnaire data containing accident reports n=4,125	Descriptive	The prevalence of accidents were significantly higher in summer months (May–June) when outdoor temperatures were between 42 °C and 48 °C.

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
Fogleman et al. (2005)[43]	Aluminium smelter	HI–11 thermal categories, considered relative humidity	Acute injury (lacerations, punctures and musculoskeletal disorders—strains, sprains and hernias) n=557 cases	Ratio of number of accidents using number of acute injury cases and person-hours Poisson regression, Logistic regression	Modified U-shaped relationship between thermal category and the occurrence of acute injuries. Higher odds ratios (OR) occurred below −7 °C and above 32 °C. *Between 33 °C and 38 °C*; OR=2.28 (95% CI:1.49–3.49). *Over 38 °C*; OR=3.52 (95% CI:1.86–6.67). Young workers—high risk of acute injuries.
Morabito M et al. (2006)[122]	Hospital admissions	AT [Daily AT max, AT24 and AT day] percentiles: <25th 25–50th 50–75th >75th	Work-related accidents n=835	Mann–Whitney U Test and Kruskal–Wallis Test Lags up to 1 day Excluded holidays and weekends	Peak accidents on current days (lag=0) characterised by high and not extreme thermal conditions (3rd quartile—average AT_{day}=24.8 °C–27.5 °C).
Bhattacherjee A et al. (2007)[142]	Coal miners	Heat exposure as risk factor	Occupational injuries	Chi-square independence test and logistic regression	28.5% of occupational injuries were due to heat exposure with a crude RR of 1.35 (95% CI: 1.03–1.78).
Chau N et al. (2008)[141]	All workers	Heat exposure as risk factor	Occupational injuries	Association analysed by crude OR and 95% CI	Heat exposure was observed in 18.6% of occupational injuries making it a risk factor (OR=2.29; 95% CI: 1.73–3.01).

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
Tawatsupa B et al. (2013)[42]	All workers	Heat stress measure: 'never', 'sometimes' and 'often'	Frequency of occupational injuries occurring in workplace both agricultural and non-agricultural (none, once, twice, thrice and more than four times)	Logistic regression	Statistically association of heat with occupational injury (OR 2.12, 95% CI: 1.87–2.42 for males and 1.89, 95% CI: 1.64–2.18 for females). Type of injuries: blunt force (24%), stab-cut (21%), fall (18%). Males were more likely to have stab-cut or blunt force injury while falls were more observed in females. Socio-economic factors (income, job location-rural), health behaviours and status (smoking, drinking, less sleep, obesity, existing illness) and nature of work (fast paced) had strong and significant influence on the relationship between heat stress and occupational injury.
Xiang et al. (2014)[45]	All workers	Daily T_{max} Daily T_{min}	Work injury claims (n=125, 267)	GEE with negative binomial distribution Piece wise linear spline function Restrictions to warm season (October–March) Weekdays Model adjusted for: Day of week, calendar month and long-term trends	Reversed U-shaped relationship between daily T_{max} and overall workers' injury claims. 0.2% increase in injuries per 1 °C increase in T_{max} for up to 37.7 °C. No delayed effects of temperature above threshold. Vulnerable groups: male workers, younger workers aged below 24 years, and those working in the 'construction', 'agriculture, forestry and fishing' and 'electricity, gas and water' industries.

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
Xiang et al. (2014)[145]	All workers	Daily T_{max} Daily T_{min} Heatwave: T_{max} ≥35 °C for three or more consecutive days	Work injury claims (n=125, 267)	GEE models with negative binomial distribution Restrictions to warm season (October–March) Weekdays Model adjusted for: Day of week, calendar month and long-term trends	A 6.2% increase in compensation claims was observed for outdoor industry workers during heatwaves. Workers in 'agriculture, forestry and fishing' and 'electricity, gas and water' had significant increase in injury claims. Type of injuries: being hit by moving objects (9.7%), chemicals and other substances (20%) and heat, electricity and other environmental factors (39%) contributed to the increased injury claims during heatwaves.
Biswas MJ et al. (2014)[143]	Iron and steel workers	Heat exposure as risk factor	Questionnaire and interview of workers history of injuries Exposed group: –Steel melting –Rolling mill –Quality control Non-exposed: –Maintenance and administration department	Descriptive analysis	Injuries were reported in 18.7% of workers with higher prevalence in exposed group than non-exposed group (94.6% vs 5.3%).

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
Adam-Popart A et al. (2015)[127]	All workers	Daily T_{max} Considered relative humidity	WRI (n=374, 078)	Generalised linear model with negative binomial distributions Lag effects considered (lags 1 and 2; mean of lags 0–1 and mean of lags 0–1–2) Model adjusted for: Day, month, year, 2-week holiday in construction sector, public holidays, relative humidity and monthly working population	Log-linear relationship between temperature and injuries. 0.2% increase in daily compensation claims with each increase in T_{max}. Statistically significant incidence rate ratios (IRRs) were found for industrial sectors involving both outside and inside work. Types of injuries: slips, trips and falls, contact with objects/equipment, exposure to harmful substances
Jain AA et al. (2015)[144]	Iron and steel workers	Heat exposure as risk factor	Questionnaire data supplemented by clinical examination and review of medical records (n=200)	Chi-square test	Out of 127 workers exposed to high temperatures, 98 (77.2%) had history of injury. Significant statistical association was found between injury and exposure to heat (X^2=33.97, df=1, p<0.0001.
Dutta P et al. (2015)[116]	Construction workers	Heat exposure as risk factor	Cross-sectional survey with anthropometric measurements (n=219) and focus groups (n=4)	Descriptive analysis	12.8% workers reported injured at work of which 9.2% of injuries were in summer compared to 14.7% in winter. However, new workers with <36 months of experience reported injuries in summer. Types of injuries: minor cuts/scrapes/minor injuries, fractures/falls.

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
Xiang J et al. (2016)[140]	Outdoor industrial workers	Heat exposure as risk factor	Questionnaire survey among apprentices, trainees (n=511) and established workers (n=238)	Descriptive analysis	25.9% workers reported experiencing heat-related injuries at work during very hot weather. Types of injuries: burns (54.1%), falls, slips and trips (44.3%), by hitting objects (27.8%), by being hit by moving objects (10.3%). 25.2% of workers reported witnessed injuries to co-worker during hot weather. Most injuries were due to falls, slips and trips (55%) and burns (42.3%).
Spector JT et al. (2016)[135]	Outdoor agricultural workers	Maximum daily humidex (HX) categories: <25 25–29 30–33 >34	Traumatic injury claims (n=12,213)	Conditional logistic regression	Increasing risk of traumatic injuries with maximum daily humidex value up to 33. Compared to HX (reference = <25): 25–29: OR=1.14 (95% CI: 1.06–1.22). 30–33: OR=1.15 (95% CI: 1.06–1.25). >34: OR=1.10 (95% CI: 1.01–1.20). High risk of traumatic injuries for cherry harvest duties occurring during June–July.
McInnes J et al. (2016)[132]	All workers	Daily T_{max} and T_{min}, Included relative humidity	WRI claims (n=46,940)	Conditional logistic regression Restricted to warm months (November–March)	Positive associations between temperature and injuries. T_{max} and injuries: non-linear relationship. T_{min} and injuries: curvilinear (U-shaped). Overall vulnerable groups: young workers, males, physically demanding occupation.
Garzon-Villalba XP et al. (2016)[44]	BP deep water horizon oil spill clean-up workers	$WBGT_{max}$	Occurrence of exertion heat illness (EHI) and acute injuries (AI) AI=1,619 EHI=1,707	Descriptive, Poisson regression model	Statistically significant increase of EHI and AI above $WBGT_{max}$ of 20 °C (RR 1.40 and RR 1.06/ °C). 13% increase of AI was observed with a 1 °C increase of WBGT. Severity of event was statistically significant for AI as the RR increased from 1.13 to 1.15 and significant cumulative effect from prior day's $WBGT_{max}$ for EHI was significant.

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
Rameez-deen R and Elmualim A. (2017)[146]	Construction workers	Daily T_{max} Daily T_{min} Heatwave: T_{max} ≥35 °C for three or more consecutive days	WRI (n=29,438)	Descriptive, Chi-square statistics	Slight over-representation but no statistically significant association with number of accidents. Expenditure in major accidents was more than twice among >55 years and higher for new workers during heatwaves. Vulnerable groups: experienced workers, male workers, those aged <35 years and >55 years, those working in small- and medium-sized companies, in the civil sub-sector and employed as bricklayer, carpenter, electrician, mechanics and plant operator.

Notes: [a] These studies are ordered by date of publication. T_{max}: maximum temperature; T_{min}: minimum temperature; WBGT: Wet Bulb Globe Temperature; AT: apparent temperature; HI: heat index; HX: humidex; EHI: exertional heat illness; AI: acute injuries; UBI: unsafe behaviour index; HRI: heat-related illness; WRI: work-related injuries.

Potential pathways to injuries

It is unclear how heat exposure exacerbates the risk of physical injury. However, studies included in this review have shown that injuries can be in addition or secondary to, HRIs and can be caused by physiological, psychological, personal behavioural and organisational (work-related) factors as summarised in Figure 2.3.

To better understand the physiological factors, it is important to know how the body maintains its heat balance and how it reacts in hot environments. Humans are homoeothermic and internal body temperature varies only slightly within a very narrow range around the 37 °C 'set point'.[3, 148-150] Although changes in body temperature can occur from hour to hour and even day-to-day, these fluctuations are usually not more than about 1 °C as the body is well equipped to regulate internal temperature with dual control systems operating at the neural and hormonal level.[3, 148-150] Thermoregulation controlled by the hypothalamus in the brain ensures heat balance via heat loss mechanisms such as radiation, convection, conduction and evaporation of sweat (Figure 2.4). Serious health risks can arise when the heat burden exceeds heat loss and the core body temperature rises to 39 °C or more. The heat burden imposed on the body can be from the combination of expended energy; external environmental sources including high air temperature, high relative humidity, lack of air movement, radiation from the sun or hot surfaces/sources, and non-climatic parameters such as internal heat generation and clothing.[120, 151]

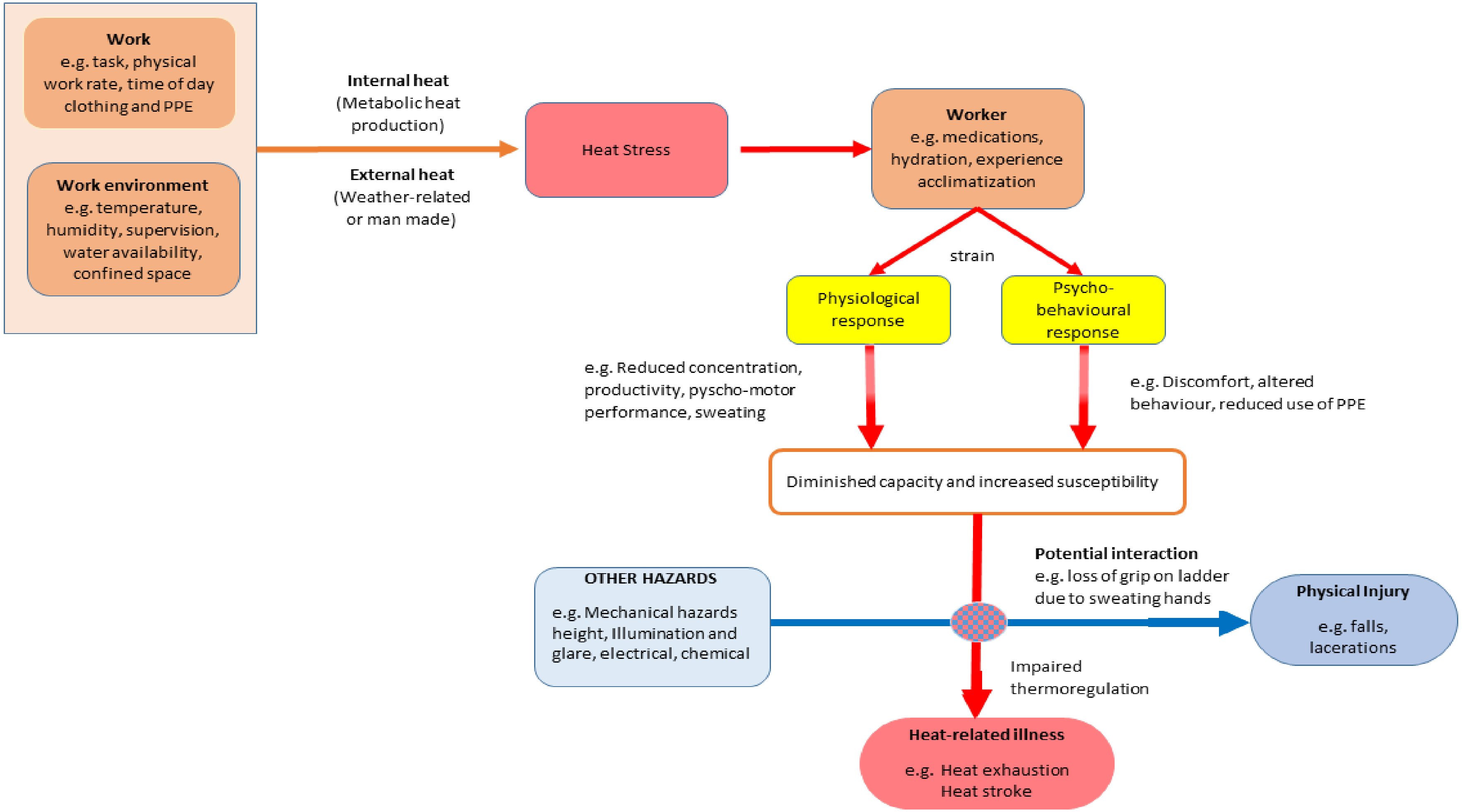

Figure 2.3 Schematic illustration of factors leading to occupational heat stress, heat strain, illness, and injuries.

Sources: Adapted from Makinen TM and Hassi J[152], Kjellstrom T et al.[29] and ILO Encyclopaedia of Occupational Health and Safety[153].

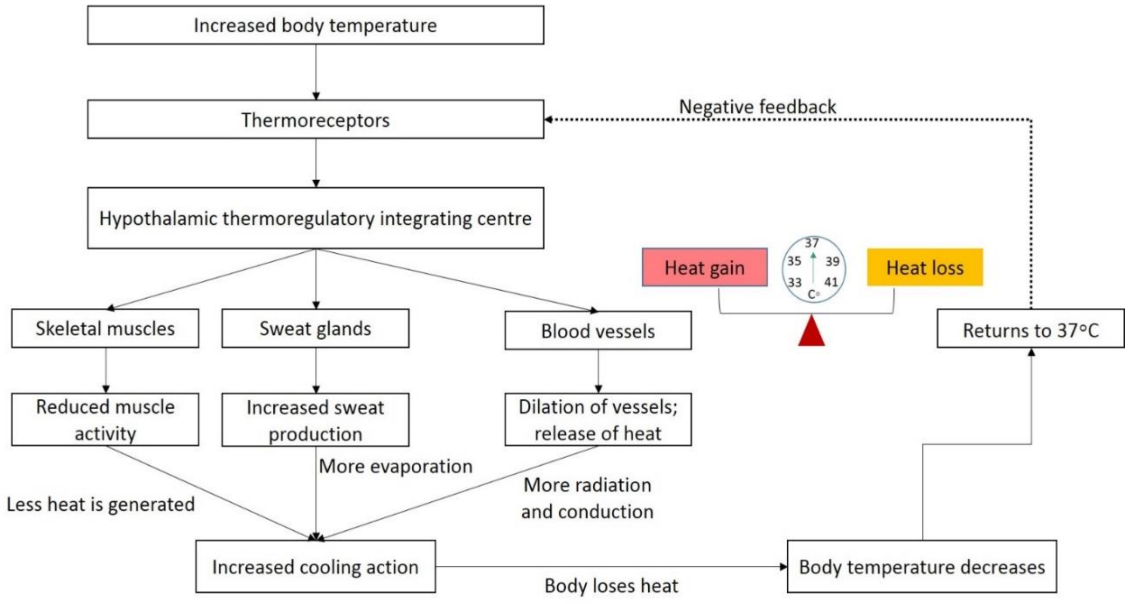

Figure 2.4 Normal thermoregulatory mechanism.

Sources: Modified from Parsons K[3] , Sherwood L[148] , Kenney WL, Wilmore J, Costill D[149] , Astrand P-0[150] and Powers SK HE[154] .

The physiological factors that pre-dispose an individual to physical injury correspond to the thermoregulatory system's capability to deal with temperatures above or below the set-point. Firstly, changes in blood circulation due to the inability of skin surfaces to lose heat results in pooling of blood in the lower extremities.[3] This in turn means that there is less blood supply to the vital organs including the brain, causing problems such as dizziness and fainting potentially leading to an injury (e.g. falls).[3]

Secondly, while radiation, conduction and convection work effectively when the surrounding temperature is lower than skin temperature, at higher temperatures the body's salt and water stores can be depleted due to continuous sweating. This results in an electrolyte imbalance that leads to heat cramps and dehydration if the lost body fluids are not continuously replenished.[154] These effects can overwhelm the body's thermoregulatory systems resulting in symptoms of HRI. The progression of these symptoms may impair workers' ability to work safely, increasing the incidence of workplace injuries[124] that occur due to loss of concentration, decreased postural stability, cognitive function and perceptual motor skills.[24, 135, 155-157]

Thirdly, the nature of work can play a role in causing injury. As metabolic rate is associated with muscular work, the total amount of heat produced is proportional to the intensity of work performed.[131] Muscle fatigue can occur if the blood pH level drops due to the increased muscle glycogen degradation, the rise of carbohydrate metabolism and lactate accumulation.[154, 158] Furthermore, highly-reactive molecules such as ‘free-radicals’ can be increased in the skeletal muscles. As a result, muscle strength can decline and affect workers’ performance, eventually pre-disposing them to injuries.[154, 158]

The physiological effects experienced by workers during hot weather conditions may be psychologically linked to increased risk taking behaviour which may translate into accidents/injuries. Ramsay[147] used a measure for risky behaviour termed the ‘Unsafe Behaviour Index’ (UBI), and identified a U-shaped relationship between unsafe work behaviours and thermal exposure whereby UBI was minimum between 17 °C–23 °C WGBT, but increased above 23 °C WBGT. The depletion of cognitive function due to heat as explained by the ‘psychological zone of maximal adaptability’ validates and further explains this U-shaped relationship.[159] In this model an individual’s performance is affected as their attention and concentration to their task declines with heat, resulting in unsafe behaviours. Interestingly, the decline in cognitive functions starts with minor elevations of the body temperature and the ability to perform tasks and productivity can be affected before a diagnosable heat-related disorder occurs.[159-163] A review of 160 studies assessed workers undertaking basic/mental tasks such as arithmetic, writing, coding, time estimation and reaction time and tasks requiring demanding perceptual motor skills including: tracking, vigilance, machine operation and complex/dual tasks. Significant decrements in the perceptual motor skills among workers engaged in such tasks compared to those engaged in basic/mental tasks was observed at temperature ranges of 30 °C–33 °C WGBT.[41]

Lastly, organisational and personal behavioural factors can also lead to injuries. These include reduced use of personal protective equipment (PPE) due to discomfort in the heat, and slippery palms, grip loss or visibility problems due to sweating.[113, 117, 120, 123, 164] Other influencing factors can be requirement to wear impermeable protective clothing, and lack of supervision and training in heat stress prevention.

Preventative strategies and barriers

The adverse effects of heat strain are preventable. A range of organisations have promulgated occupational criteria on heat health hazard recognition, evaluation and control.[165-168] Reducing heat exposure for outdoor workers can involve increasing ventilation, modifying clothing, or providing shields/shade against radiant heat/solar radiation.[165-168] In addition to these, safer-work practices such as provision of drinking water, acclimatisation, suitable work-rest intervals, rearrangement of work tasks to cooler parts of the day, education and training on the hazards of work in hot environments, and awareness of HRI symptoms, are also key in reducing workplace heat exposure.[165-168] These critical health and safety strategies for working in hot weather are also mentioned in the regulations and guidelines of different countries such as US, UK, Canada, Australia, New Zealand, Hong Kong, Japan, and China. It is noted however, that there are few or no specific regulations and codes for heat stress prevention in developing countries such as Thailand, India, Costa Rica, and South Africa.[169, 170]

Despite many standards that refer to a ‘general duty of care provision’, the health hazards of working in hot weather are not specifically addressed in current OHS legislation and policies.[171, 172] As a result, less conscientious employers may be more likely to be non-compliant with these standards and guidelines for different reasons. A recent study in Adelaide found that accidents in small-sized businesses increased with daily T_{max}[45] and WC claims from small-sized construction companies are over-represented during heatwaves[146] possibly due to their lack of compliance/ management of current OHS policies. The authors recommend that small-sized businesses be targeted for ‘policies and practice of adaptation and preventative measures’.[45, 146]

In Canada, 7 out of 13 provinces require employers to implement administrative and engineering controls for both indoor and outdoor workers to reduce heat exposure.[24] Although tough heat-specific laws protecting workers from heat exposure were enacted in the state of California and Washington (US) in 2010, poor compliance of heat standards by employers was reported in 2012 during inspector audits.[173] In a recent survey of workers in Adelaide, about 56% of workers suggested the need for more heat-related training, while 64% suggested the need for heat-related regulations and guidelines.[140] Although heat stress management policies sometimes entail a cessation of work when temperatures are extreme, whether workplaces comply with this guideline is unknown. Only 20% of workers surveyed in a South Australia study selected ‘ceasing work’ as a heat prevention measure.[140, 174]

2.3.5 Discussion

This review summarises evidence published to date regarding the role of meteorological elements, particularly hot temperature, in occupational injury causation. Despite differences in study design and analysis strategies, evidence presented in this review indicates an association between heat and WRIs.

Vulnerable subpopulations identified include male workers, younger workers aged 15–24 years, outdoor and indoor workers.[45, 127, 132, 135] Increased risk of occupational injuries was found among the 'electricity', 'manufacturing', 'utilities', 'transport', 'agriculture', 'fishing' and 'construction' industries.[45, 127] As well as heat stress, the kinds of injuries sustained during hot weather included 'wounds, lacerations and amputations', 'burns', 'falls', 'cuts', 'fractures', 'slips', and 'trips'.[42, 145] Although associations were established, the mechanism underlying occupational injuries attributed to hot weather remains unclear. However, in this review we have identified both direct and in-direct risk factors (Figure 2.3) by which exposure to heat may lead to occupational injuries. This needs to be further investigated in future studies to explain the underlying mechanism.

It is known that cognitive and physical performance can be affected by exposure to excess heat. The likelihood of unsafe behaviours leading to injuries and illnesses are higher when factors such as judgement, concentration, coordination, endurance, strength, vision and comfort are influenced by physiological changes induced by heat and dehydration.[159, 175-177] Physical workload was considered in only two studies[127, 132] that found significant associations between T_{max} and heavy physical work and T_{min} and light and medium strength occupations.

Apart from these factors, many studies have also attempted to hypothesise a long list of other factors that may pre-dispose an individual to experience a higher risk of workplace injuries in hot conditions. These include: sweaty palms, fogged up safety glasses, accidental contact with hot surfaces, physical demanding work, lack of training and skills, ageing-induced dysfunctional thermoregulatory mechanisms, use of heavy impermeable PPEs, workplace pressures, poor hydration behaviours and attitudes to strenuous work.[33, 45, 120, 132, 178] A cohort study undertaken in Thailand, though limited on its reliance on qualitative measures of occupational injuries and heat exposure as reported by participants, provided important evidence of heat stress risk by taking into account several of the above factors.[42] Future quantitative studies also need to investigate specific at-risk occupations as type of work, body posture and movement also determine an individual's response to heat stress.[168]

Apart from standard climate descriptors such as maximum and minimum temperature that are used to assess workplace heat risks by policy makers, supervisors and safety professionals, other metrics such as AT, HI, HX, and WBGT can also be used.[168] WBGT is a heat stress metric that was developed for US military in the 1950s and is now used more broadly in industrial and sporting sectors, incorporating air temperature, humidity, wind speed and solar radiation.[179, 180] HI (also known as AT or HX) is a combined metric of air temperature and humidity.[181] These thermal composite indices provide a more comprehensive picture of the hazards posed by heat to an individual or group of workers than air temperature alone. Hence, studies using a more comprehensive index may provide more robust estimates of thermal comfort and risk of heat stress. Importantly, behavioural factors, clothing and PPE; levels of physical exertion and personal factors (age, health, medications etc.) also influence how our bodies react to heat.[168]

Apart from studies using onsite heat stress measurements, most of the included studies have relied on weather data from fixed-site monitoring stations, thus raising the issue of bias from exposure misclassification as they may not adequately capture individual exposures to temperatures recorded at central monitoring stations. This limitation of ecological study designs can only be addressed by empirical studies using individual measurements across a range of industries and in hazardous locations (such as construction sites) that would give more precise exposure estimates than ecological studies. However, the impracticality and expense involved in conducting these studies justifies the use of administrative databases such as WC data covering many types of work, workers and workplaces, and spanning extended periods of time advantageous to public health researchers.

Ideally, using the number of workers on a given day as the denominator would produce precise estimates of rates of injury risk in an industry or occupation type. At present this has only been undertaken in onsite studies[44, 136] that have used workplace injury records provided by employers. Access to reliable and meaningful population denominators in broader spatial scale studies such as those using worker compensation databases at a city/regional level is difficult, as raised by Xiang et al.[45] Adam-Poupart et al.[127] used the log of regional monthly working populations as an offset in their generalised linear model to estimate the association between temperature and injury risks. Two studies[132, 135] have attempted to overcome this limitation by employing a CCO study design whereby each case is its own control.

Despite these caveats, evidence is growing of the relationship between heat and impaired worker health and safety. As suggested by one study, providing information on risk factors and appropriate training and awareness to prevent such incidents is highly crucial to tackle this issue effectively.[45] This lends support to the argument that reducing exposure to heat by implementation of appropriate engineering and preventative control strategies may result in a reduction in the number of workplace accidents/injuries. Guidance documents have been released by various health and occupational groups and government authorities that provide guidelines and recommendations for workers (for detailed review, see McInnes et al.[171]). However, at present, there is little focus specifically on injury prevention in moderately hot, as distinct from extremely hot, thermal conditions. Hence, modifications to OHS policies and design of evidence-based training plans for workers and supervisors may be needed.

There are some limitations in this study. Although multiple databases were searched using a number of keywords, the possibility of missing studies reporting negative associations between hot weather and WRIs cannot be ignored. We have addressed publication bias to an extent in this review with the inclusion of both published and unpublished studies. Gaps identified in this review warrant further investigation to elucidate the complex mechanisms involved, and better characterise workers at risk based on occupations, physical activity level (sedentary/moderate/heavy) and co-morbidities. Further research is needed to examine how other factors mentioned previously (behavioural, personal and climatic) may modify/confound the already established relationship between temperature and workplace injuries to get a more accurate picture of the effect. This is particularly important with projections of further rises in global temperatures that range between 1 °C and 5 °C by 2070 (depending on the greenhouse gas emissions) may increase the risk of heat-associated injuries and illnesses for those employed outdoors.

The lag-effects of temperature on the occurrence of injuries also needs to be further investigated as injuries may not potentially occur on the same day as the heat exposure. Further work is also required to look at impacts of heatwaves in terms of intensity and duration using newly proposed metrics such as the Excess Heat Factor (EHF).[182] There also exists limited research on the economic impact of heat on the occurrence of occupational injuries and the cost to the health sector and more work is needed. Practical economic implications could be associated with improved worker safety through averted injuries, poor health outcomes and lost productivity.

2.3.6 Conclusion

This review presents an evidence base addressing hot weather hazards and associated direct and in-direct risk factors for occupational injury. The need for targeted interventions and workplace policies focussed on preventative strategies is highlighted. Results from studies included in this review indicate a strong but variable relationship between outdoor temperature and risk of workplace injuries that vary by worker demographics (age, gender, occupations and industries). However, the mechanisms underlying the occurrence of these injuries remain unclear. With the influence of global warming resulting in higher temperatures and more hot days, we might expect to see a rise in occupational accidents and injuries and associated productivity losses, the impact of which may be reduced by adaptation of specific behavioural and workplace controls among workers of vulnerable occupational groups and industries.

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*****End of published paper*****

2.4 UPDATE: REVIEW OF MORE RECENT LITERATURE

In April 2019 a literature search was conducted using the aforementioned search strategy to identify heat and WRI studies subsequently published since the publication of the above article in April 2018. Eight studies were identified and a brief overview of these studies is presented below, with the additional details summarised in Table 2.2.

In total, five studies[183-187] utilised TS study designs and three studies[188-190] used time-stratified CCO study designs to examine the effects of high temperatures (n=5) and heatwaves (n=3) on WRI sourced from WC claims data. In regard to study populations, some studies investigated specific outdoor workers such as those in agriculture (n=1), construction (n=1) or mining (n=1), while others focussed on a range of workers (n=5) including migrant workers (n=1).

In terms of location, there were two studies each from Italy[184, 186], US[187, 189] and China,[183, 190] respectively; and one study from Australia[188] and Spain.[185] The studies were spread across climate zones defined using the Köppen–Geiger classification[191] (Figure 2.5), the locations varying from an oceanic temperate climate,[188] warm temperate climate,[184, 186] humid subtropical climate[183, 187, 190] and a combination of different climates (warm/hot-summer Mediterranean, warm/hot humid continental, cold desert/semi-arid).[185, 189] In regard to the geographical area covered, studies were based at the city,[183, 188, 190] state[184, 186, 187, 189] or country-wide level.[185, 187]

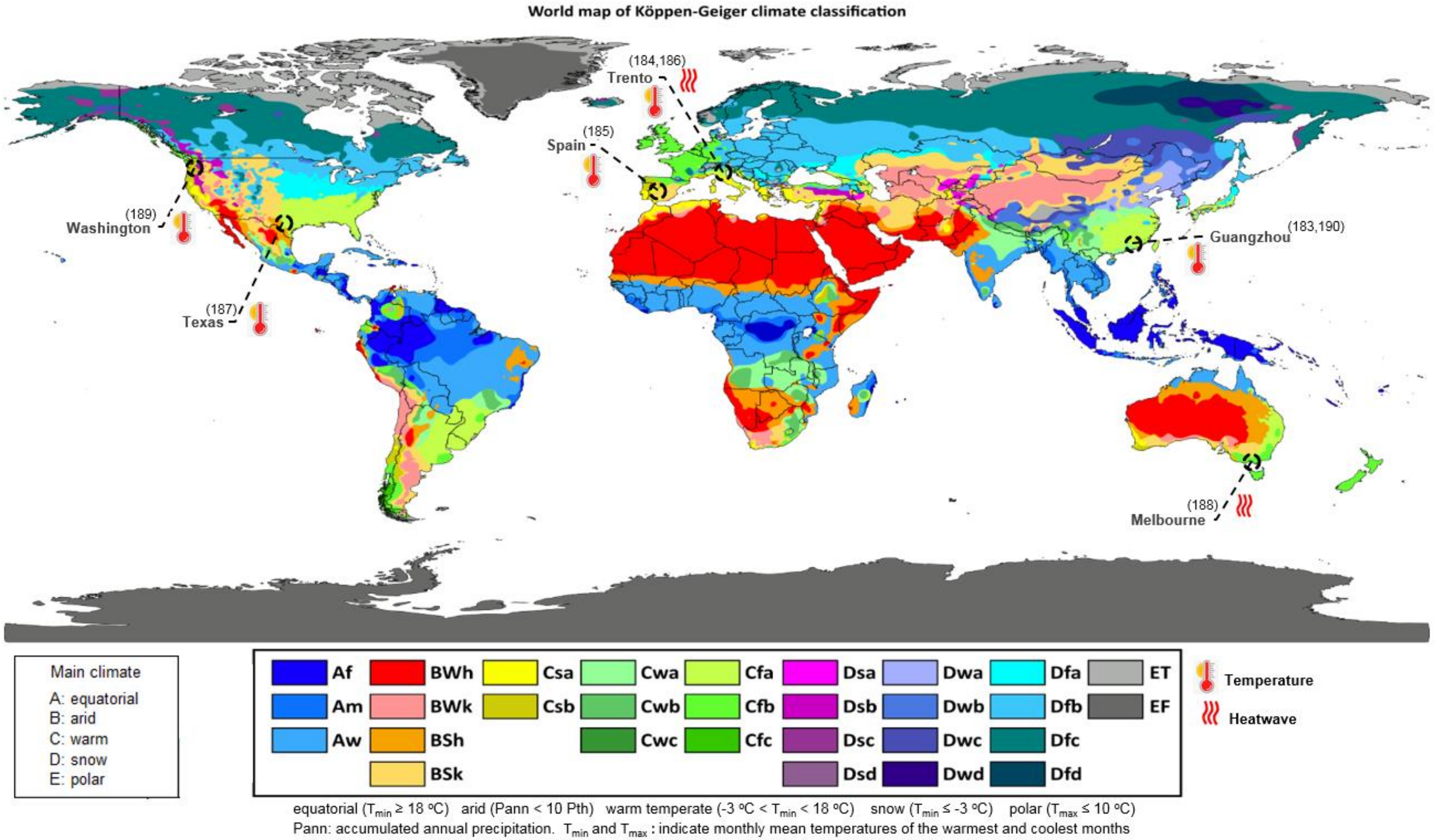


Figure 2.5 Distribution of heat and work-injury studies across five Köppen Geiger climate zones (A-E). References on the map show the locations of the studies referred to in Table 2.2.

Source: Peel et al.[192] (used with permission).

A range of temperature metrics were used in these studies as exposure indicators. These were: T_{max} (n=5),[184-186, 188, 190] T_{mean} (n=3),[184, 186, 187] T_{min} (n=2),[188, 190] HX (n=1)[189] and WBGT (n=1).[183] The analytical models used included logistic regression (n=1),[186] Poisson regression (n=1),[184] conditional logistic regression (n=2),[188, 189] conditional Poisson regression (n=1),[190] and distributed lag-nonlinear models (DLNM, n=2),[183, 185] the latter of which considers both the non-linearity and the lagged effect of the relationship.

In general, the findings of these studies showed a positive association between high temperatures/heatwaves and WRI in all the eight studies with varying effect sizes depending on the methods and metrics of temperature measure used. For example, two studies[189, 190] presented the effect estimates per 1 °C increase in daily temperature, while six studies[183-187] reported effect estimates (RR/OR) relative to a reference temperature or temperature category. The percentage change in injury risks per unit increase in temperature ranged from 0.4% to 1.4%.[189, 190]

Overall these recent studies show similar findings to those published up to 2017. A study by Martinez-Solanas et al.[185] covering 50 provinces and approximately 15 million records of injuries in Spain identified that extremely high temperatures (99th percentile) were associated with a 10% increase in injury risks. In contrast to other studies[45, 122, 135] that found a reverse U-shaped exposure-response relationship between high temperatures and overall injuries as discussed previously in Section 2.3, most studies published since 2017[183-185, 187, 189, 190] reported that the risk of injuries increases with temperature without any decline at the extremes. This discrepancy may be due to the statistical methods used. For example, the studies which incorporated the number of workers (denominator data) in TS modelling[185,

[187] or in CCO design[188-190] resulted in U-shaped exposure-response curves as typically seen in heat-associated mortality/morbidity studies[5] and other occupational heat exposure studies.[43, 44, 127, 132, 183-185, 187, 189, 190]

Several reviews[5-7, 193-195] on temperature-health outcomes in the general population have indicated that people living in areas where higher ambient temperatures are less common have stronger heat effects compared to those in warmer areas. In agreement with this observation is the finding by Calkins et al. [189] who found a larger effect of high temperatures on traumatic injury risk in construction workers in Western Washington state with a cooler climate than Eastern Washington with hotter summers. In contrast, Martinez-Solanas et al.[185] found higher heat effects in the hotter southern and eastern provinces of Spain, while Dillender[187] found no evidence for a higher heat effect on injury rates among mining workers in cooler climates than in warmer climates across the US.

Besides examining the relationship between temperature and work injuries, two of the recent studies quantified the burden of injury claims attributable to temperature. This ranged from 2.5% in Spain[185] using T_{max}, to 4.8% in Guangzhou, China[183] using WBGT. Two of the studies also examined productivity loss associated with occupational heat exposure. One found that heat accounted for an annual loss of 36 workdays per 1,000 workers in Spain.[185] Furthermore, heat accounted for 87% of the total annual cost of lost working days due to extreme temperatures (€320 million) with moderate heat contributing the most (€298 million).[185] Similarly, a study in China found that 4.1% of the insurance payouts for WRIs were attributed to high temperatures (i.e. WBGT above 25 °C).[183] These two studies[183, 185] demonstrate the significant economic burden of WRIs attributable to workplace heat exposure.

Consistent with previous studies[42, 45, 127, 132] (see Section 2.3), the more recent studies identified similar subgroups vulnerable to injury (comparing hot days to cool conditions), i.e. males[185, 190] and young workers.[185, 188, 189] Interestingly, overall injury risks were not limited to outdoor industries (i.e. agriculture, construction, waste collection)[185, 190] or manual workers[185] alone, but also included some indoor industries (i.e. manufacturing, hotel industry, finance, property and business services)[185, 190] and non-manual workers.[185] Additionally, the studies reported that females,[185] middle-aged workers,[188, 190] older workers,[189] workers with less experience,[189] those with low educational attainment,[183] and from small- and medium-sized businesses[183, 190] and migrant workers[186] were also at risk. The latter group of workers are commonly found to work in at-risk industries such as agriculture and construction,[196] and cultural and religious aspects as well as adaptation barriers also contribute to their increase in safety risks.[197]

Taken together, the findings of these eight studies are in agreement with the majority of the studies identified earlier in this chapter, in that WRI risk increases with rising temperatures and during heatwave periods.

Table 2.2 Characteristics of recently published studies on the association between heat exposure and work-related injuries (WRI).

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
McInnes J et al. (2018)[188]	All workers	Daily T_{max} and T_{min} Used a range of temperature percentiles (60^{th} to 95^{th}) of daily T_{max} and T_{min} to define two and three consecutive hot days and two and three hot nights, respectively. Included relative humidity	WRI claims (n=46,288)	Conditional logistic regression Restricted to warm months (November–March)	Positive associations between exposures of two and three consecutive days of hot weather and risk of WRI were found with the effect apparent at low daily T_{max} of 27.6 °C up to the 90^{th} percentile. No significant association between exposures and risk of WRI for either 2 or three consecutive days at the 95^{th} percentile. Higher risks observed for three-day exposures than for two-day exposures (OR 1.15, 95% CI: 1.01–1.30 vs 1.07, 95% CI: 1.02–1.12). No relationship identified between consecutive hot nights and risk of WRI. Vulnerable groups: young workers (<35 years), middle age groups (35–49 years), workers in regulated indoor climate, and working in vehicle or cab.
Sheng R et al. (2018)[190]	All workers	Daily T_{max} and T_{min}	WRI claims (n=5418)	Conditional Poisson regression Restricted to warm months (May–October)	Increase in 1 °C in T_{max} and T_{min} was associated with 1.4% and 1.7% increased risk of WRI, respectively. Vulnerable groups: males, middle-aged workers, small- and medium-sized enterprises, manufacturing, finance, property and business services.
Ricco M (2018)[184]	Agriculture workers	Daily T_{max} and T_{mean} Three exposure groups based on temperature percentiles: $<75^{th}$ $75–95^{th}$ $>95^{th}$ Heatwaves: T_{max} ≥35 °C for three or more consecutive days	WRI claims (n=7,325)	Poisson regression model <75th percentile of T_{max} and T_{mean} were defined as the referent category Controlled for age, sex, ethnicity, and time period (month and day of week) Restricted to warm months (May–September) Considered three time lags (0–2)	A positive relationship was identified on days with temperatures higher than the 95^{th} percentiles compared those with less than 75^{th} percentile of T_{max} and T_{mean}. During heatwaves, higher daily rates of WRI were found compared to non-heatwave days (IRR 1.09, 95% CI: 1.02–1.17).

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
Martinez-Solanas E et al. (2018)[185]	All workers	Daily T_{max} and T_{min}	WRI claims (n=15,992,310)	DLNM and multivariate meta-regression model to pool the results across 50 provinces Controlled for seasonality and long-term trends using natural cubic B-spline of time (8 df/year), indicator for day of week, holidays, month and number of workers as an offset term Considered four time lags (0–3) Calculated the attributable risk and fraction to cold and heat	A U-shaped curve was found for the relationship between temperature and risk of WRI. Extremely high temperatures were associated with a 10% increase in WRI while cold days were associated with 4% increase in WRI. Overall, 2.4% of all WRI were attributed to heat with moderate heat accounting for the greatest fraction of WRI (2.2%). Heat accounted for an annual loss of 36 workdays per 1000 workers. In terms of economic losses, loss of working days due to heat had an annual cost of about €320 million. Vulnerable groups: men, women, younger workers, agriculture, construction, waste collection, transport, hotel industry, manufacturing, and extractive industries. Types of injuries: superficial injuries, bone fractures, strains, burns, and multiple injuries.
Calkins M et al. (2019)[189]	Construction workers	Daily HX	Work-related traumatic injury claims (n=63,720)	Conditional logistic regression with linear splines Restricted to warm months (March–October)	A 1 ºC increase in HX was associated with a 0.5% increase in odds of traumatic injuries. A nearly linear association was observed in the spline analyses. Vulnerable groups: young workers (18–24 years), older workers (>54 years), workers with less experience, smaller employers, workers working in Western Washington, and workers with lower extremity injuries.
Ma et al. (2019)[183]	All workers	Daily WBGT	WRI claims (n=9,550)	Quasi-Poisson regression with DLNM	There was a 15% increase in WRI at 30 °C WBGT compared to median WBGT (24 °C). Temperatures above 25 °C were attributed to 4.8% and 4.1% of WRI and insurance payouts. Vulnerable groups: male workers, small enterprises, and those with low educational attainment.

Study[a]	Population	Heat exposure indicator	Outcome indicator	Methods	Main results
Ricco M et al. (2019)[186]	All workers (EMRO migrant workers and EURO natives)	Daily T_{max} and T_{mean} Calendar days categorised by T_{min} and T_{max} as: • frost days (days with T_{min} <0 °C) • summer days (days with T_{max} >25 °C) • summer days/tropical nights (days with T_{max} >25 °C and T_{min} >20 °C) • neutral days (T_{min} >0 °C, T_{max} <25 °C) Heatwaves: T_{max} ≥35 °C for three or more consecutive days	WRI claims (n=147,024) Islamic Holiday (IH) time period=13,150	Multivariate logistic regression. Adjusted for sex and age of the workers. Relative humidity, atmospheric pressure, wind speed and solar radiation included as covariates.	An increased risk of WRI was found in EMRO migrant workers during the warm season (OR 1.41, 95% CI: 1.01–1.84). Increased risk of WRI in EMRO migrant workers during Islamic holiday period occurring during the hottest hours of the summer days, particularly during heatwave time periods (OR 1.74, 95% CI: 1.01–3.01). A reduced occurrence of WRI was found in EMRO migrant workers on 'summer days' occurring during the Islamic holiday period (OR 0.74, 95% CI: 0.59–0.92), while no significant increase was found on summer days with tropical nights (OR 1.21, 95% CI: 0.31–4.60).
Dillender (2019)[187]	All workers in Texas	Daily T_{mean}	WRI claims (n=1,916,590)	Fixed effect models Controlled for day fixed effects, year-month fixed effects, precipitation indicator variables	As temperatures rose above 21 °C, there was an increase in WRI rates. A day of temperatures above 30 °C–31 °C increases same-day claim rates by 7.6–8.2% and 3-day claim rates by 2.1–2.8% and that above 37 °C increases by 3.5–3.7%, relative to days with temperature of 15 °C–16 °C. Types of injuries: traumatic injuries.
	Mining workers across US		Daily WRI rates from mining sites (n=44,124)	Fixed effect models Controlled for precipitation, weather of the previous three days and proceeding two days, site-year-month fixed effects, and day fixed effects	A day with temperatures above 37 °C increases WRI rates by 6.9 per 100,000 workers or 67% relative to days with temperature of 15 °C–16 °C. Higher heat effects were found in warmer climates than in cooler climates among workers in the mining industry. It was found that an additional day above 32 °C resulted in more decline in weekly hours worked in cooler climates than in warmer climates.

Notes: [a] These studies are ordered by date of publication. T_{max}: maximum temperature; T_{min}: minimum temperature; T_{mean}: mean temperature; WBGT: Wet Bulb Globe Temperature; AT: apparent temperature; HI: heat index; HX: humidex; EHI: exertional heat illness; AI: acute injuries; UBI: unsafe behaviour index; HRI: heat-related illness; EMRO: Regional Office for the Eastern Mediterranean; WRI: work-related injuries.

2.5 REVIEW OF LITERATURE CONCERNING STAKEHOLDER PERCEPTIONS

The literature concerning the determinants of heat-related work injuries from stakeholder perspectives is addressed below. The rationale that underpins the development, analysis and interpretation of study methods presented in Chapters 8 and 9 (Section D) is also outlined.

The vulnerability to the health effects of heat exposure i.e. HRI and WRI depends on three factors: the levels of actual exposure, individual sensitivity, and the adaptation capacity of the worker.[198] As a result, actions taken in workplaces to prevent HRIs and/or WRIs due to hot weather is therefore likely to be determined by the perception of risks that individuals, supervisors, managers, and employers, associate with heat exposure. Understanding the knowledge and perceptions of stakeholders (including the health and safety representatives and safety professionals who are at the ‘coalface in controlling hazards’) can thus inform policy making, risk information and communication.

A targeted literature search was conducted in 2016 aiming to identify literature specific to the health effects of workplace heat exposure from a stakeholder point of view. The key search words used for this literature review were the same as those used in the previous review in Section 2.3, plus ‘safety and health representatives, safety and health management, safety and health professionals, OHS professionals, inspectors, safety managers, safety advisors, supervisors, and trade unions and safety’ and ‘perceptions’. The search revealed that literature specific to perceptions of these stakeholders was virtually non-existent.

An update to this search conducted in April 2019 yielded only two studies[199, 200] both of which used cross-sectional study designs, one targeting industrial hygienists and other specialists, and the other targeting workplace supervisors. These two studies are described below.

A study conducted by Xiang et al.[199] sought to examine hygienists' perceptions of extremely hot weather management in a warming climate and the current preparedness of workplaces for extreme heat. A survey was conducted of industrial hygienists attending the 2014 Australian Institute of Occupational Hygienists (AIOH) Inc. conference in Adelaide.[199] The findings showed that of the 180 participants, nearly 90% were at least moderately concerned about workplace extreme heat exposure; however 53% of participants were not willing to change their recommendations to management or companies.[199] While 90% of participants reported having heard workers express concerns over heat during hot weather, 53% reported having investigated injuries or illnesses attributed to extreme heat. Half (50%) of the participants were satisfied or strongly satisfied with current heat prevention measures adopted in workplaces, indicating that more needs to be done for better prevention. The study also indicated that lack of awareness, training, management commitment and low compliance of heat prevention policies were major barriers for heat prevention and adaptation.[199]

In contrast to the above-mentioned study the second study[200] was conducted in a developing country context. This study in Ghana assessed the perceptions of supervisors and other stakeholders in the mining industry, on climate change, occupational heat stress risks, and adaptation strategies.[200] The study utilised a concurrent mixed-methods approach involving questionnaires and interviews with

19 respondents. Findings showed that 56% of the participants were concerned about heat-stress morbidity and mortality. Some 87% of the mining supervisors reported having heard of workers' concerns about workplace heat exposure during hot weather conditions. More than half (56%) of the supervisors indicated that workers had heat-related injury concerns and that 37% of supervisors had witnessed injuries to mining workers, with the extent of injury being described as minor. The most common types of injuries reported by supervisors included burns from hot objects/surfaces and falls, trips and slips due to fainting, fatigue and dizziness.[200] This study also reported that adaptation strategies in mining sites included work breaks and rest, drinking water, using cooling systems and wearing loose and light-coloured clothing.[200]

Together, these two studies have gauged perceptions of stakeholders such as industrial hygienists and supervisors on workplace heat exposure risks. However, there are limitations to these studies such as the relatively smaller sample size and the purposive convenience sampling method employed which potentially limits the generalisability of the results.[199, 200] Moreover, these studies were not focussed on understanding the circumstances underpinning injury occurrence in hot weather which has implications for the design of preventive strategies aimed at reducing workplace injuries.

Additionally, it should not be overlooked that workers are also stakeholders. A combination of qualitative methods involving focus group discussions and interviews and quantitative methods involving cross-sectional surveys have been used to assess workers' heat awareness, knowledge and behaviours and risk factors for working in hot weather.[140, 201-204] These studies cover a wide range of workers including outdoor labourers,[140, 170, 205, 206] firefighters,[207, 208] farmers,[117-120, 204, 209-222] miners,[115, 202, 223] transport workers,[221] hotel and accommodation workers,[221] foundry workers,[221, 224, 225] manufacturing,[221] construction workers[116, 140, 206, 221] and oil-spill workers.[226] However, all these studies which focus on HRIs alone and not on heat-related work injuries, show that while workers may have good understanding of the heat and risks of HRIs overall,[140, 204] there is an element of normalisation of the risks, particularly in warmer locations where heat exposure is considered as ‘routine’ and as ‘part of the job’.[203] This normal acceptance of the risks by workers along with lack of awareness among supervisors and employers may mean that without interventions heat-related incidents, injuries, and deaths will continue to occur.

In summary, this section has highlighted that there is limited information available from stakeholder perspectives concerning the determinants of heat-related work injuries and prevention practices adopted in workplaces during hot weather.

2.6 GAP ANALYSIS

Together, Sections 2.3, 2.4 and 2.5 present a comprehensive review of current literature related to the effects of heat exposure on the risk of WRI and the risk factors from stakeholder perspectives. However, at the commencement of this research in February 2016 and from the original literature search, several gaps in evidence were identified, providing justification for the research presented in this thesis. Eleven identified gaps in evidence are outlined below.

1. There is a small body of previous research and lack of evidence in Australia.

Prior to 2016, a small body of epidemiological research[42, 43, 45, 122, 145] had investigated the relationship between high temperatures and WRI. While Adelaide, Australia was the location of two studies,[45, 145] there was a lack of evidence from other Australian cities with diverse climates, therefore warranting further research.

2. Why and how do occupational injuries occur during hot weather?

Studies[45, 122, 127, 132, 135] examining the link between WRI and hot weather had found that injuries occur in moderately and extremely hot conditions. However, there remained the need to elucidate the underlying reasons or potential mechanisms as to why these injuries occur. This is because while physiological explanations existed for HRIs, a direct biological mechanism for WRI was lacking. Varghese et al. (2018)[50] (see Section 2.3) identified that a range of factors including physiological, psycho-behavioural, organisational and work-related factors are likely to contribute to injury risks in workers during hot weather. However, there was a gap in knowledge about factors which are determinants of injury risks. By understanding the mechanisms behind injury risks, there is the potential to inform prevention practices both at the workplace and the worker-level.

3. Refining exposures for indoor/outdoor workers beyond the indoor/outdoor industrial classification.

There is a need to obtain a more refined measure of workers' potential environments of exposures as being simply 'outdoors' or 'indoors' based at the occupational level. This is because a number of studies[45, 127, 145] have defined work environments using a 'binary' category of either 'indoor' versus 'outdoor'[45, 145] or 'mostly indoor' versus 'mostly outdoor',[127] both based at the industrial classification. However, defining exposure this way introduces misclassification if workers work outdoors only some of the time or not at all. For example, the construction industry comprises a range of occupations including civil engineers, carpenters, plumbers, electricians, labourers, concreters, and administration staff (e.g. clerks, office staff). Some of these occupations are more likely to be frequently exposed to outdoor temperatures than others who may be occasionally or rarely exposed. This misclassification due to the heterogeneity in exposures within industry[187] is therefore likely to bias the comparisons between 'outdoor/indoor' workers towards the null as the exposed group is diluted with unexposed workers. Therefore, it is important to refine exposures for indoor/outdoor workers at the occupational level.

As administrative data sources such as the WC data that have been extensively used in previous studies[45, 127, 132, 135, 145] do not contain information on physical work conditions, the ability of epidemiological studies to assess exposure is limited. However, the US BLS Occupational Information Network (O*NET) tool[227] and the Canadian National Occupation Classification (NOC) codes[228] provide work context information in terms of the physical work conditions as to 'how often an occupation is required to work outdoors exposed to all weather conditions or under cover and indoors in controlled or non-controlled environments'. This information can be ascertained by conducting 'cross-walks' between the occupational codes and O*NET or NOC codes. The utility of either of these tools to Australian occupational codes have been documented in studies[229-232] assessing other workplace issues, and only one study[132] has used the NOC codes to refine exposures for indoor/outdoor workers. Although O*NET and the NOC codes provide more detail in the proportion of time a worker spends outdoors, it is important to note that these are still job exposure matrices, and the issue of misclassification still applies since all people in one job receive the same exposure assessment.

4. Comprehensive assessment of a range of risk factors to better characterise workers at risk in Australia.

Published literature prior to 2017 primarily examined the effect of factors such as gender,[42, 45, 127, 132, 145] age,[42, 45, 127, 132, 145] industry,[45, 127, 145] occupations,[42, 45, 145] and business size[145] for all workers combined. However, there was a gap in knowledge about how these factors affect the occurrence of heat-related injury risks in an Australian context.

Furthermore, gaps also existed in the understanding of the heat and work-injury risks in terms of: (a) workers' characteristics (e.g. experience, ethnicity and educational level); (b) work factors (e.g. physical demands, potential workplace temperature exposure, PPE); (c) workplace factors (e.g. location of workplace); and (d) organisational and prevention issues (e.g. policies, supervision, rest breaks, water, shade).

Furthermore, only two studies had examined mechanisms of injury[127, 145] and the nature of heat-associated work injuries[145] and gaps existed regarding other characteristics such as the agency of injury, body location of injury, and time of injury. A more comprehensive understanding of these injury characteristics together with the aforementioned risk factors constituting the worker, work, and work environment dimension as presented in Section 2.3 would be useful for risk assessment purposes.

5. Use of thermal indices in estimation of injury risk.

As indicated earlier in Section 2.3,[50] most studies had used temperature (e.g. $T_{max}/T_{min}/T_{mean}$) as a measure of heat exposure and very few had used thermal indices such as AT,[122] HI,[43] HX[135] and WBGT[44] that account for humidity, wind speed, solar radiation and air temperature. This is an important aspect to consider as the air temperature is only one among the many environmental factors which impact on workers' health and safety.[31] As such there is a need to use multi-variate thermal indices that summarise the influence of thermal environment stressors on WRI for an appropriate assessment of the problem and to get a clearer picture of the actual exposure in an Australian context.

6. Lack of denominator data.

It is known from occupational health studies that day-to-day variations in workforce participation across demographic, industrial and occupational settings are likely to influence WRI rates.[132] Indeed, the lack of appropriate denominator data (i.e. the number of people working on a particular day) to calculate and model WRI rates with heat exposure has been raised as a limitation by previous studies.[45, 133, 134]

The use of denominator data—either the number of workers or the hours worked—is a key determinant of the shape of the exposure-response curve. For example, some studies[45, 122, 135] have observed a reverse-U-shaped curve whereby the injuries only increase up to a certain point and then decline at extremely high temperatures. Other studies[43, 127, 132, 147] have found a U-shaped curve whereby injuries rise with increasing temperatures. This difference in the shape of the relationship between studies has been attributed to the lack of denominator data. Hence the decline in injuries at higher temperatures may not reflect the true reductions in risk, but rather could be an artefact of the possible reduction in the number of workers working during extreme heat. This may be due to work ceasing due to workplace heat policies or if the high temperature days coincide with summer vacations or public holidays. However, when denominator data are unavailable, the use of CCO study design, a commonly and extensively used method in environmental epidemiological studies is recommended. Only two studies[132, 135] were identified to have used the CCO design before 2017 and there is a need for more studies using this methodology to assess the association between heat and WRI while accounting for the lack of denominator data.

7. Use of modelling techniques to address non-linearity and lagged effects.

There is a need for studies to address the non-linearity and lagged effects of temperature on WRI as effects may be delayed rather than acute. Studies[45, 127, 132, 135, 188, 189] have utilised standard Poisson regression models with piecewise linear regression or flexible splines[45] and quadratic polynomials[132] to describe the shape of the temperature-WRI relationship. Furthermore, lagged variables of exposure are typically used in the models as sequential single individual lags. While these are valid methods in TS designs, with limitations,[233] DLNM models have been increasingly used in temperature-health studies in the general population. The advantage of the DLNM model is that it can simultaneously model the non-linear and lagged effects of temperature.[234] However, no occupational health studies using DLNM were identified from the review presented in Section 2.3.

8. Quantification of the burden of occupational heat-related injuries.

Published studies[42, 44, 45, 127, 132, 135] have typically quantified the effects of heat exposure on injuries using measures of association such as RRs, IRRs or ORs.

While these measures are useful to assess the strength of the relationships, other measures of impact such as the ‘attributable fraction’ or ‘population attributable fraction’ can be used to estimate the proportion of WRI attributed to the exposure, or that would be prevented if the exposure was avoided or minimised, respectively. These may be useful to measure the preventable public health burden and inform the development and implementation of strategies to prevent or control WRI caused by hot weather.[235-237] However, as indicated previously,[50] none of the studies presented in Section 2.3 had quantified the burden of heat-associated work-injuries this way, suggesting the need for further studies. Additionally, heat stress is known to result in labour productivity losses through reduced work capacity and efficiency and an impairment in physical performance.[238] More frequent occurrences of occupational injuries in hot weather is likely to therefore increase health service costs and reduced labour productivity, the impact of which had not yet been quantified.

9. Impacts of heatwaves on occupational injuries.

Evidence on the impacts of heatwaves on WRI is scarce and limited. Only two studies conducted in Adelaide[145, 146] have examined the effects of heatwaves on WRI. Both these studies used a heatwave definition based at a threshold of T_{max} of 35 °C for three or more days. However this threshold temperature may not necessarily define heatwave events in different locations, making comparisons and extrapolations of findings difficult in other locations due to diverse demographic, socioeconomic and climatic factors. There is therefore a need for studies to use consistent heatwave definitions such as the EHF which considers local climate and population adaptation.[17]

10. Alternative source of surveillance data.

The majority of the heat-work injury studies[45, 127, 132, 135, 145] based on surveillance data had used WC as the source of outcome data, while only one study[122] used hospital records. While WC data are useful, their limitations in terms of coverage is a well-documented aspect in the literature.[239, 240] Alternatively, occupational health studies[241-246] have demonstrated the utility of other surveillance data sources such as physician records, ambulance call-outs, hospital admissions and emergency department presentations. These data sources may complement the WC data to obtain the full magnitude of WRI and their impact on health service usage.

11. Stakeholder perceptions of risks of workplace heat exposure?

There is an identified lack of studies assessing risk factors for heat-related work injuries from a stakeholder perspective. Workplace health and safety professionals (HSPs) and health and safety representatives (HSRs) are key players in workplace safety management and the views of these stakeholders is key for developing and implementing effective prevention policies and programs to minimise the risk of WRI in hot weather. However, to date there have been no studies targeting the heat and work-injury perceptions of HSPs and HSRs.

2.6.1 Recent literature addressing these gaps

Subsequently, over the course of this research, some studies have addressed a number of the identified gaps in knowledge mentioned above. These studies[183-190] have been discussed in Section 2.4 where eight recently published studies are reviewed. Nevertheless, the majority of the studies identified from the original literature search[43, 44, 122, 127, 135] and the recent studies[183-185, 187, 189, 190] are based in other countries whereas evidence in Australia is limited.[45, 132, 145]

In this context, the research presented in this thesis (Chapters 4–9) addresses the identified research gaps and consequently serves two purposes. Firstly, it expands on previous research while contributing to the growing body of epidemiological evidence. Secondly, for Australia, a country known to be complacent about heat, it advances the knowledge base in WHS heat policy and management by filling gaps related to epidemiology, risk factors, and stakeholder perceptions, thus providing a comprehensive picture of the heat-work injury issue and informing prevention strategies.

2.7 CHAPTER SYNOPSIS

In summary, this chapter has provided the background underpinning the research presented in this thesis. This was accomplished by reviewing the existing literature on: (i) heat and WRI relationships and (ii) and the determinants of injury occurrence in hot weather from stakeholder perceptions. Sections 2.3 and 2.4 have provided an overview of existing literature concerning the effects of heat exposure on WRI. The results from studies discussed in these sections have confirmed that an association exists between workplace heat exposure and occupational injuries. Furthermore, the updated review in Section 2.4 indicates that the evidence base is growing as shown by the increasing number of recent studies. Section 2.5 has highlighted that studies pertaining to stakeholder perceptions on heat-related injuries, determinants, management and prevention is limited. Finally, Section 2.6 has outlined the research gaps confirming the need for studies to further examine the heat-work injury issue. In the following chapter, an overview of the study design and methods underpinning the research presented in this thesis is outlined.

03

Chapter 3: Study Design and Methodology

3.1 PREFACE

In this chapter, a brief background to the research project is provided in Section 3.2 followed by the overall aims and specific objectives of this thesis in Section 3.3. The research questions used to address these aims and objectives are listed in Section 3.4, followed by the description of the overall study setting, design and period in Section 3.5.

Section 3.6 covers the conceptual framework of the studies conducted in this thesis, followed by Sections 3.7 through to 3.9 describing the data sources and aspects of data collection and data management. A brief overview of the analytical methods is described in Section 3.10, while detailed statistical methods linked to each of the six studies undertaken are described later. Although efforts have been made to minimise repetition between the details provided in this chapter and those outlined in each manuscript, some may still exist.

3.2 BACKGROUND TO THIS RESEARCH

The research conducted in this thesis was part of a national project ‘Workers’ health and safety at high temperatures: new perspectives on injury prevention’ funded by the Australian Research Council (ARC) Discovery Program. Led by the University of Adelaide, the project also involved researchers from the Queensland University of Technology, University of Western Australia, and Monash University.

The aims of the larger project were to (a) systematically examine the association between ambient heat and occupational injury in Australia; (b) investigate a range of stakeholder perceptions towards heat-related injury, its prevention, and management; (c) generate new evidence to inform national injury prevention policy and guidance and (d) facilitate the development of practical resources for use in industries to aid in the prevention of heat-related injury.

The objectives were:

1. To extend investigations of the association between ambient thermal parameters (hot weather) and recorded WRIs and illnesses in Adelaide, and also in a further three Australian cities.
2. To characterise the recognition and management of heat-related injury, using a mixed-methods approach, incorporating a national online survey and a series of injury case studies.
3. To engage stakeholders and experts in the review and design of evidence-based preventive strategies.

To achieve the above mentioned research aims and objectives, the national project consisted of four distinct parts (see Figure 3.1), with the research contained within this thesis embedded in Parts 1 and 2.

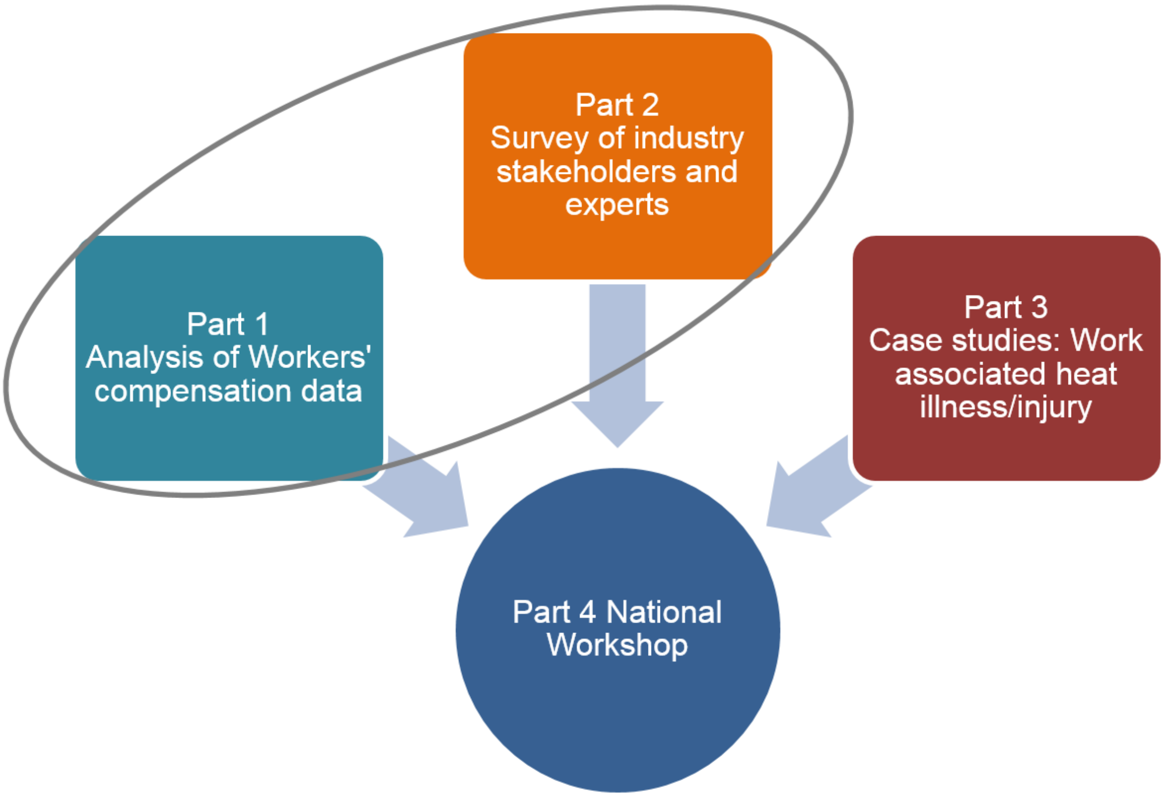


Figure 3.1 Project overview: study plan showing Parts 1–3 merging to inform Part 4, a platform for injury prevention.

While Aims (a) and (b) and Objectives (1) and (2) became the focus of the PhD (discussed in detail below) resulting in six studies (Chapters 4–9), attention is also drawn to three other associated studies from the project, the findings from which complement this PhD research (see other relevant manuscripts in page xxxvii).

3.3 AIMS AND OBJECTIVES OF THE RESEARCH WITHIN THIS THESIS

3.3.1 Aims

The overall aim of this research was to better understand the heat and work-injury phenomenon, and to: (1) quantify the relationship between ambient temperatures, and heatwaves, and the risk of WRI recorded in WC claims data; and (2) determine the underlying determinants of heat-related injuries, their management, and prevention based on stakeholder perspectives from workplace HSRs and professionals.

3.3.2 Objectives

The aims of this thesis will be attained through addressing the following objectives which are:

- To examine the effect of ambient temperatures and risk of WRI recorded in WC claims data from four Australian capital cities with diverse climates.
- To assess to the extent to which heatwaves of varying severity affect the risk of WRI recorded in WC claims data from four Australian capital cities.
- To identify the characteristics of workers at-risk during high temperatures and heatwaves.
- To better understand the nature of heat-related injuries in Australian workplaces, the potential risk factors and prevention measures being employed to reduce the effects of heat stress; and to characterise the potential barriers faced in workplaces for injury prevention.

3.4 RESEARCH QUESTIONS

Overall the occupational impact of hot work environments is multi-faceted (i.e. with effects on productivity, health and safety, industry policy and education, occupational hygiene and professional practice), with potentially wide reaching consequences. To attain the overall aims and objectives presented above and address the highlighted knowledge gaps presented in Chapter 2, a quantitative approach is used to address the following two research questions:

- What is the epidemiology of occupational heat-related injury in Australian cities?
    - Is there a relationship between ambient temperatures and heatwaves and the risk of WRI identified from WC claims in Adelaide, Brisbane, Melbourne and Perth?
    - How does the relationship between ambient temperatures and heatwaves and the risk of WRI vary according to work, worker, and work environment characteristics?
    - What are the types of injuries sustained with ambient heat exposure (high-temperatures and heatwaves)?
- What are the stakeholders' perceptions of occupational injuries occurring during hot weather?
    - How often do WRI occur in hot and/or humid weather and what types of injuries occur in workplaces where heat exposure could have been a (direct or in-direct) contributing factor?
    - What are the influencing organisational issues, work factors and hazards that are associated with heat-related injuries?
    - Which types of workers incur heat-related injuries?
    - What are the current prevention measures for indoor and outdoor workers and how often are these adopted in workplaces?
    - What are the levels of training, policies, risk assessment tools, and guidelines in relation to working in hot weather in workplaces?

- What are the potential barriers to the prevention of heat-related injuries in workplaces?
- To what extent does hot weather contribute to productivity loss and what are the potential solutions to address this issue?

3.5 STUDY SETTING

This section introduces the study settings of this research. Part 1 (analysis of WC claims data) focussed on four major Australian capital cities: Adelaide, Brisbane, Melbourne, and Perth, the capitals of the states of South Australia, Queensland, Victoria and Western Australia, respectively. These study settings and their relevant climate zones are shown in Figure 3.2. Part 2 (survey of stakeholders) was conducted nationally.

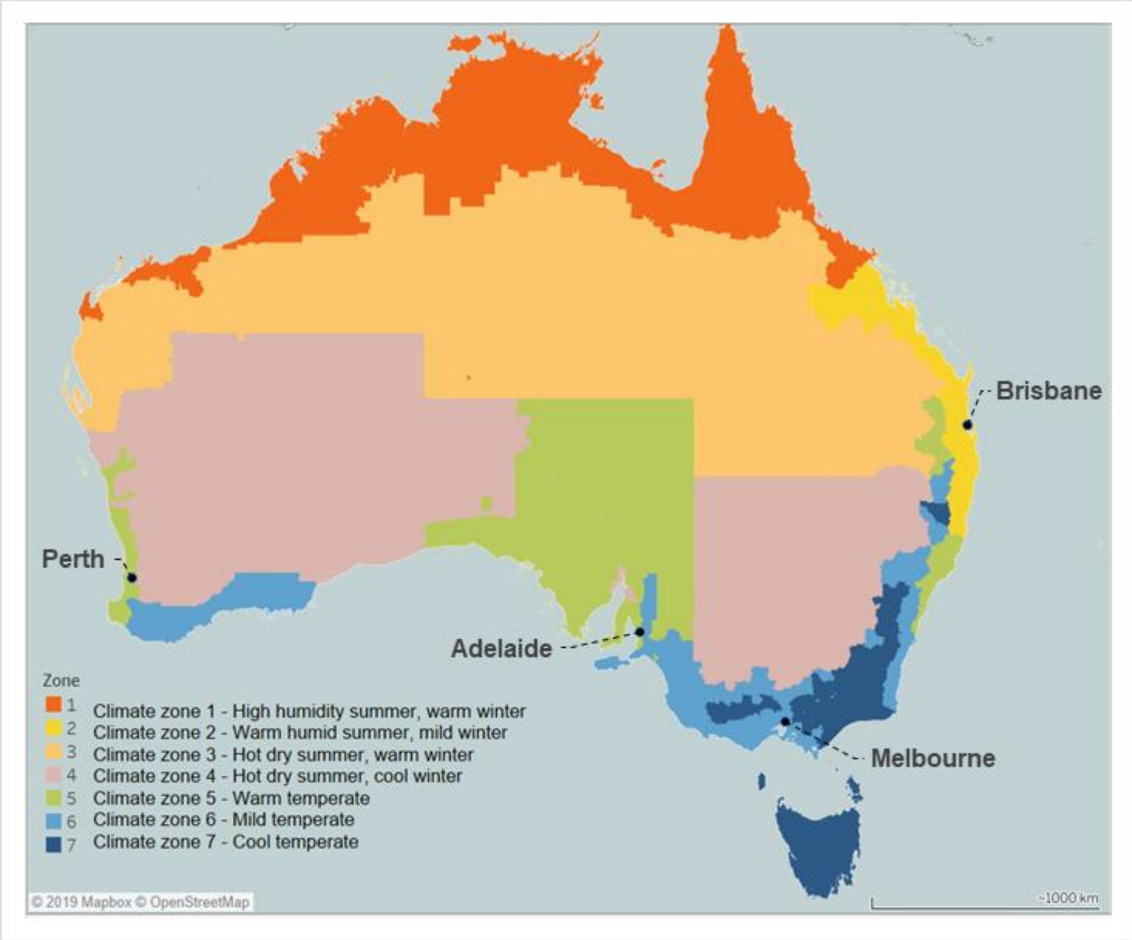


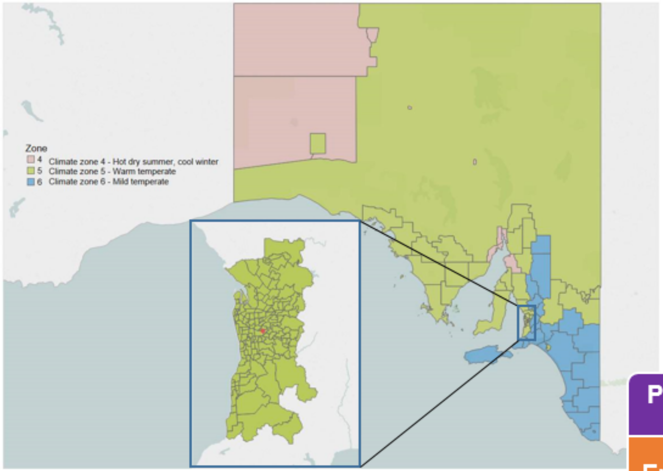
Figure 3.2 Climate zone map of Australia showing the location of the four study cities.

Source: Australian Building Codes Board (ABCB).[247]

The rationale for selecting the four cities used in Part 1, is three-fold. Firstly, these cities represent four of Australia's largest cities. Secondly, these cities have different climates which may influence an individual's response to heat stress (described below). Third, Adelaide and Melbourne have experienced severe and extreme heatwaves in Australia in recent years, whereas Brisbane and Perth regularly experience high summer temperatures.[248-250] Thus, workers in these four cities are likely to be faced with increased heat stress due to rising temperatures from climate change.[251]

The Australian Statistical Geography Standard of Postal Areas (POAs)[252] was used to define the central business district (CBD) and metropolitan areas in each of these cities. In each state except Queensland the majority of the population live in the metropolitan areas of the capital cities. As such, the geographical area for the study was restricted to the metropolitan areas of the study cities. The section below briefly outlines the characteristics of these cities in terms of their climate, and workforce demographics.

Adelaide, the capital city of the state of South Australia located in the southern part of Australia, is home to about 1.4 million people, making it the fifth largest city in Australia. According to the Koppen-Geiger climate classification,[192, 253] Adelaide has a temperate climate (Zone 5, Figure 3.3) also referred to as Mediterranean, with relatively mild winters and very warm to hot dry summers. Mean monthly temperatures in Adelaide range from around 11.4 °C to 23.4 °C. Besides having more hot days (i.e. days when T_{max} >35 °C) than Melbourne and Brisbane, in the last 30 years Adelaide has also experienced an average increase of 4.3 °C in the intensity of the peak day during heatwaves.[254] In comparison to the other three study cities, Adelaide has low levels of relative humidity (37% during November–March). Adelaide has a workforce of 587,100 people (78.8% of the state's employed workforce) according to the Australian Bureau of Statistics (ABS) 2016 Census, with most people working in the 'health care and social assistance', 'retail trade', 'education and training', 'construction', and 'public administration and safety' industries.[255]



Profile Area | **Population** | **Adelaide** | **Employment** | **Climate**

Population

People: 1.4 million
Male 48.9%
Female 51.1%
Median Age 39

Cultural diversity:
Country of birth:
Australia 67.7%

Other top responses
England (6.2%), India (2.1%), China (1.9%), Italy (1.4%), Vietnam (1.1%)

Population density: 404. 205/km²

Residential air-conditioning:
Reverse cycle/heat pump (58.8%)
Evaporative (25.5%)
Refrigerated (7.3%)
No air conditioner used (7.7%)

Workforce[3]

Employed total: 587,100 (78.8% in Metropolitan area)
Male 51.9%
Female 48.1%

Age distribution (%):

18-24	25-34	35-49	50-59	60-69
9.5	13.8	19.7	13.1	11.1

Top five occupations:

Professionals	22.3%
Clerical and Administrative workers	14.1%
Technicians and Trade workers	13.2%
Community and Personal Service workers	12.3%
Managers	11.5%

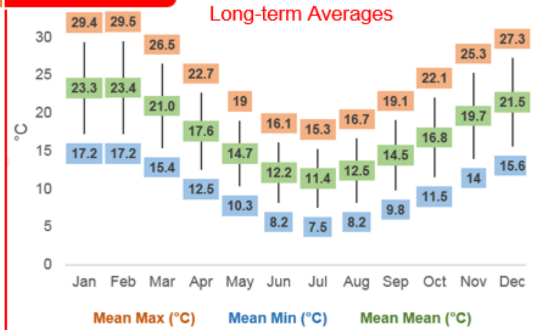
Top five industries:

Health Care and Social Assistance	15.6%
Retail Trade	10.8%
Education and Training	8.9%
Construction	7.8%
Public Administration and Safety	7.7%

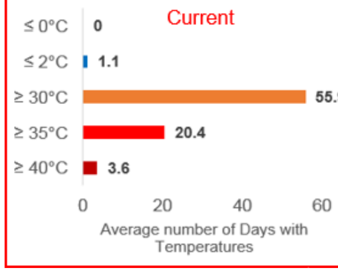
Outdoor or indoor industries (Xiang et al 2014):

Outdoor industry	12.0%
Indoor industry	88.0%

Long-term Averages



Current



Heatwaves

Number of heatwave days:
1950-1980: 5
1981-2011: 9
Length of longest event:
1950-1980: 4
1981-2011: 6

Changes in average intensity of the heatwave: 2.5 °C
Changes in average intensity of the peak day: 4.3 °C

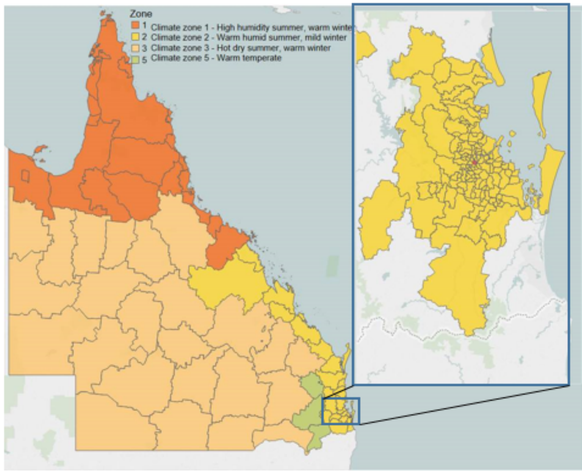
Changes in timing of first event (days): -2

Projections

Threshold	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
≥ 35°C	26 (24 to 29)	32 (29 to 38)	47 (38 to 57)
≥ 40°C	5.9 (4.7 to 7.2)	9.0 (6.8 to 12)	16 (12 to 22)
≤ 2°C	0.5 (0.8 to 0.4)	0.2 (0.4 to 0.1)	0.0 (0.0 to 0.0)

Figure 3.3 Summary profile of study area: Adelaide.[103, 109, 255-257]

Brisbane, the capital city of Queensland is located on the east coast of Australia and is the third largest city in Australia with a population of 2.3 million people. It has a humid sub-tropical climate (Zone 2, Figure 3.4) with relatively high temperatures throughout the year. Mean monthly temperatures in Brisbane range from 15.1 °C to 25 °C. Compared to the other three study cities, Brisbane has higher levels of humidity (58% during November–March).The city has an employed workforce of 1.2 million people or 50.3% of the state's employed workforce.[255] The top five industry sectors of employment are 'health care and social assistance', 'retail trade', 'education and training', 'construction' and 'professional, scientific, and technical services'.[255]



Profile Area | Population | Brisbane | Employment | Climate

Population

People: 2.4 million
Male 48.9%
Female 51.1%
Median Age 36

Cultural diversity:
Country of birth:
Australia 67%

Other top responses
New Zealand (5.4%), England (4.4%), China (1.5%), India (1.4%), South Africa (1.1%)

Population density: 145/km^2

Residential air-conditioning:
Reverse cycle/heat pump (59%)
Evaporative (1.6%)
Refrigerated (9.9%)
No air conditioner used (26.6%)

Workforce[3]

Employed total: 1,073,800 (50.3% in Metropolitan area)
Male 52%
Female 48%

Age distribution (%):

18-24	25-34	35-49	50-59	60-69
10.2	15.1	20.9	12.1	9.6

Top five occupations:

Professionals	22.9%
Clerical and Administrative workers	14.8%
Technicians and Trade workers	13.0%
Managers	11.8%
Community and Personal Service workers	10.9%

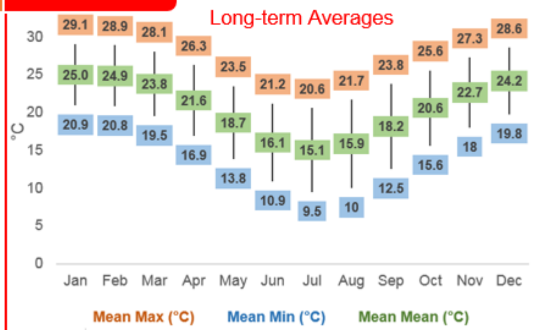
Top five industries:

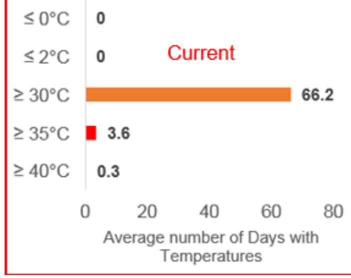
Health Care and Social Assistance	13.1%
Retail Trade	9.5%
Education and Training	9.2%
Construction	8.6%
Professional, Scientific and Technical Service	7.9%

Outdoor or indoor industries (Xiang et al 2014):

Outdoor industry	11.6%
Indoor industry	88.4%

Climate





Heatwaves

Number of heatwave days:
1950-1980: 10
1981-2011: 10
Length of longest event:
1950-1980: 6
1981-2011: 6

Changes in average intensity of the heatwave: 1 °C
Changes in average intensity of the peak day: 1.5 °C

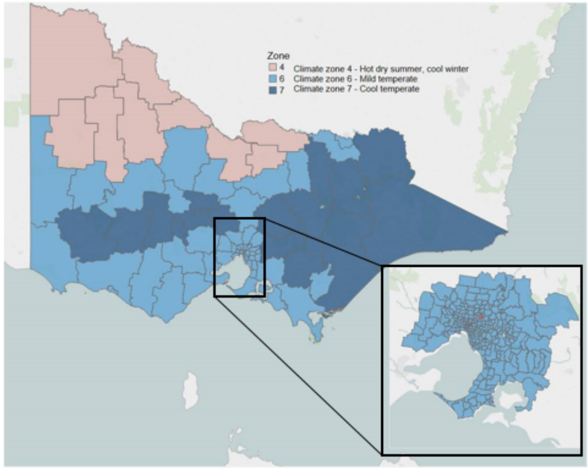
Changes in timing of first event (days): - 8

Projections

Threshold	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
≥ 35°C	18 (15 to 22)	27 (21 to 42)	55 (37 to 80)
≥ 40°C	1.2 (1.1 to 1.6)	2.1 (1.5 to 3.9)	6.0 (2.9 to 11)

Figure 3.4 Summary profile of study area: Brisbane.[103, 109, 255, 257, 258]

Melbourne, the capital city of the state of Victoria, is located on the south coast of Australia and is home to more than 4.4 million people. Melbourne's climate is mild temperate (Zone 6, Figure 3.5) with milder temperatures than the other three study cities in winter and moderate summer temperatures. Mean monthly temperatures in Melbourne range from 9.8 °C to 20.2 °C. In comparison to the other three study cities, Melbourne is known for its within-day changeable weather conditions. The city has an employed workforce of 2.1 million people or 77.4% of the state's employed workforce with the top five industry sectors of employment being 'health care and social assistance', 'retail trade', 'professional, scientific, and technical services', 'education and training' and 'construction'.[255]



Population

People: 4.8 million
Male 49%
Female 51%
Median Age 36

Cultural diversity:
Country of birth:
Australia 60%

Other top responses:
India (3.6%), China (3.5%), England (2.9%), Vietnam (1.7%), New Zealand (1.7%)

Population density: 453/km^2

Residential air-conditioning:
Reverse cycle/heat pump (35.8%)
Evaporative (23.5%)
Refrigerated (15.9%)
No air conditioner used (20.7%)

Profile Area | **Population**
Melbourne
Employment | **Climate**

Workforce[3]

Employed total: 2,115,500 (77.4% in Metropolitan area)
Male 52.6%
Female 47.4%

Age distribution (%):

18-24	25-34	35-49	50-59	60-69
10	16.3	21.1	11.9	9.3

Top five occupations:

Professionals	25.0%
Clerical and Administrative workers	13.9%
Managers	13.2%
Technicians and Trade workers	12.6%
Community and Personal Service workers	10.2%

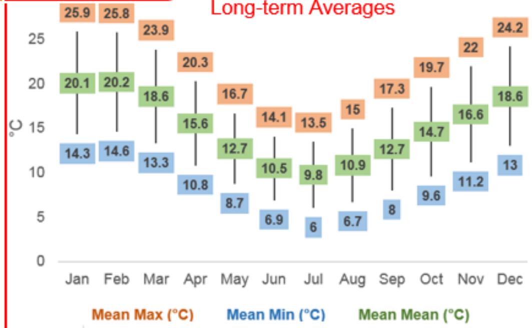
Top five industries:

Health Care and Social Assistance	12.0%
Retail Trade	10.1%
Professional, Scientific and Technical Services	9.0%
Education and Training	8.6%
Construction	8.2%

Outdoor or indoor industries (Xiang et al 2014):

Outdoor industry	10.0%
Indoor industry	90.0%

Long-term Averages

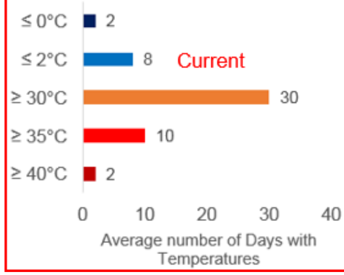


Heatwaves

Number of heatwave days:
1950-1980: 5
1981-2011: 6
Length of longest event:
1950-1980: 4
1981-2011: 4

Changes in average intensity of the heatwave: 1.5 °C
Changes in average intensity of the peak day: 2 °C

Changes in timing of first event (days): - 17

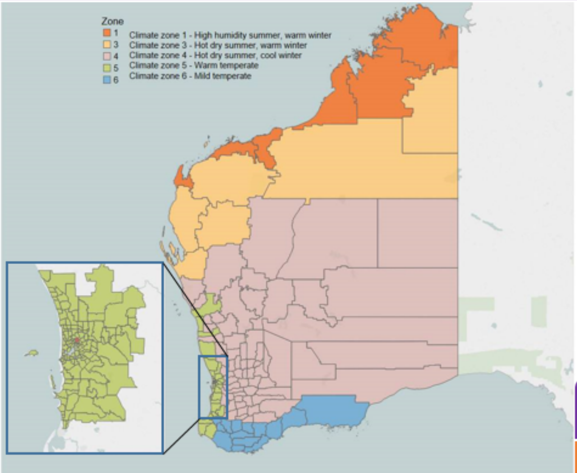


Projections

Threshold	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
≥ 35°C	13 (12 to 15)	16 (15 to 20)	24 (19 to 32)
≥ 40°C	2.4 (2.1 to 3.0)	3.6 (2.8 to 4.9)	6.8 (4.6 to 11)
≤ 2°C	0.6 (0.8 to 0.4)	0.2 (0.3 to 0.1)	0.0 (0.0 to 0.0)

Figure 3.5 Summary profile of study area: Melbourne.[103, 109, 255, 257, 259]

Perth is the capital city of the state of Western Australia and is located on the west coast of Australia. It has a warm temperate climate or Mediterranean type climate (Zone 5, Figure 3.6), similar to Adelaide, but has more hot days (>35 °C) than the other three study cities. Mean monthly temperatures in Perth range from 13.1 °C to 25 °C. The city has an employed workforce of 920,200 people (79.6% of the state's employed workforce). The top five industry sectors of employment are 'health care and social assistance', 'construction' 'retail trade', 'education and training', and 'professional, scientific, and technical service'.[255]



Population

People: 2.1 million
Male 49.5%
Female 50.5%
Median Age 36

Cultural diversity:
Country of birth:
Australia 57.1%

Other top responses
England (8.6%), New Zealand (3.2%), India (2.4%), South Africa (1.8%), Malaysia (1.5%)

Population density: 317.736/km^2

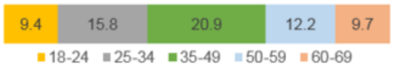
Residential air-conditioning:
Reverse cycle/heat pump (52.3%)
Evaporative (27.4%)
Refrigerated (8.2%)
No air conditioner used (11.5%)

Profile Area | **Population** | **Perth** | **Employment** | **Climate**

Employed total: 920,200 (79.6% in Metropolitan area)
Male 53.5%
Female 46.5%

Workforce[3]

Age distribution (%):



Top five occupations:

Professionals	22.2%
Technicians and Trade workers	15.6%
Clerical and Administrative workers	13.6%
Managers	11.5%
Community and Personal Service workers	10.8%

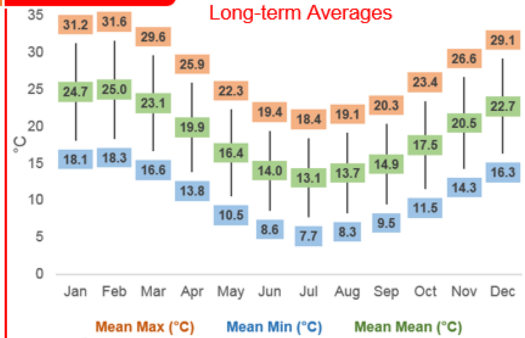
Top five industries:

Health Care and Social Assistance	12.3%
Construction	9.9%
Retail Trade	9.8%
Education and Training	8.8%
Professional, Scientific, and Technical Services	7.2%

Outdoor or indoor industries (Xiang et al 2014):

Outdoor industry	16.4%
Indoor industry	83.6%

Long-term Averages



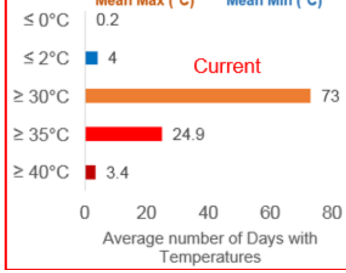
Heatwaves

Number of heatwave days:
1950-1980: 6
1981-2011: 9
Length of longest event:
1950-1980: 4
1981-2011: 5

Changes in average intensity of the heatwave: 1.5 °C
Changes in average intensity of the peak day: 1.5 °C

Changes in timing of first event (days): +3

Current



Projections

Threshold	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
≥ 35°C	36 (33 to 39)	43 (37 to 52)	63 (50 to 72)
≥ 40°C	6.7 (5.4 to 7.5)	9.7 (6.9 to 13)	20 (12 to 25)
≤ 2°C	2.1 (2.5 to 1.4)	0.9 (1.3 to 0.7)	0.1 (0.4 to 0.0)

Figure 3.6 Summary profile of study area: Perth.[103, 109, 255, 257, 260]

3.6 FRAMEWORK OF THE STUDY

This section describes the conceptual framework under-pinning the six studies conducted in this thesis as part of this research. To address the overall aims and proposed research questions, a multi-data approach was adopted, as the research questions posed cannot be appropriately answered using a single-data source. The utility of this approach is that different perspectives on the research problem under investigation can be obtained from multiple data sources, thus enabling a more comprehensive investigation. Two strands of data collection and analysis techniques were incorporated. These included data from existing databases and two online surveys, thereby enhancing the research validity and allowing a contextually rich dataset. Thus, the research methods applied in this thesis were largely quantitative, except for some open-ended survey questions (see Chapter 8).

As illustrated in Figure 3.7, Part 1 of the research, pertaining to Studies 1–4 (i.e. Chapters 4–7), involved detailed analysis of roughly 10 years of WC claims data to examine the association between ambient temperatures and heatwaves, and WRI. This also enabled the identification of vulnerable subgroups by worker, work and work environment characteristics. Study areas as described earlier were restricted to the metropolitan areas of four Australian main capital cities. For logistical reasons the study periods varied in study locations. For Adelaide the study period was 2003–2013, whereas for Brisbane, Melbourne and Perth the study period was 2005–2016. Studies 1–4 address the first research question of 'the epidemiology of occupational heat-related injuries in Australian cities' using principles of descriptive epidemiology, i.e. defining the 'what', 'who', 'when', and 'where' of the issue under investigation.

Part 2 of the research, comprising Studies 5 and 6 (i.e. Chapters 8 and 9), used responses from two national cross-sectional online surveys to elicit information on the underlying determinants of heat-related work-injuries, their management and prevention from a stakeholder point of view. Stakeholders surveyed included workplace HSPs and HSRs.

HSPs have a health and safety qualification and perform a broad range of activities (Figure 3.7), including inspection of workplaces, providing training to workers, advising and supporting the management on health and safety issues, risk assessments and controls, and ensuring that the workplace complies with laws and regulations.[261, 262] They have a broad range of roles and are usually employed in large-sized businesses or are employed by jurisdictional regulators as WHS inspectors.

HSRs on the other hand have a health and safety responsibility in their own workplace. They are the key to safety in the workplace as they operate at the interface between workers and management, representing the health and safety interests and concerns of workers to the management.[263-267] In Australia WHS legislations require that the employer consult with their workers on health and safety matters as 'reasonably practicable'.[268] This consultation usually occurs in most workplaces through either HSRs or committees, or both.

In essence, a snapshot of the issue of heat-related work injuries at many worksites and those specific to a worksite can be obtained by surveying HSPs and HSRs, respectively. The use of stakeholder perception surveys extends the research and the understanding beyond the use of WC claims. Thus, Studies 5 and 6 (i.e. Chapters 8 and 9) address the second research question of 'stakeholders' perceptions of occupational injuries occurring during hot weather' by looking at the 'how' and 'why' aspect of the issue under investigation. This part of the study provides a broad perspective on the views of key stakeholders from a workplace setting.

Put together, the studies presented within this thesis progress in a hierarchical manner, by enabling a broader picture to be drawn from a macro-population level perspective identifying clear blackspots, through to uncovering the circumstances underlying injury occurrence at a workplace level. Figure 3.7 shows how the six studies from Part 1 and Part 2 of the research come together to facilitate a better understanding of the issue under investigation. The different perspectives offered by both these sources of data allows for a comprehensive investigation of the research questions.

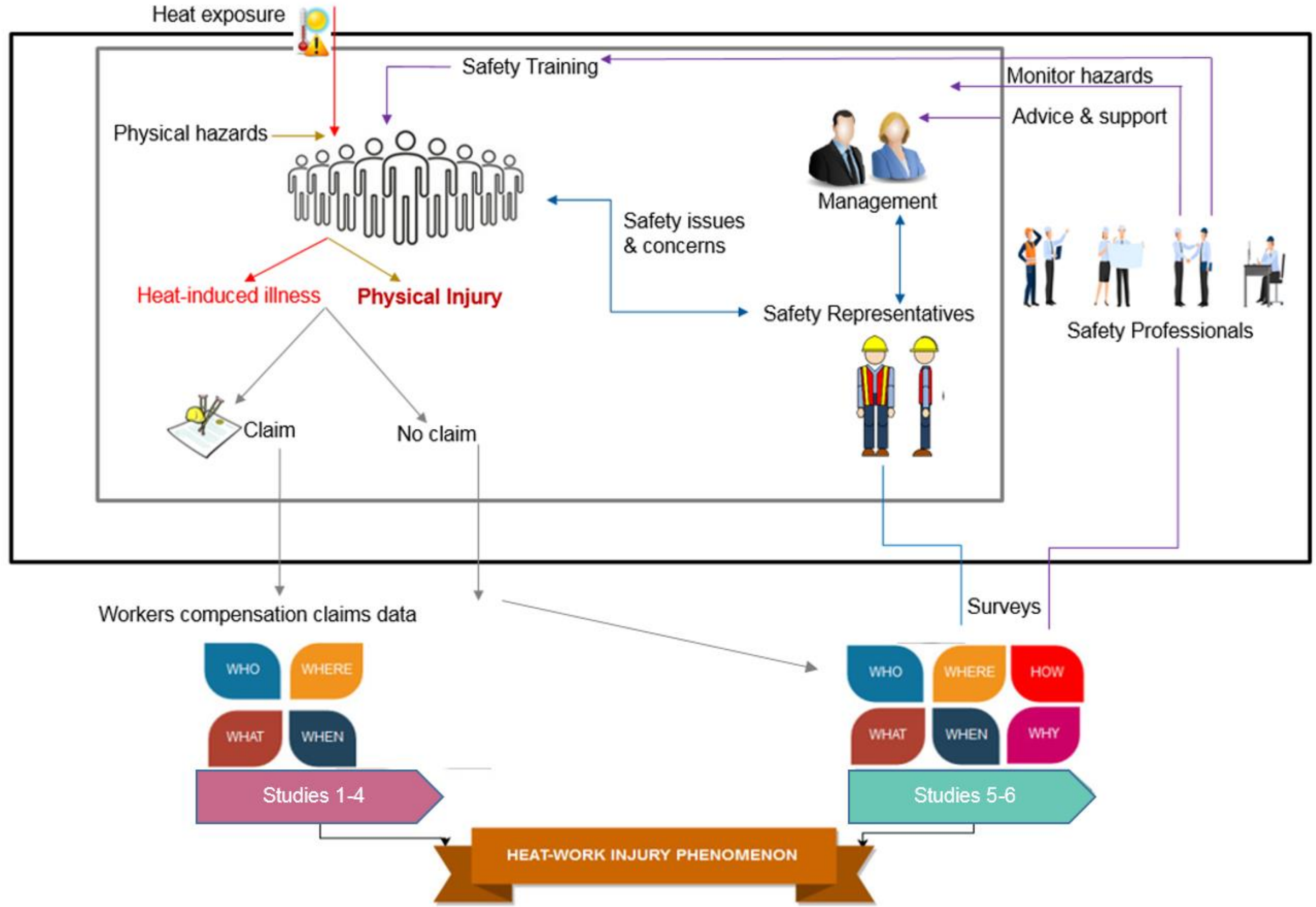


Figure 3.7 Schematic diagram outlining the framework of the studies conducted and presented in this thesis.

3.7 DATA SOURCES

3.7.1 Meteorological data

To examine the relationship between heat exposure and WRI, two exposure measures representing estimates of outdoor heat were used. These were daily T_{max}, and EHF, the latter being used to define heatwave severity.[182] Both these exposure measures were sourced from the Australian Bureau of Meteorology (BOM) with data from weather stations shown in Figure 3.8. For each city, data from one monitoring weather station identified to be representative of the city-specific metropolitan area by BOM, were chosen (see Table 3.1).

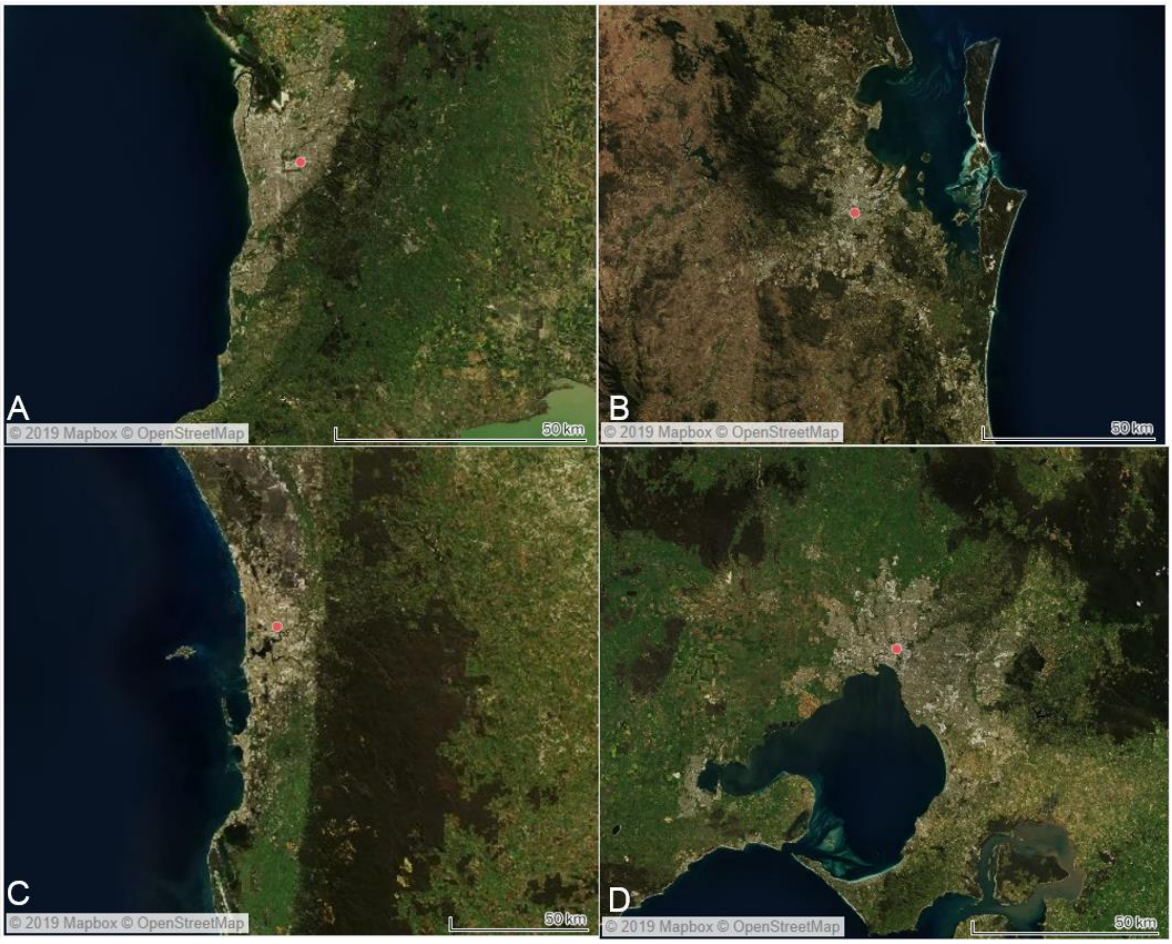


Figure 3.8 Weather stations used in each of the study areas: (A) Adelaide; (B) Brisbane; (C) Perth; (D) Melbourne.

Table 3.1 Australian Bureau of Meteorology weather observation stations from which daily exposure data were sourced.

City	Site name and number	Latitude	Longitude	Elevation (metres)	Reference
Adelaide	Adelaide (Kent Town) (023090)	−34.92	138.62	51	20, 21, 45, 145, 269-275
Brisbane	Brisbane (040913)	−27.48	153.04	8	248, 276-279
Melbourne	Melbourne Regional Office (086071)	−37.81	144.97	31	275, 276, 280-284
Perth	Perth (09225)	−31.93	115.98	15	282, 285-287

The rationale for choosing T_{max} as the main exposure metric in Studies 1 and 2 (i.e. Chapters 4 and 5) was two-fold. One, measures of temperature (T_{mean}/ T_{min}/ T_{max}) are highly correlated and therefore have similar predictive ability as demonstrated by previous studies.[288] Two, according to the BOM, T_{max} is the highest temperature for the 24 hours after 09:00 hours (usually occurring in mid-afternoon), thus characterising the utmost physiological stress experienced by workers at a time when they are most exposed and active on a given day.[288, 289]

While T_{max} was the selected exposure metric used in Chapters 4 and 5, other climatic data including daily T_{min}, daily T_{mean}, relative humidity (Rh %), wind speed (m/s), global solar radiation (w/m^2), and vapour pressure (hPa) were also obtained from the BOM. An example of the climatic data for seven consecutive days from one monitoring station in Adelaide provided by the BOM is shown in Table 3.2. These additional meteorological variables were used to calculate other thermal indices that incorporate air temperature and humidity, such as HI, HX, AT, Universal Thermal Comfort Index (UCTI), and WBGT (details provided in Appendix B.2-the supplementary material of Chapter 4). The thermal indices thus calculated were used in sensitivity analyses.

Table 3.2 An example of the data format of meteorological variables provided by Bureau of Meteorology for seven consecutive days from one monitoring station in Adelaide.

Station ID	Year	Month	Day	SR	T_{max}	T_{min}	T_{mean}	DP	WB	Rh	WS	VP	SP
23090	2003	7	1	5.53	15.8	6.8	11.3	8.5	9.7	86.1	4.2	11.2	13.2
23090	2003	7	2	7.79	16.4	5.8	11.1	7.9	9.2	84.9	4.8	10.7	13
23090	2003	7	3	8.76	16.4	6.4	11.4	7.6	9.4	81.1	5.7	10.5	13.5
23090	2003	7	4	6.22	16.5	9.1	12.8	9.8	11	87.1	8.1	12.1	14.1
23090	2003	7	5	11.4	18.5	8.3	13.4	5	9.3	60.3	12.1	8.7	15.3
23090	2003	7	6	10.6	18.7	10.7	14.7	2.3	8.9	45.1	18.9	7.2	16.3
23090	2003	7	7	10.8	17.8	9.8	13.8	6.7	9.9	67	8.6	9.9	15

Abbreviations:

SR: Total daily global solar exposure—derived from satellite data in MJ.m-2
T_{max}: Maximum temperature in 24 hours after 9am (local time) in degrees Celsius
T_{min}: Minimum temperature in 24 hours before 9am (local time) in degrees Celsius
T_{mean}: Mean temperature (using all available observations) in degrees Celsius
DP: Average daily dew point temperature in degrees Celsius
WB: Average daily wet bulb temperature in degrees Celsius
Rh: Average daily relative humidity in percentage (%)
WS: Mean daily wind speed in km/h
VP: Average daily vapour pressure in hPa
SP: Average daily saturated pressure in hPa

Considering that there is no universal heatwave definition,[16, 290] a newly proposed metric of heatwave severity used by the BOM in their national heatwave forecasting service, EHF was utilised across regions with different climates. EHF is a measure of heatwave severity that is relative to location factors in how ambient temperatures compare with the norm, and accounts for acclimatisation.[182] The more unusual the heat the higher the EHF severity value, with positive EHF values signifying the presence of a heatwave event. The BOM classifies the severity levels of heatwave events into three categories: low-intensity event; severe event and extreme event. These heatwave severity categories (EHF_{sev}) are location-specific as they are derived from the ratio of EHF to the historical 85th percentile of all positive EHF values at each location. Colour coded assessment and forecast maps produced by BOM and found on their website show the location, or predicted location, of heatwaves and their severity over a three-day period. An example of such a map is shown in Figure 3.9.[291]

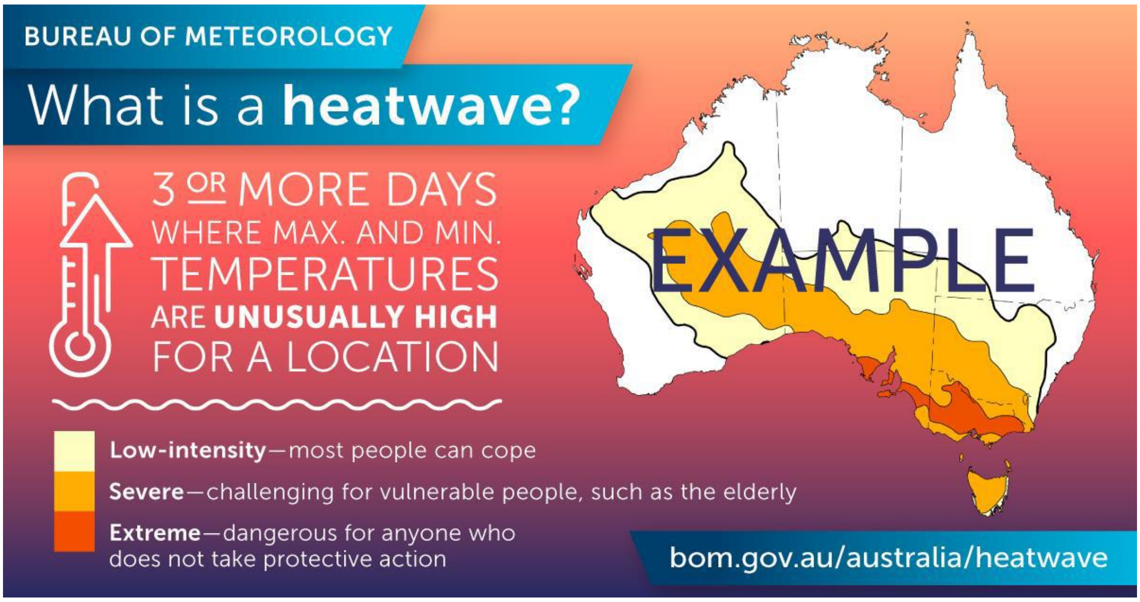


Figure 3.9 Schematic illustration of heatwave definition currently used in the National Heatwave Forecasting and Assessment Service in Australia.[291]

The EHF and EHF_{sev} metrics for each of the study sites were obtained from the BOM which uses low-resolution (0.25°x0.25°, approximately 25 km x 20 km) operational daily temperature analyses as described by Nairn and Fawcett in the calculation of the metric.[182] Additional details on how EHF_{sev} is calculated is provided in the supplementary material of Chapter 7. Briefly, the following EHF_{sev} categories were used in Chapters 6 and 7 to describe the intensity and severity of heatwaves:

- No heatwave: daily $EHF_{sev} \leq 0$
- Low intensity: daily $EHF_{sev} > 0$ and < 1
- Moderate severity: daily $EHF_{sev} \geq 1$ and < 2
- High severity: daily $EHF_{sev} \geq 2$

These categories of EHF_{sev} equate to the BOM's 'low', 'severe' and 'extreme' categories although the few 'extreme' days were included within the 'high' severity category. As there were few days of high-severity ($EHF_{sev} \geq 2$) in Brisbane, Melbourne and Perth, these days were included within the moderate-severity category to create a combined moderate/high-severity category (Chapter 7).

3.7.2 Workers' compensation (WC) claims

In Australia, there are eleven WC systems, one from each of the eight state and territories, one representing workers employed by the Commonwealth or the Commonwealth Authority (Commonwealth Comcare), one representing seafarers (Commonwealth Seacare), and one representing members of the defence force (Commonwealth DVA).[292] Together these WC systems cover the majority of workers (89–90% coverage of employed labour force) and are indeed an alternative source of injury data providing the most robust and more detailed information on workers who have incurred WRI under respective jurisdictions.[293] The WC data files contain information on the claimant, their employer, job characteristics, injury or illness details, and claims outcomes. The occupational and industrial details of the injured worker are classified in accordance with the Australian and New Zealand Standard Classification of Occupations (ANZSCO) and the Australian and New Zealand Standard Industrial Classification (ANZSIC), respectively.[294, 295] In the WC database, the injury details including the nature or type of the injury, event or exposure that led to the injury (mechanism of injury), body part or site affected, and the primary/secondary source of injury (agency of injury) are coded according to the Type of Occurrence Classifications System, Version 3.1 (TOOCS3.1) codes.[296] The longitudinal nature of the data, population coverage, and comprehensive and robust level of detail available makes WC data attractive to use for research by occupational epidemiologists.[239]

The term 'WRIs' according to WC legislation includes physical injuries and illnesses and the aggravation or acceleration of pre-existing injuries 'arising out of, or in the course of the worker's employment', all of which could be either acute or chronic in nature, respectively.[297-300] Workplace heat exposure can contribute to acute injuries at a point in time and the cumulative exposure may also lead to chronic injuries and illnesses over a period of time. As such, WC data for all injuries and illnesses for which a claim was made and accepted by the regulator/insurance provider regardless of severity were considered in this research, as per the approach taken in previous similar studies.[45, 145, 146, 301] It is acknowledged that the consideration of all claims as the outcome variable may possibly include illnesses resulting from long-term exposures, and this may introduce individual exposure classification errors. However, 90% of all accepted claims in Australia are due to injury and musculoskeletal disorders, both of which are reported as 'WRIs', while 10% of claims are for diseases with short-term and long-term latency periods.[72] For the purposes of this thesis, the terms 'all claims' or 'claims' and 'injuries' or 'injury' have been used interchangeably to describe 'WRIs and illnesses' or 'work-injuries', respectively.

Two sources of WC data were obtained, firstly from SafeWork SA (SWSA, Tabulator dataset) and Safe Work Australia (SWA, National Dataset for Compensation-Based Statistics, NDS3 dataset). Although both these sources of data capture information on WRI, the key difference is in their source: the first is a jurisdictional dataset (i.e. from South Australia) and the second is a dataset compiled using jurisdictional data from individual states and territories. The section below briefly describes these two data sources.

3.7.2.1 Workplace Health and Safety Tabulator (Tabulator)

In Chapters 4 and 6, the WC data came from the Workplace Health and Safety Tabulator database provided by SWSA, the data custodian at the time when the research was conducted (now Return To WorkSA is the data custodian).[146, 301-305] The Tabulator database covers all claims for WRI over the period 1 July 2003–30 June 2013 (2004–2013 financial years) that were accepted and compensated in South Australia.[304, 306] In Chapters 4 and 6, the data were restricted to the claims that occurred in the Adelaide metropolitan area—defined as postcodes between 5000 and 5200.[146, 270, 273, 274, 307] The complete list of variables in the Tabulator dataset is provided in Table A1, Appendix A. Before using the data for statistical analysis, the tabulator dataset was updated thus:

- Occupation codes assigned to each claims were upgraded from the previous Australian Standard Classification of Occupations (ASCO) codes to ANZSCO 3.1 which is the current and latest version of occupational classification.
- Injury classification codes were upgraded from TOOCS2.0-TOOCS3.0-TOOCS3.1 which is the current and latest version of injury classification.

Prior to data analyses, the data were subject to a range of data cleaning procedures consistent with previous studies using the data.[45, 293] Briefly, cases with missing industry or occupation codes, injury details, and those for persons under 15 years were excluded from the analysis (detailed flowchart of data preparation is shown in the supplementary material of Chapter 4, Figure B1, Appendix B2).

3.7.2.2 National Data Set for Compensation-Based Statistics (NDS)

The NDS was developed and endorsed by the National Occupational Health and Safety Commission (NOHSC) in 1987 as a prime comprehensive source of information on WRIs and illnesses at a national level and for comparative purposes between jurisdictions. The dataset is compiled by SWA using data supplied by WC authorities from each state, territory and the Commonwealth Government.[72, 308] In Chapters 5 and 7, WC data for claims lodged in Brisbane, Melbourne, and Perth were sourced from the third version of the NDS dataset (i.e. NDS3).[308] Details on information collected in NDS3 are provided in Table A2, Appendix A.

De-identified data on cases of accepted and compensated WRI occurring over the period 1 July 2005–30 June 2016 (2005–2016 financial years) was obtained from SWA upon receipt of jurisdictional approvals (see Appendix C for approvals) from:

a. South Australia: Return to Work South Australia

b. Queensland: Office of Industrial Relations—Queensland Treasury

c. Western Australia: WorkCover Western Australia

d. Victoria: Worksafe Victoria

As with the Tabulator data, the NDS3 data were subject to a range of data cleaning procedures before use. Consistent with studies using NDS3,[293, 309-314] claims with unlikely age ranges (i.e. <15 years and >100 years), abnormal weekly working hours prior to injury (i.e. <1 and >100 hours), those missing injury details, and/or occupation or industry codes, were excluded from the dataset. Also, a modified version of the TOOCS3.1 developed by researchers at the Monash University[293, 313] (see Table D1, Appendix D), was used to account for differences in injury coding changes within jurisdictions over time and inconsistencies in coding between jurisdictions. Additionally, to ensure comparable jurisdictional datasets, claims arising from travel to and from work were also excluded as such claims are not compensable in Victoria and Western Australia.[292] In order to consider the severity of the injuries, claims comprised minor and major claims. Minor claims were defined as claims where workers had an absence from work of less than one working week, while those with absences of one working week or more were classed as major claims. This definition of minor and major claims is based on the operational definition used by SWA.[72]

3.7.3 Work-related ambulance call-outs

An alternative source of health morbidity data, i.e. de-identified ambulance-call-outs data (excluding between hospital transfers) was sourced for the Adelaide metropolitan area from the South Australian Ambulance service (SAAS).[20, 21, 269] These data were used in the study outlined in Chapter 6. The study period was defined as 1 July 2003–30 June 2013, similar to that used in studies using the Tabulator dataset. For the purpose of this thesis, SAAS call-outs with a 'work-related/industrial' code were selected from the pre-defined categories for ambulance call-out data. It should be noted that compared to the WC data, there was no information about the industry, occupation, and injury details of the injured worker in this dataset, but nevertheless this dataset provides useful additional data from an alternative source. Indeed, the value of using different data sources of WRI has been identified by other researchers.[241-244, 315]

3.8 DATA MANAGEMENT

Due to the lack of information on the physical demands of occupations and workers' potential temperature exposure in the WC data, a 'cross-walk' (merge between classifications) was performed between the ANZSCO and the Canadian NOC classification system. Using this method, the physical demands, potential temperature exposure (outdoors[1]/indoors[2]), and potential workplace hazard allocated to each occupational title could be assigned to each claimant's ANZSCO coded occupation title. The process by which NOC codes are associated with each ANZSCO occupational title has been described elsewhere[316, 317] and has been previously used for WC data and validated in the Australian context.[132, 188, 231] According to the NOC codes[228], there are four categories of location where the work is performed assigned to each occupational group, and these were used to characterise the potential temperature exposure location in Chapters 4 to 7. These are: 'regulated indoor climates' (e.g. an office worker); 'unregulated indoor climates' (e.g. warehouse workers); 'outside' (e.g. road construction worker); and 'in a vehicle or cab' (e.g. transport workers).[228]

After the addition of the above described variables, the WC data and work-related ambulance call-out data were transformed into a TS structure comprising of a series of the daily counts of WRI and weather exposures, both of which were aggregated at the city level. Such a transformation of individual-level data to a TS format is computationally less-intensive for analysis as demonstrated by other researchers.[318-320] Other variables such as day of the week (1–7), day of the year,

[1] An outdoor work environment is defined as where worker is exposed to sun, wind, and rain.

[2] An indoor work environment is defined as being sheltered from sun and at least partially sheltered from wind and rain.

season (summer/non-summer), and public holidays were added to the TS transformed WC and work-related ambulance call-outs datasets. These variables are known to be potential confounders in the relationship between environmental exposures and health outcomes. Table 3.3 shows the list of public holidays included in the datasets.

Table 3.3 List of Public Holidays in Australia.[321]

National public holidays	Jurisdiction-specific public holidays				
New Year's Day		Vic	Qld	WA	SA
Australia Day	Easter Saturday	✓	✓	✓	✓
Labour Day	Melbourne Cup Day	✓			
Good Friday	Royal Show Day		✓		
Easter Monday	Adelaide Cup Day				✓
ANZAC Day	Foundation Day			✓	
Queen's Birthday					
Christmas Day					
Boxing Day					

An overview of the relevant variables of interest from the WC datasets used in the final analysis is illustrated in Figure 3.10.

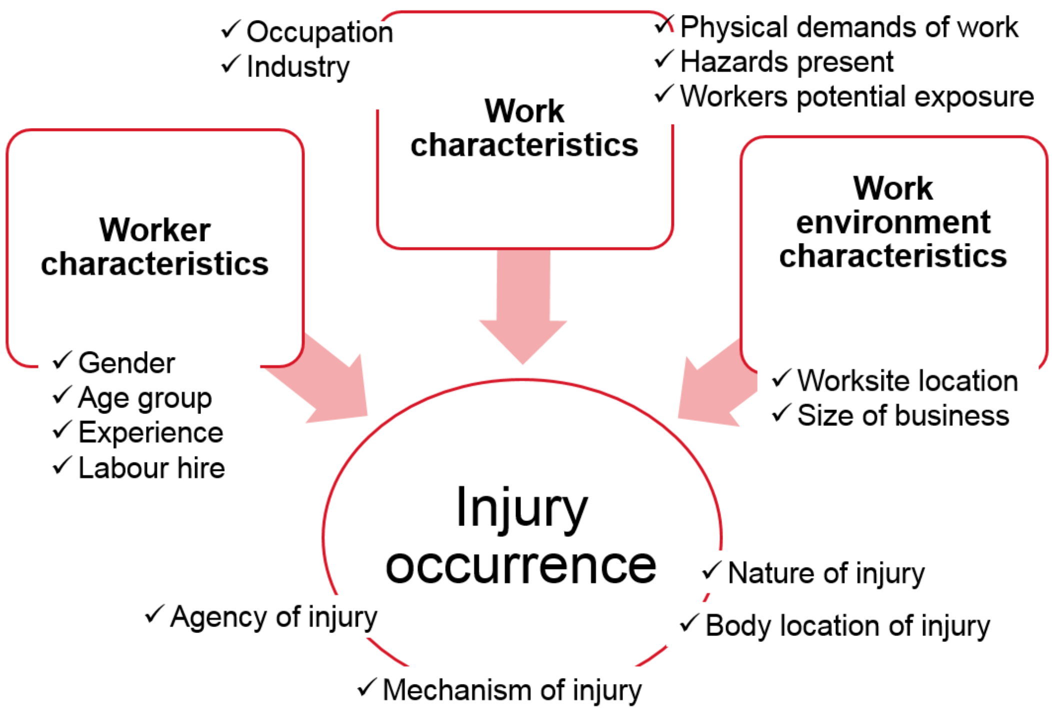


Figure 3.10 Variables of interest from the workers' compensation datasets after data processing divided into worker, work, work environment and injury occurrence characteristics.

3.9 STAKEHOLDER SURVEYS

3.9.1 Study population

As mentioned in Section 3.6, the study population for the surveys (Chapters 8 and 9) consisted of two stakeholder groups: HSPs and HSRs. Only individuals with a main responsibility of health and safety (e.g. safety consultants, health and safety managers, and inspectors) were recruited for the survey of HSPs. Other individuals for whom health and safety is part of, but not their main role, such as union officials, site supervisors, health and safety delegates and members of health and safety committees were recruited for the survey of HSRs. Engaging with these stakeholders was considered important to gauge their perceptions on current and future risks posed to workers' health and safety by high temperature days.

3.9.2 Data collection—participants and recruitment

To streamline and facilitate the recruitment process, a webpage (http://www.adelaide.edu.au/oeh/heat/) was developed for the ARC-funded project. Potential respondents were directed to visit this website where the landing page contained information about the project and the information sheet about the surveys, along with the links to the two online questionnaire surveys. Recruitment was assisted by SWA, state-based jurisdictional authorities, WHS professional bodies (e.g. the Safety Institute of Australia and the Australian Institute of Occupational Hygienists), unions (e.g. the Australian Council of Trade Unions and OHSreps), and industry contacts. Additionally, HSR training providers assisted by placing notices inviting participation on their websites, and newsletters and organisational internal emails (see examples of some notices in Appendix E). An information pack (Appendix F) with the 'general information about the research', together with one-page information sheets (Appendix G) were provided to these channels to dissipate the survey information to interested persons. Additionally, leaflets on the project and participation information sheets containing the links to the surveys were also placed at several OHS workshops/meetings/conferences.

The two anonymous and voluntary national online surveys were hosted using SurveyMonkey™ from March 2017 to early April 2018. Informed consent was provided by the respondents prior to completing the survey. Questions centred on heat-associated risks and direct and in-direct injury experience, how these risks were addressed, details of on-site training and heat health protection policies, and implications of heat on productivity loss. These questions were clearly structured under different sections. The final section had two open-ended questions so that participants could provide their comments related to recommendations for the prevention of heat-related injuries. Due to the nature of participant recruitment and distribution of survey information, a response rate could not be calculated for the surveys. Full details of the survey questions and the complete questionnaire are provided in the supplementary material of Chapters 8 and 9 (Appendix B6 and B7).

3.10 OVERVIEW OF ANALYTICAL METHODS

3.10.1 Analysis of occupational surveillance data

3.10.1.1 Study designs in existing literature

Prior to describing the statistical models used in Chapters 4–7, a brief introduction to some of the epidemiological study designs and methods used in environmental epidemiology is outlined below.

Descriptive,[322] case-series or case-only,[21, 323-327] case-control,[328, 329] CCO[319, 320, 330-340] and TS[9, 10, 16, 290, 341-352] are among a range of ecological study designs and models used in environmental epidemiological studies to assess and quantify the association between ambient temperature and health effects.[5, 7] Among these, CCO and TS are the most commonly used ecological study designs which, after controlling for potential confounding variables such as seasonality and temporal trends,[342, 353] aim to estimate the associations between exposure (daily temperatures) and health outcomes (daily counts of hospitalisations/deaths/ injuries). As mentioned in the literature review (Chapter 2), most previous studies[44, 45, 122, 127, 133, 134, 145, 183-185, 354] examining the effects of high temperatures on WRI have used TS designs. However, to precisely model the relationship, the number of workers (denominator) is to be taken into account and when such data are unavailable, the CCO design can be an alternate choice as discussed in Chapter 2.

3.10.1.2 Study design for this project

A CCO study design was used to examine the relationship between the risk of daily WRI and T_{max} (Chapters 4 and 5) and heatwave severity (Chapters 6 and 7). This design is a 'special case of matched case-control study' whereby the cases are matched with control days using a relatively small time window i.e. a calendar month, thus effectively controlling for both seasonal effects and secular long-term trends.[355, 356] This design, developed by Maclure (1991) only samples cases and compares the changes in exposures during the risk-period and the control-period to examine the risk of acute health events.[357] Figure 3.11 graphically illustrates the concept under-pinning the CCO study design.

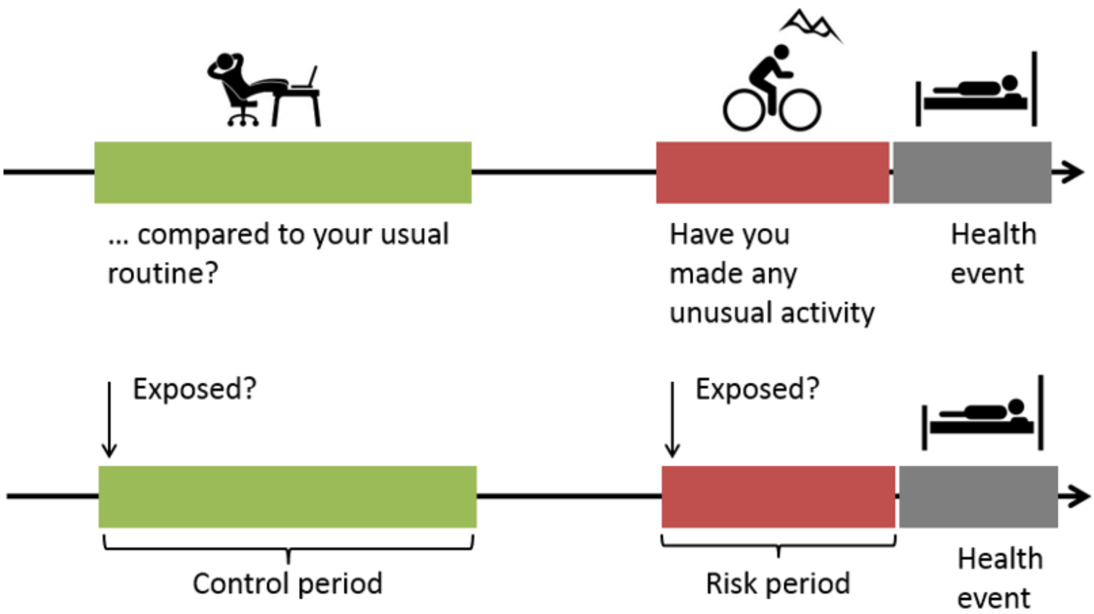


Figure 3.11 Case-crossover design conceptual diagram.[358]

While the CCO design was originally used for individual level data,[357] its useability in aggregated TS data[318-320] and equivalence to TS analysis[359-364] has also been demonstrated, especially as exposures measured at the ecological level (e.g. air temperature or pollution) are shared at the geographical level by the population under study.[359-361] In the case of aggregated TS data as in this research, 'cases' on the event day (day of the injury) are compared with their own 'controls' (day when the injury did not occur) on nearby days and it is the difference in exposures between the 'case days' and 'control days' that forms the basis of estimating the exposure-response.[319, 320] As 'control days' are chosen close to the 'case-days', by design, this implicitly controls for both known and unknown time-invariant individual confounding factors such as age, gender, fitness level, genetics, and occupational history which generally do not vary within a short time period.[356]

The selection of control days relative to a case day can be made using different designs such as the uni-directional design,[357] full-stratum bi-directional design,[365] symmetric bi-directional design,[366, 367] semi-symmetric design,[368] and the time-stratified design.[356] However, except for the time-stratified design, the potential for bias exists.[369-373] Uni-directional and symmetric bidirectional designs do not adequately control for trends over time in exposure or outcomes and bidirectional designs do not control for seasonal patterns in exposure or outcome.[370, 374]

The time-stratified method[356] using a fixed and disjointed window, i.e. a calendar month where case days are compared with only control days from the same strata was chosen in this research. This method of control selection is known to perform well in terms of overcoming overlap bias, an issue for the semi-symmetric design which randomly selects a control day before or after the case day with a non-disjointed strata.[370] For studies 1–4 (Chapters 4–7), a relatively narrow seven-day window for the strata was chosen for two reasons: firstly to remove the seasonal patterns in exposure, and secondly to account for the weekly changes in the numbers of workers, which can have a marked effect on injury/accident numbers. Estimates of the number of current workers in an industry are available only on a monthly level for the study areas. Hence, the CCO design avoids the need to use denominator data.

This approach of a narrow strata differs to the more commonly used monthly strata of 28 or 30 days where control days are selected on the same day of the week as the case day for other weeks in the same calendar month.[132, 188, 190] Hence, in this research a case day was compared to six other control or referent days within the same calendar week. For example, the temperature exposure for a worker injured on Wednesday is compared to temperature exposures on other days in the same week when the injury did not occur (Figure 3.12).

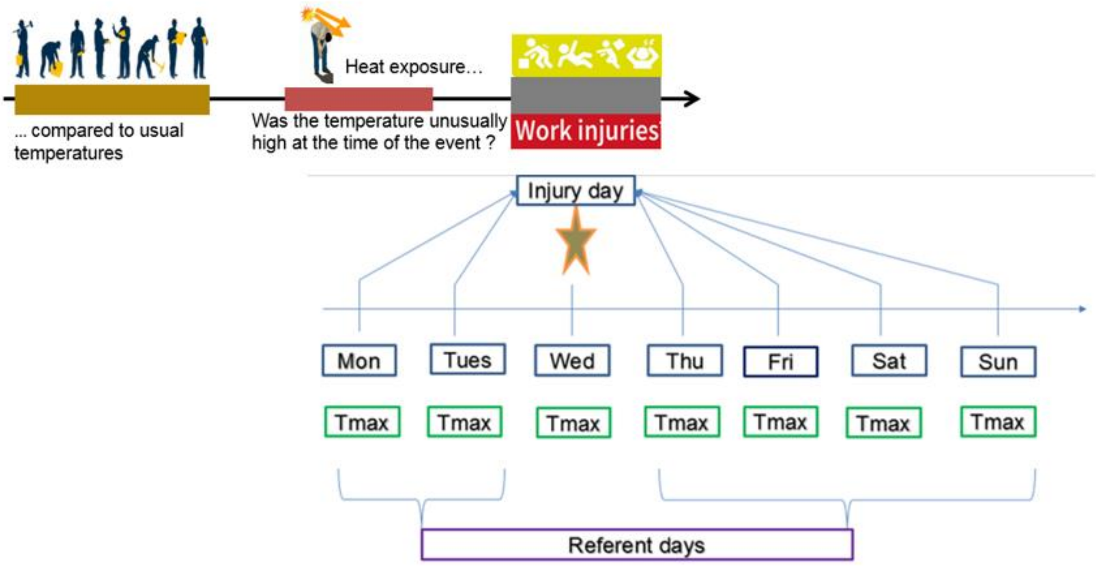


Figure 3.12 Conceptual diagram for the time-stratified case-crossover design used in this thesis.

In contrast to most CCO studies[132, 135, 188, 189, 331, 332] using conditional logistic regression models to generate ORs as effect estimates, the CCO models used in this research were fitted using generalised linear models (GLMs) assuming a Poisson distribution, thus providing RR as effect estimates. This approach is similar to that used in other existing studies.[190, 338] However, the choice of modelling approach for studies in Chapters 4 and 5 was different from that of studies in Chapters 6 and 7 as briefly described below.

3.10.1.3 Data analysis

Relationship between ambient temperature and work-related injuries

As mentioned in Chapters 1 and 2, the relationship between temperature (exposure) and health outcomes such as mortality/morbidity (response) has been described to be non-linear by numerous epidemiological studies, typically taking the functional form of a U, V or J-shaped curve.[9, 10] Figure 3.13 provides examples of how these exposure-response curves may look graphically, whereby the increases in health risks expressed as RRs are observed as temperatures depart from an optimal range i.e. at both extremes of temperature with a zone in the middle of the curve where the risks are either null or minimal.

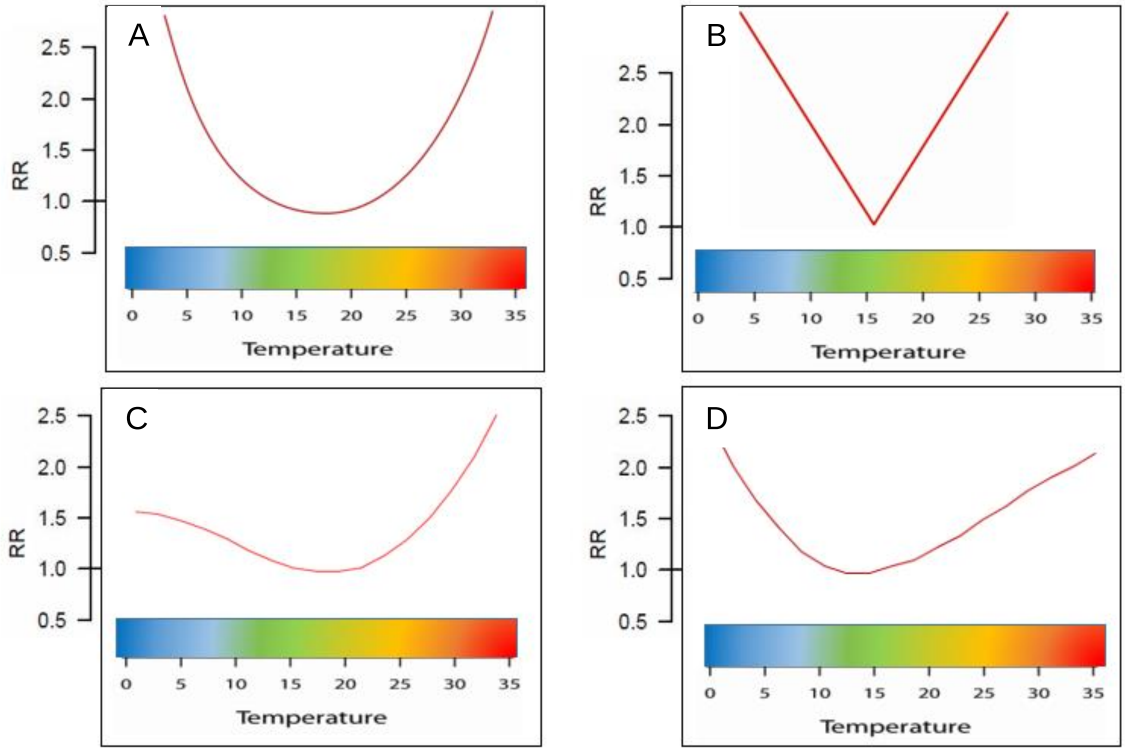


Figure 3.13 Common U-/V- or J- shapes shown in A-D, describing the relationship between ambient temperature and morbidity/mortality.

The non-linearity of the relationship is therefore one aspect that needs to be considered in the choice of modelling. Another aspect that needs consideration is that the effects of temperature may not be limited to the day of exposure, as there can be a lagged or delayed effect. This may occur if a WRI occurs from the ongoing effects of hot days. The DLNM model[234, 375] provides a modelling framework that simultaneously models the non-linear and lagged exposure-response relationships of temperature-health outcomes using a 'cross-basis' which is a bi-dimensional matrix combining two independent functions (predictor-temperature and lags).[234] A reference value of the predictor is used to report the quantified associations as RR.[234, 375]

Studies 1 and 2 (Chapters 4 and 5) therefore utilised the DLNM model combined with the CCO design to model the delayed and non-linear effect of temperature while adjusting for temperature collinearity on neighbouring days.[319, 320, 337, 338, 376] This modelling approach applied to the CCO design flexibly considers both the non-linearity of the exposure-response relationship and the lagged effect[234, 375] after controlling for temporal trends and seasonality by design.[338]

To allow an expected U-shaped association, a natural cubic spline with three degrees of freedom (df) was used to model the non-linear temperature effects, while lagged effects were modelled using two df based on previous studies using DLNM.[375, 377] A maximum lag of six days was used to fully capture lag patterns of temperature on WRI. Confounders such as days of the week and public holidays were controlled for in the models using indicator variables.

The effects of temperature on WRI were quantified as RR with 95% confidence intervals (CIs) using a reference value for the cross-basis upon which the DLNM model was built. In Chapter 4, the lowest point of the exposure-response curve across the whole temperature spectrum during the study period was taken as the reference value, while the median value of temperature was taken as the reference value in Chapter 5. This difference was mainly because of the nature of the associations as identified in the relevant chapters. The rationale for the use of the median value of T_{max} is that the 50th percentile of temperature represents a relatively typical temperature upon which other days could be compared.[8, 338, 376, 378-385] Thus, RR of WRI, comparing the 99th percentile (extremely hot) to the reference value, and the 1st percentile (extremely cold) to the reference value were calculated. Additionally, RR comparing the 90th percentile (moderately hot) to the reference value and the 10th percentile (moderately cold) to the reference value were also calculated. These choices of percentiles were based on previous heat-health studies using DLNM.[9, 380, 381, 386-390] Further details are presented in Chapters 4 and 5.

All statistical analyses were conducted using the R statistical software version 3.2.3, with packages such as ‘dlnm’ and ‘season’ used to fit the DLNM model and the CCO design.

Relationship between heatwaves and work-related injuries

In Chapters 6 and 7 the time-stratified CCO design was used to assess the association between heatwave severity (defined using EHF) and the risk of WRI. The risk periods were pre-defined periods of heatwave days and the referent period was all non-heatwave days. For the heatwave studies, the analysis was restricted to the warm-season (October–March in Study 3 and November–March in Study 4) and confounders such as day of the week and public holidays were adjusted. The CCO design was fitted using a GLM model assuming a Poisson distribution. Results are presented as RR with 95% CIs during heatwave periods of low, moderate and high severity, compared with non-heatwave periods during the warm season. Further details are presented in Chapters 6 and 7.

3.10.2 Stakeholder surveys

3.10.2.1 Study design

A cross-sectional descriptive design was used for the two national online surveys of HSPs and HSRs.

3.10.2.2 Data analysis

All the data from the surveys were exported from SurveyMonkey™ into an Excel database and later imported into a Stata 15 database (College Station, TX). The demographic distribution of the sample and responses to questions were summarised using descriptive statistics. The main outcome variables for both the surveys were derived from the perceived frequency of injury experience question. A detailed description of the outcome variables and the risk factors assessed is presented in Chapters 8 and 9.

Bivariate regression analyses using log-Poisson models presented as prevalence ratio (PR) with 95% CI were used to examine the relationship between reported perceived frequency of injury experience and risk factors (work factors and hazards, organisational issues, type of workers, and frequency of preventive measures).[118, 391, 392] Response options to a question on injury experience ("In your workplace (s), would you say that injuries or incidents caused by (partly at least) hot/very humid weather occur?") based on a 4-point Likert scale were combined to create a binary variable (never/rarely versus sometimes/often). The responses to a question on prevention measures ("How often are the following work practices adopted in your workplace(s)?") based on 5-point Likert scale, were dichotomised into 'never/rarely/sometimes' versus 'often/always'.[393-395] This was because the latter categories i.e. 'often/always' denote a relatively safer workplace as compared to one where prevention measures were used 'never/rarely/sometimes'. Multiple response questions regarding risk factors were converted into multiple dichotomies, whereby each of the responses within a question were assigned separate variables in the data file with the variables coded as 0 for No (not selected) and 1 for Yes (selected) with the counted value totalling 1.[396] The survey responses were analysed using Stata 15 (College Station, TX).

3.11 ETHICS

Given the collaborative nature of this project involving researchers from different institutions and using data covering multiple jurisdictions, several ethical approvals were required and thus obtained from each participating research University. Ethics approval for the analysis of the WC claims data and the two national online surveys were obtained from the Human Research Ethics Committees of the following institutions:

- The University of Adelaide (Ethics approval No: H-2016-085) (Appendix H1-H3)
- Queensland University of Technology (Ethics approval No: 1600000760) (Appendix H4)
- The University of Western Australia (Ethics approval No: RA/4/1/8583) (Appendix H5)
- Monash University (Ethics approval No: 0895) (Appendix H6)

No worker was identifiable in any of the datasets provided by SWSA, SWA and SA Health as the data were supplied in a de-identified format. No personal details were captured and links to the surveys provided were generic links with no unique identifiers, thus ensuring the participant rights, privacy, and confidentiality.

For the surveys, the ethical aspects were covered in the survey preamble which required the participants to provide a response whether they agree to continue with the survey or disagree with the information provided. Those selecting the agree to continue option proceeded with the survey and this was considered as an implied consent to participate, while those selecting the disagree option exited the survey. On the whole, this research used de-identified data and only members of the research team had access to the data.

3.12 CHAPTER SYNOPSIS

This chapter has described the study region, framework, main data sources, and analytical approach of the study.

Part 1: Workers' compensation (WC) claims

- Data on WRI among workers in Adelaide, Melbourne, and Perth (temperate climate) and Brisbane (sub-tropical climate) were sourced from two WC datasets: Tabulator (Adelaide data) and NDS3 (Brisbane, Melbourne, and Perth data).
- Data on heat exposure (T_{max}, and EHF_{sev}-defined heatwave severity) at the study sites were accessed from the BOM.
- Daily time-stratified CCO design combined with a DLNM model; and time-stratified CCO design combined with a GLM model adjusting for confounders, were used to characterise the effects of ambient temperatures and heatwave severity on WRI risks, respectively.

Part 2: Stakeholder surveys

- Two national cross-sectional online questionnaire surveys were conducted between 31 March 2017 and 4 April 2018 among HSPs, and HSRs, to gauge their perceptions on determinants of heat-related work injuries.

- Survey data were analysed descriptively and log-Poisson regression models were used to examine associations between the frequency of reported injury experience and specific risk factors, and the frequency of prevention measures in workplaces of HSRs and workplaces visited/managed by HSPs.

Summary of Section A

This first section of the thesis, consisting of two chapters, provided the basis, background, and design for the research presented in this thesis. The comprehensive literature review presented in Chapter 2 summarised the current knowledge regarding the association between heat exposure and WRI and that concerning stakeholder perceptions. In brief, the review and its update yielded 34 relevant yet diverse articles from countries across the world, albeit mainly from those in the Northern Hemisphere. The evidence showed a clear relationship between hot weather (also heatwaves) and a range of occupational injuries, with contributing factors to injury risk being fatigue due to the heat, loss of concentration and alertness, and reduced psychomotor performance. The review of stakeholder perceptions on heat and WRI identified only two studies while the majority were concerned with heat and HRIs, warranting the need for further studies. Finally, Chapter 3 outlined the study design, aims and objectives, research questions, conceptual framework of the study, main data sources, and rationale for the chosen study methods. The next section will focus on how ambient temperatures influence the risk of WRI.

SECTION B: AMBIENT TEMPERATURES AND WORK-RELATED INJURIES

Overview of Section B

This second section of the thesis, consists of two chapters. Chapters 4 and 5 collectively investigate the impacts of daily ambient temperatures on WRI. Chapter 4 reports on the analysis of WC claims data in Adelaide, Australia, while Chapter 5 reports on the analysis of the WC claims data in Brisbane, Melbourne and Perth. Together, these two chapters provide city-specific exposure-response curves and estimates in relation to daily ambient temperatures and WRI thereby providing an overview of the issue.

04

Chapter 4: Effects of Ambient Temperatures on the Risk of Work-Related Injuries and Illnesses: Evidence from Adelaide, Australia 2003–2013

4.1 PREFACE

The study (Study 1) presented in this chapter is the first of two studies that addresses the first and the third objective, and examines the effects of ambient temperatures on the risk of WRI in Adelaide, the capital city of South Australia with a temperate climate.

This study is an expansion of findings from a previous study by Xiang and colleagues[45] in Adelaide by not only examining the relationship between ambient temperatures and WRI but also quantifying the temperature-associated WRI burden at both moderate and extreme temperature ranges.

A time-stratified CCO study design combined with a DLNM model was utilised to examine the associations between WRI and daytime daily T_{max}. The CCO design controlling for season and secular trends, combined with DLNM accounting for the nonlinear and lagged effects of temperature on WRI, is a unique strength and novel aspect of this study.

This chapter has been published in the journal of Environmental Research as:

Varghese BM, Barnett AG, Hansen A et al. The effects of ambient temperatures on the risk of WRIs and illnesses: Evidence from Adelaide, Australia 2003–2013. Environmental Research. 2019; 170: 101–9. doi:10.1016/j.envres.2018.12.024.

4.2 STATEMENT OF AUTHORSHIP

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Publication Status	☑ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Varghese BM, Barnett AG, Hansen AL, Bi P, Hanson-Easey, Heyworth J, et al. The effects of ambient temperatures on the risk of work-related injuries and illnesses: Evidence from Adelaide, Australia 2003-2013.Environ Res. 2019; 170:101-9. https://doi.org/10.1016/j.envres.2018.12.024.

Principal Author

Name of Principal Author (Candidate)	Blesson Mathew Varghese		
Contribution to the Paper	B Varghese contributed to the study concept, method and analysis approach, gained ethics approval, extracted the data and performed data analyses, interpreted the data, prepared and submitted the manuscript and made corrections based on reviewer's comments and resubmitted the manuscript for publication.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	12/8/19

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Adrian Barnett		
Contribution to the Paper	A Barnett contributed to the study concept, assisted in the design of the study, data analysis, interpretation of data and results, reviewed and provided feedback on the manuscript		
Signature		Date	12/8/19

Name of Co-Author	Alana Hansen		
Contribution to the Paper	A Hansen contributed to the study concept, assisted in the design of the study, interpretation of data and results, reviewed and provided feedback on the manuscript, evaluated the revised manuscript against reviewers' comments, and supervised the development of work.		
Signature		Date	13/8/19

Name of Co-Author	Peng Bi		
Contribution to the Paper	P Bi contributed to the study concept, assisted in the design of the study, interpretation of data and results, reviewed and provided feedback on the manuscript, evaluated the revised manuscript against reviewers' comments, and supervised the development of work.		
Signature		Date	13/8/19

Name of Co-Author	Scott Hanson-Easey		
Contribution to the Paper	S Hanson-Easey contributed to the study concept, assisted in the design of the study, interpretation of data and results, reviewed and provided feedback on the manuscript.		
Signature		Date	13/8/19

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Contribution to the Paper	J Heyworth contributed to the study concept, assisted in the design of the study, interpretation of data and results, reviewed and provided feedback on the manuscript.		
Signature		Date	12/8/19

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Contribution to the Paper	M Sim contributed to the study concept, assisted in the design of the study, interpretation of data and results, reviewed and provided feedback on the manuscript.		
Signature		Date	12/8/19

Name of Co-Author	Dino L Pisaniello		
Contribution to the Paper	D Pisaniello contributed to the study concept, assisted in the design of the study, interpretation of data and results, reviewed and provided feedback on the manuscript, evaluated the revised manuscript against reviewers' comments, and supervised the development of work.		
Signature		Date	12/8/19

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The accepted version of the published paper is reproduced as follows.

4.3 PUBLICATION

4.3.1 Abstract

Background: The thermal environment can directly affect workers' occupational health and safety, and act as a contributing factor to injury or illness. However, the literature addressing risks posed by varying temperatures on work-related injuries (WRIs) and illnesses is limited.

Objectives: To examine the occupational injury and illness risk profiles for hot and cold conditions.

Methods: Daily numbers of workers' compensation (WC) claims in Adelaide, South Australia from 2003 to 2013 (n=224,631) were sourced together with daily weather data. The impacts of maximum daily temperature on the risk of WRIs and illnesses was assessed using a time-stratified case-crossover study design combined with a distributed lag non-linear model.

Results: The minimum number of WC claims occurred when the maximum daily temperature was 25 °C. Compared with this optimal temperature, extremely hot temperatures (99th percentile) were associated with an increase in overall claims (RR: 1.30, 95% CI: 1.18–1.44) whereas a non-significant increase was observed with extremely cold temperatures (1st percentile, RR: 1.10 (95% CI: 0.99–1.21). Heat exposure had an acute effect on workers' injuries whereas cold conditions resulted in delayed effects. Moderate temperatures were associated with a greater injury burden than extreme temperatures.

Conclusion: Days of very high temperatures were associated with the greatest risks of occupational injuries; whereas moderate temperatures, which occur more

commonly, have the greatest burden. These findings suggest that the broader range of thermal conditions should be considered in workplace injury and illness prevention strategies.

Keywords: Occupational Health; Temperature; Injuries; Case-crossover design; Attributable risk; Distributed lag non-linear model.

4.3.2 Introduction

The relationship between temperature extremes and adverse effects on population health is well documented, with increased risks for vulnerable groups such as the elderly, and those with chronic morbidities.[5, 28] To date, most of the research has focussed on the general population while the occupational health impacts on workers have received less attention.[25, 29, 30] Recent reviews[50, 397, 398] indicate that while studies have considered the effects of either high or low temperatures on work-injuries, there is limited research on the effects of both heat and cold conditions on injury risks for workers, thus calling for more research in this area.

In addition to heat or cold related illnesses, occupational injuries can occur when an individual’s coordination, strength, vision, endurance, or judgement are influenced by temperature-induced physiological changes.[33, 163, 178, 399] A US study examining the association between temperature and injury risk found that compared to ambient temperatures of 10 °C–16 °C, the odds ratios (ORs) of acute injury risks in aluminium smelter workers were: 2.28 (95% CI:1.49–3.49) between 32 °C and 38 °C; and 3.52 (95% CI: 1.86–6.67) above 38 °C.[43] In Australia, studies in Melbourne,[132] and Adelaide[45] have also shown increased risks for workers in hot weather and during heatwaves. On the other hand, studies have also reported a strong relationship between workplace injuries and cold temperatures.[185, 400-403]

An understanding of increased injury risk is important in light of scenarios of increasing, and more variable temperatures worldwide. In Australia, there has been a 27% increase in the number of hot days over 35 °C with further indications that this trend will continue.[404] Thus, while it is known that hot weather may pose an increasing threat to workers' health and safety in Australia, risks of injury and the temperature associated injury burden at other temperature ranges have not been investigated. This study aims to: a) examine the relationship between ambient temperatures and work-related injuries (WRIs) and illnesses; b) identify susceptible worker subgroups by occupation and their working environment (outdoor vs indoor); and c) quantify the burden of WRIs and illnesses in association with hot and cold temperatures in Adelaide, South Australia.

4.3.3 Materials and methods

4.3.3.1 Study setting

Adelaide (latitude 34°55'S, 138°35'E) is the capital city of South Australia and its population of more than 1.3 million comprises 78% of the state's population. The labour force in Adelaide in 2016 was estimated to be 636,115 with most employed in the 'health care and social assistance', 'retail trade' and 'manufacturing' industry sectors.[255] Adelaide has a Mediterranean climate with mild winters and warm to hot dry summers. Temperatures above 35 °C occur on average 17 days per year.[405] The warmest months are January and February with average daily maximum temperatures (T_{max}) of 29 °C and heatwaves are quite common. During winter (June–August) the average daily T_{max} is 15 °C–16 °C.

4.3.3.2 Data sources

Workers compensation (WC) claims data

Workers who have experienced a WRI or illness in South Australia can lodge a claim for compensation covering medical expenses and/or loss of wages.[297] The criteria for workers compensation as stated by the Return to Work Act 2014 is that the injury/illness sustained by the worker must arise from their employment.[297] All reported compensation claims in South Australia are aggregated and managed by the jurisdictional government-run regulator (SafeWork SA). Since 1987, surveillance of WRIs and diseases has been conducted using these data to identify target areas for prevention, as well as to evaluate safety improvement programs.[304] Details of each claim are recorded according to the Type of Occurrence Classification System (TOOCS 3.1).[296] WRIs were classified as those coded under the TOOCS3.1 nature of injury or disease code group A to group H and work-related illnesses were classified as those coded under the TOOCS3.1 nature of injury or disease code group I to group Q.[72] It should be noted that 90% of all compensation claims in Australia are for WRIs.[72]

The data for the period from 1 July 2003 to 30 June 2013 were drawn from a dataset of de-identified claimant information that included demographics (gender, age, industry sector, occupation), details of injury or illness (time, bodily location, type, mechanism and agency of injury) and outcome information (days lost from work and total expenditure). Information on the workers' level of experience was also available in the dataset i.e. 'new workers' (operationally defined as <1 year of experience at the time of the injury/illness). Those not meeting this criterion were considered as 'experienced workers'. Only 'active claims' (88.4% of all claims) determined to be valid claims by the regulator, were included in the analysis, while ‘pending’, ‘withdrawn’, ‘rejected’ and ‘incident’ claims were excluded (details provided in Figure B1, Appendix B2). Data were aggregated and restricted to the Adelaide metropolitan area (postcodes 5000–5200).[406]

Workers’ potential exposure to temperature in the workplace was examined at the industrial and occupational level. Consistent with previous research,[45, 145] the following industries were classed as ‘outdoor industries’: ‘agriculture, forestry, fishing and hunting’; ‘electricity, gas and water’; ‘mining’; and ‘construction’, while other remaining industries were classed as ‘indoor industries’. Considering the heterogeneity in exposures among a range of occupations within any one industry, a ‘cross-walk’ (merge between two classifications) between the Australian and New Zealand Standard Classification of Occupations (ANZSCO) system[294] and the Canadian National Occupational Classification (NOC) system[228] was performed to extract information on potential locations where the main duties of an occupation are conducted (e.g. ‘regulated indoor climates’, ‘unregulated indoor climate’, ‘outside’, ‘in a vehicle or cab’ and ‘multiple locations’). The process by which NOC codes are associated with each occupational title has been described elsewhere[316, 317] and validated in the Australian context.[132, 231, 232] Additionally, occupational groups were further characterised (Table I1, Appendix I) according to the method of Carey et al.[407]

4.3.3.3 Meteorological data

Weather data including daily T_{max} (highest temperature in the 24 hours after 09:00 hours) and minimum temperatures (T_{min}- lowest temperature in the 24 hours before 09:00 hours), relative humidity, global solar radiation and vapour pressure were obtained for a central Adelaide weather station from the Australian Bureau of Meteorology (BOM).

4.3.3.4 Study design

A time-stratified case-crossover (CCO) design was used to examine the relationship between the risk of daily WC claims (comprising WRIs and illnesses) and daily T_{max}. This design controls for known and unknown time-invariant individual confounding factors such as age, gender and fitness level which generally do not vary within a short time period.[357] The advantage of this study design is that it does not require denominator data (i.e. the number of workers) for which estimates were unavailable on a weekly basis. In this study, the 'cases' are accepted WC claims for a WRI or illness sustained by a worker aged above 15 years at a workplace situated in the Adelaide metropolitan area. To avoid overlap bias that can occur in uni- or bi-directional design, a time-stratified CCO method was selected which uses a fixed and disjointed window where case days are compared with control days from the same strata.[356] We used a seven-day strata as weekly changes in the number of workers (particularly over the summer and the festive season break) can have an effect on injury/claim numbers. Hence, the exposures on the case day (day of the injury) are compared with exposures on control days (other six days in the same calendar week when the injury did not occur). We fitted the CCO using a generalized linear model (GLM) assuming a Poisson distribution.

4.3.3.5 Statistical modelling

A distributed lag nonlinear model (DLNM) was used to model the delayed and nonlinear effect of temperature while making adjustments for temperature collinearity on neighboring days.[234, 375] A natural cubic spline with three degrees of freedom (df) was used to model the nonlinear temperature effects to allow for an expected U-shaped association, while lagged effects were modeled using two df. A maximum lag of six days was chosen. Days of the week were controlled for in the models using an independent binary variable for each seven-day window except Friday, which was the reference day. Effects of public holidays were also controlled for by creating indicator variables for 'Christmas Day' and 'New Year's day' (which occur during the Australian summer) and an indicator for all other public holidays. Residuals were plotted and assessed for approximate normality, outliers, and autocorrelations, and the variance inflation factor was used to check for collinearity in the predictor variables. Initial residual checks led to the modeling of New Year's Day as a separate variable.

The lowest point of the exposure-response curve across the whole temperature spectrum, i.e. the temperature at which the claim risk was lowest, was 25 °C (i.e. 65th percentile of T_{max}). This point, referred to as the optimal temperature (OT), was the reference value. We calculated the relative risks (RRs) of claims at moderately hot (90th percentile) and extremely hot (99th percentile) temperatures, and at moderately cold (10th percentile) and extremely cold (1st percentile) temperatures compared with the OT.[185] Subgroup analyses by the worker, work, workplace and injury characteristics were conducted for the WC claims data to define factors with relatively strong associations with temperature.

T_{max} was selected as the exposure metric, although we also calculated other meteorological indices that incorporate air temperature and relative humidity (i.e. Apparent Temperature (AT), Humidex (HX), Heat Index (HI), Universal Thermal

Climate Index (UTCI) and Wet Bulb Globe Temperature (WBGT) for sensitivity analyses (details provided in the supplementary material, Appendix B2).

4.3.3.6 Computation of attributable risk

The burden of WC claims due to hot and cold temperatures was calculated using 25 °C as the reference temperature. We used the 'backward perspective' approach where the series of past exposure events are attributed to the present risk of WRI and illness.[236] The total attributable number (AN) of claims due to non-optimum temperatures was derived by adding the contributions from all days during the study period, and its proportion in the total number of claims provided the total attributable fraction (AF). The claims attributable to hot and cold temperatures were calculated by summing the claims from days with temperatures higher or lower than 25 °C, respectively.

The overall temperature-related effect was further stratified into moderate and extreme conditions according to the method of Gasparrini and Leone [(236)] In line with previous studies,[185, 236] temperatures between 25 °C and the 97.5th percentile and those higher than the 97.5th percentile were classified as moderate and extreme heat, respectively; and temperatures between the 2.5th percentile and 25 °C and those lower than the 2.5th percentile, were classified as moderate and extreme cold, respectively. Empirical 95% confidence intervals (CIs) were obtained for AF and AN using 5000 Monte Carlo simulations assuming a multivariate normal distribution of the reduced coefficients.[236]

All statistical analyses were conducted using R statistical software version 3.2.3, with the packages 'dlnm' and 'season' to fit the DLNM model and the CCO design.[355, 375] The attributable risks (AF and AN) were calculated using the function ‘attrdl’.[236]

Ethics approval for the study was granted by the Human Research Ethics Committee of the University of Adelaide.

4.3.4 Results

4.3.4.1 Descriptive statistics

Over the study period the daily T_{max} in Adelaide ranged between 9.9 °C and 45.7 °C with a mean of 22.9 °C. There were 224,631 active claims submitted in the Adelaide metropolitan area during this period. On average, there were 61 claims per day, of which 55 were injury-related (TOOCS3.1 nature of injury/disease code Group A–Group H) and 6 were illness-related (TOOCS3.1 nature of injury/disease code Group I–Group Q). The annual number of claims ranged from 17,745 and 28,834 with a 38% reduction in the number of claims from 2003/04 to 2012/13 financial years (supplementary Figure B3, Appendix B2). About two-thirds of all claims occurred among males and about 48.6% occurred in people aged 35–54 years (see supplementary Tables B2-B4, Appendix B2).

4.3.4.2 Exposure-response relationship

Overall association

The cumulative association between temperature and WC claims is shown in Figure 4.1A. A J-shaped association was observed between all WC claims and daily T_{max}, with significantly higher RR above 25 °C. The overall RR for moderately (90th percentile, 33.3 °C) and extremely hot temperatures (99th percentile, 40.6 °C) were 1.08 (95% CI: 1.05, 1.12) and 1.30 (95% CI: 1.18–1.44), respectively. The increase in injury claims at extremely hot temperatures was greater than that for illness claims (RR=1.48, 95% CI: 1.08–2.04 vs. RR=1.30, 95% CI: 1.17–1.44; Figure 4.1B). For moderately (10^{th} percentile, 15 °C) and extremely cold temperatures (1^{st} percentile, 12.6 °C), the overall RRs were 1.08 (95% CI: 1.01–1.15) and 1.10 (95% CI: 0.99–1.21), respectively. The effects of heat on WC claims were acute and immediate while that of cold were delayed (see supplementary Figure B4, Appendix B2).

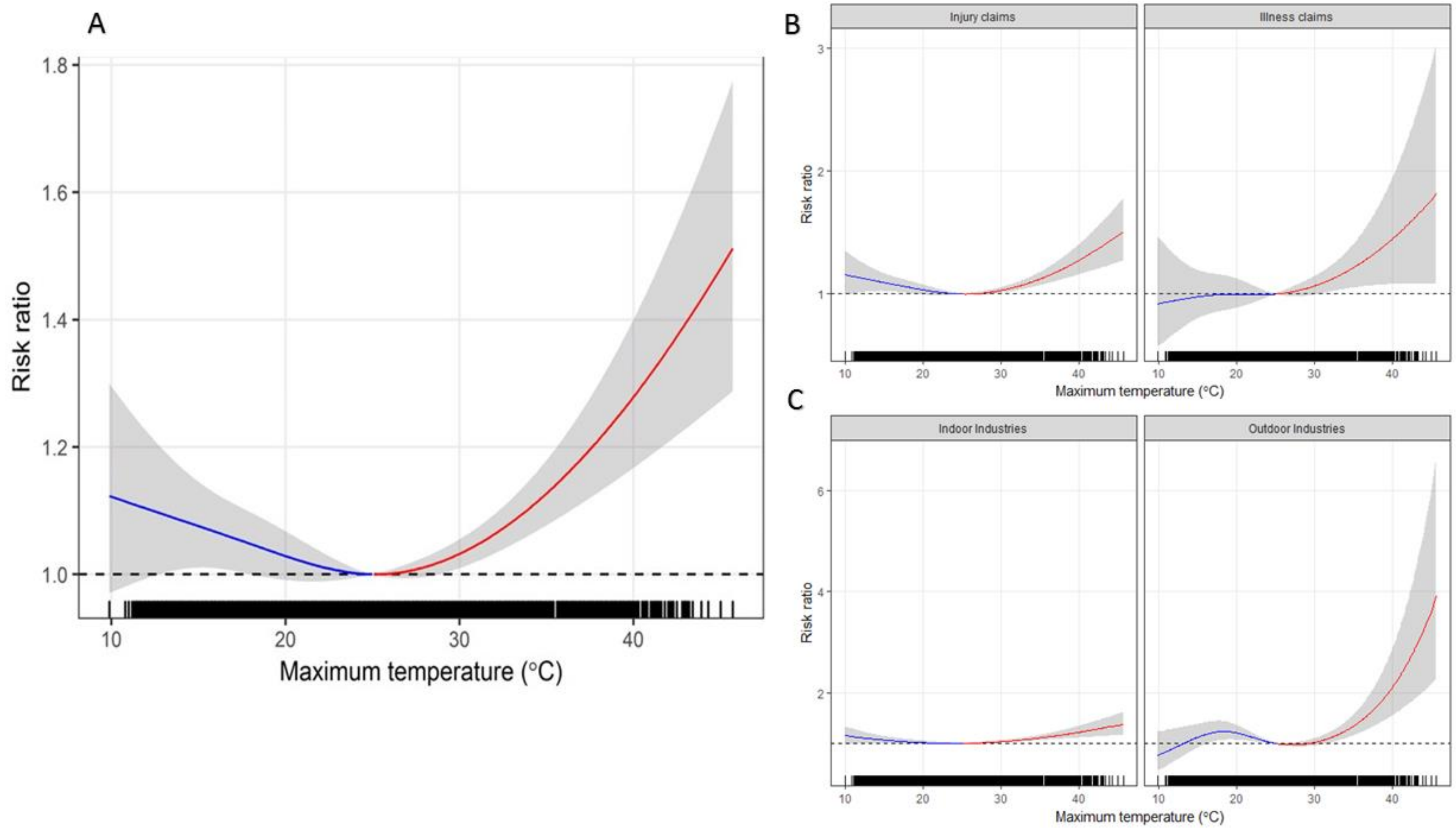

Figure 4.1 Overall relative risks of varying daily maximum temperatures on workers' compensation claims relative to 25 °C in the Adelaide metropolitan area, 2003–2013: A) overall; B) by type of claims; C) by industry.

Workers with increased risk of injury and illness at non-optimal temperatures

Higher than optimum temperatures resulted in an increase in the numbers of WC claims. Total claims showed significant associations with moderately hot (90^{th} percentile) and extremely hot temperatures (99^{th} percentile) and the effects were comparable between genders, while no significant effects were seen at moderately cold (10^{th} percentile) and extremely cold (1^{st} percentile) temperatures (Table 4.1).

Compared with 25 °C, extremely hot temperatures were associated with increase in claims for workers aged 15–24 years (RR 1.51, 95% CI: 1.19–1.92), 35–54 years (RR 1.39, 95% CI: 1.20–1.60) and experienced workers (RR 1.32, 95% CI: 1.18–1.46). Significant increase in WC claims were seen among workers employed in 'medium' and 'heavy' strength occupations and those working in 'regulated indoor climates' (Table 4.1). Specifically, the following occupations were vulnerable during extremely hot temperatures: 'animal and horticultural workers', 'cleaners', 'food service workers', 'metal workers' and 'warehouse' workers (Table 4.2).

As with hot temperatures, cold temperatures had the greatest effect on workers aged 15–24 years and experienced workers (Table 4.1). A statistically significant increase in WC claims was seen in 'food factory' workers at (moderately and extremely) cold temperatures (Table 4.2). The highest effects of extremely cold temperatures were observed on workers in 'light' and 'heavy' strength occupations (Table 4.1).

Stratification by industry characteristics

There were significant relationships between T_{max} and total WC claims in both outdoor and indoor industries (Table 4.1). During moderately hot temperatures the highest increase in total WC claims was observed for the 'electricity, gas and water' industry (RR: 1.79, 95% CI: 1.19–2.67). During extremely hot temperatures the risk for this industry was 9.06 (95% CI: 2.86–28.7) and for other outdoor industries such as 'agriculture, forestry, fishing and hunting', 'mining', and 'construction' the RR were 4.01 (95% CI: 1.24–12.9); 3.86 (95% CI: 1.19–12.5), and 1.72 (95% CI: 1.18–2.52), respectively.

Among the indoor industries, 'transport and storage', 'manufacturing' and 'community services' had increased RR at extremely hot temperatures. Compared with 25 °C, moderately and extremely hot temperatures were associated with an increase in claims in enterprises categorised by size as medium (20–199 employees) and large-sized (≥200 employees).

In contrast, at moderately cold and extremely cold temperatures, 'manufacturing' was the only industry with significant increase in total WC claims (Table 4.1).

Table 4.1 Relative risks for workers' compensation claims in hot and cold temperatures stratified by worker, work and work environment characteristics in Adelaide metropolitan area, 2003–2013 (RR with 95% CI).

	Temperature category[a]			
Claim characteristics	**Extreme cold[b]**	**Moderate cold[c]**	**Moderate hot[d]**	**Extreme hot[e]**
Gender				
Female	1.07 (0.91,1.25)	1.09 (0.98,1.21)	1.07 (1.01,1.14)*	1.36 (1.15,1.60)*
Male	1.10 (0.97,1.24)	1.06 (0.98,1.15)	1.09 (1.05,1.14)*	1.28 (1.13,1.45)*
Age group (years)				
15–24	1.32 (1.04,1.66)*	1.18 (1.02,1.38)*	1.16 (1.07,1.26)*	1.51 (1.19,1.92)*
25–34	1.04 (0.84,1.28)	0.96 (0.84,1.11)	1.09 (1.01,1.17)*	1.08 (0.86,1.34)
35–54	1.12 (0.97,1.28)	1.12 (1.03,1.23)*	1.08 (1.03,1.13)*	1.39 (1.20,1.60)*
>55	0.80 (0.62,1.04)	0.92 (0.78,1.09)	1.01 (0.92,1.11)	1.19 (0.90,1.55)
Worker experience				
Experienced worker	1.11 (1.00,1.23)*	1.08 (1.01,1.16)*	1.09 (1.05,1.13)*	1.32 (1.18,1.46)*
New worker	1.03 (0.79,1.34)	1.05 (0.88,1.24)	1.05 (0.96,1.15)	1.24 (0.96,1.59)
Industrial sectors				
Outdoor industries (sub-total)	0.95 (0.69,1.31)	1.12 (0.91,1.38)	1.18 (1.05,1.32)*	2.25 (1.62,3.14)*
Agriculture, Forestry, Fishing & Hunting	0.39 (0.13, 1.22)	0.78 (0.36,1.65)	1.24 (0.83,1.86)	4.01 (1.24,12.9)*
Construction	1.06 (0.74, 1.52)	1.15 (0.90,1.46)	1.11 (0.97,1.26)	1.72 (1.18, 2.52)*
Electricity, Gas & Water	0.54 (0.18,1.59)	0.83 (0.43,1.81)	1.79 (1.19,2.67)*	9.06 (2.86,28.7)*
Mining	0.91 (0.30,2.72)	1.18 (0.7,2.41)	1.33 (0.89,1.99)	3.86 (1.19,12.5)*
Indoor industries (sub-total)	1.10 (0.99, 1.22)	1.07 (0.99,1.14)	1.08 (1.04,1.11)*	1.24 (1.12,1.37)*
Finance, Property & Business Services	1.35 (0.86,2.10)	1.17 (0.87,1.57)	1.17 (0.99,1.37)	1.46 (0.93,2.27)
Manufacturing	1.24 (1.01, 1.51)*	1.19 (1.04,1.36)*	1.05 (0.97,1.13)	1.28 (1.03,1.60)*
Public Administration & Defence	0.81 (0.45,1.48)	0.91 (0.61,1.36)	0.90 (0.72,1.13)	0.82 (0.43,1.55)
Recreation, Personal & Other Services	1.27 (0.87, 1.84)	1.18 (0.91,1.51)	1.04 (0.90,1.18)	1.16 (0.78,1.70)
Transport & Storage	0.86 (0.58, 1.29)	0.89 (0.68,1.16)	1.20 (1.04,1.37)*	1.50 (1.01, 2.25)*
Wholesale & Retail Trade	1.15 (0.91,1.45)	1.09 (0.93,1.28)	1.07 (0.98,1.16)	1.21 (0.95,1.53)
Communication	0.43 (0.01,26.5)	0.65 (0.04,9.64)	1.54 (0.43,5.44)	3.89 (0.14,108.0)
Community Services	0.98 (0.83,1.16)	0.98 (0.88,1.10)	1.08 (1.01,1.14)*	1.20 (1.01,1.43)*
Size of business				
Small (1–19 employees)	1.14 (0.88,1.46)	1.04 (0.87,1.22)	1.06 (0.97,1.16)	1.07 (0.82, 1.38)
Medium (20–199 employees)	1.02 (0.85,1.20)	1.03 (0.91,1.15)	1.09 (1.03,1.16)*	1.33 (1.11,1.58)*
Large (≥200 employees)	1.13 (0.99,1.29)	1.11 (1.02,1.21)*	1.08 (1.04,1.14)*	1.36 (1.19,1.56)*
Physical demands of work				
Limited (≤5kg)	0.91 (0.74,1.12)	0.95 (0.83,1.09)	1.05 (0.97,1.14)	1.17 (0.93,1.45)
Light (5–10kg)	1.38 (1.11,1.71)*	1.31 (1.13,1.51)*	0.98 (0.91,1.06)	1.16 (0.93,1.46)
Medium (10–20kg)	0.97 (0.83,1.13)	1.00 (0.90,1.11)	1.14 (1.08,1.21)*	1.51 (1.29,1.77)*
Heavy (>20 kg)	1.27 (1.03,1.56)*	1.13 (0.98,1.30)	1.09 (1.01,1.18)*	1.22 (0.97,1.52)
Potential workplace temperature exposure				
Regulated indoors	1.11 (0.99,1.24)	1.08 (1.00,1.16)	1.07 (1.03,1.12)*	1.26 (1.12,1.41)*
Unregulated indoors	1.23 (0.18,8.18)	1.67 (0.47,5.91)	0.47 (0.25,0.90)*	0.35 (0.06,1.96)

Claim characteristics	Temperature category[a] Extreme cold[b]	Moderate cold[c]	Moderate hot[d]	Extreme hot[e]
Outside	0.74 (0.24,2.27)	0.86 (0.41,1.82)	1.28 (0.85,1.93)	2.15 (0.63,7.21)
In a vehicle or cab	0.76 (0.49,1.19)	0.82 (0.61,1.10)	1.06 (0.91,1.24)	1.08 (0.69,1.69)
Multiple locations	1.11 (0.91,1.34)	1.10 (0.97,1.25)	1.12 (1.05,1.20)*	1.51 (1.23,1.84)*

Abbreviations: CI: confidence interval; RR: relative risk. *p<0.05

a. All temperatures were compared with the optimum temperature of 25.0 °C
b. The 1st percentile of temperature (12.6 °C)
c. The 10th percentile of temperature (15 °C)
d. The 90th percentile of temperature (33.1 °C)
e. The 99th percentile of temperature (40.6 °C)

Table 4.2 Relative risks in hot and cold temperatures for workers' compensation by occupational groups in Adelaide metropolitan area, 2003–2013 (RR with 95% CI).

	Temperature category[a]			
Occupational groups	**Extreme cold[b]**	**Moderate cold[c]**	**Moderate hot[d]**	**Extreme hot[e]**
Animal & Horticultural	1.18 (0.65,2.11)	1.16 (0.79,1.71)	1.21 (0.98,1.50)	1.95 (1.05,3.62)*
Automobile Drivers	1.35 (0.44,4.05)	1.11 (0.53,2.34)	1.10 (0.73,1.66)	1.09 (0.31,3.78)
Carpenters	0.85 (0.45,1.59)	0.98 (0.66,1.50)	1.09 (0.86,1.38)	1.55 (0.76,3.12)
Cleaners	0.97 (0.57,1.66)	1.11 (0.78,1.58)	1.09 (0.90,1.32)	1.74 (1.01,3.00)*
Construction	0.53 (0.25,1.15)	0.55 (0.33,0.92)	1.22 (0.92,1.60)	0.98 (0.43,2.21)
Electrical	0.65 (0.36,1.20)	0.72 (0.48,1.09)	1.27 (1.02,1.58)	1.63 (0.86,3.07)
Emergency Workers	0.84 (0.49,1.45)	0.88 (0.62,1.26)	1.02 (0.85,1.22)	0.99 (0.60,1.64)
Engineers	2.01 (0.60, 6.74)	1.57 (0.71,3.46)	1.53 (0.96,2.44)	3.52 (0.89,13.80)
Farmers	0.20 (0.01,3.53)	0.60 (0.09,4.00)	0.57 (0.21,1.51)	0.70 (0.05,9.2)
Food Factory	2.70 (1.47,4.96)*	1.60 (1.07,2.40)*	1.20 (0.95,1.50)	1.20 (0.62,2.32)
Food Service	1.11 (0.69,1.77)	1.23 (0.90,1.68)	1.15 (0.97,1.36)	2.13 (1.31,3.46)*
Handypersons	0.95 (0.44,2.06)	0.97 (0.58,1.62)	1.21 (0.93,1.57)	1.71 (0.78,3.71)
Health & Personal Support	0.89 (0.65,1.23)	0.94 (0.76,1.17)	1.01 (0.90,1.13)	1.05 (0.75,1.46)
Heavy Vehicle Drivers	1.18 (0.78,1.80)	1.09 (0.82,1.43)	1.07 (0.92,1.23)	1.14 (0.74,1.75)
Hospitality	1.19 (0.58,2.41)	1.07 (0.66,1.70)	1.03 (0.80,1.33)	0.98 (0.48,2.02)
Machine Operators	1.26 (0.93,1.71)	1.22 (0.99,1.49)	1.00 (0.90,1.12)	1.17 (0.85,1.62)
Metal Workers	1.28 (0.93,1.71)	1.19 (0.96,1.45)	1.12 (1.00,1.25)*	1.46 (1.05,2.03)*
Miners	1.64 (0.34,7.83)	1.61 (0.56,4.58)	1.07 (0.62,1.84)	1.93 (0.39,9.42)
Nurses	0.90 (0.60,1.36)	0.95 (0.72,1.26)	1.08 (0.93,1.26)	1.29 (0.84,1.98)
Office	1.10 (0.85, 1.40)	1.07 (0.90,1.26)	1.03 (0.93,1.12)	1.11 (0.85,1.43)
Other Health Professionals	2.13 (0.48,9.39)	1.59 (0.59,4.26)	0.78 (0.46,1.31)	0.51 (0.11,2.39)
Outdoor Work NEC[f]	1.20 (0.37,3.92)	1.11 (0.49,2.45)	1.09 (0.71,1.67)	1.25 (0.37,4.16)
Painters	1.21 (0.18,7.77)	1.51 (0.43,5.22)	0.96 (0.50,1.86)	1.95 (0.29,12.80)
Passenger Transport	0.44 (0.16,1.20)	0.59 (0.30,1.14)	1.03 (0.71,1.47)	0.97 (0.33,2.78)
Plumbers	1.31 (0.71,2.40)	1.39 (0.93,2.07)	1.03 (0.82,1.27)	1.64 (0.88,3.05)
Printers	2.05 (0.58,7.18)	1.71 (0.74,3.04)	1.34 (0.84,2.12)	2.93 (0.71,12.10)
Scientists	1.99 (0.63,6.25)	1.21 (0.56,2.60)	0.89 (0.59,1.35)	0.41 (0.13,1.31)
Teachers	0.85 (0.50,1.44)	0.92 (0.65,1.31)	1.01 (0.82,1.24)	1.07 (0.58,1.98)
Vehicle Workers	0.70 (0.41,1.20)	0.77 (0.54,1.10)	1.10 (0.90,1.33)	1.14 (0.65,2.00)
Warehousing	1.16 (0.78,1.73)	1.15 (0.88,1.50)	1.23 (1.06,1.41)*	1.99 (1.32,3.01)*

Abbreviations: CI: confidence interval; RR: relative risk. *$p<0.05$

a. All temperatures were compared with the optimum temperature of 25.0 °C
b. The 1st percentile of temperature (12.6 °C)
c. The 10th percentile of temperature (15 °C)
d. The 90th percentile of temperature (33.1 °C)
e. The 99th percentile of temperature (40.6 °C)
f. NEC: not elsewhere classified

Injury and Illness characteristics

At moderately and extremely hot temperatures, injuries such as ‘fractures’ and ‘traumatic joint/ligament injuries’ increased respectively; while ‘burn(s)’, ‘wounds, lacerations, amputations and internal organ damage’ increased both at moderately and extremely hot temperatures (Table 4.3). There was also an increase in injuries occurring as a result of ‘being hit by moving objects’, ‘body stressing’, ‘heat, electricity and other environmental factors’, ‘chemicals and other substances’ and ‘vehicle incidents and other’ in extremely hot temperatures. Claims for illnesses involving ‘skin and subcutaneous tissue’ and ‘respiratory system diseases’ also increased at extremely hot temperatures (Table 4.3).

At moderately cold temperatures, claims due to ‘traumatic joint/ligament injuries’ increased while ‘wounds, lacerations, amputations and internal organ damage’ increased at both moderately and extremely cold temperatures (Table 4.3).

Table 4.3 Relative risks in hot and cold temperatures for workers' compensation claims by injury characteristics in Adelaide metropolitan area, 2003–2013 (RR with 95% CI).

	Temperature category[a]			
Injury characteristics	**Extreme cold[b]**	**Moderate cold[c]**	**Moderate hot[d]**	**Extreme hot[e]**
Mechanism of injury				
Falls, trips and slips of a person	1.21 (0.95,1.52)	1.15 (0.98,1.34)	0.98 (0.90,1.07)	1.03 (0.80,1.32)
Hitting objects with a part of the body	1.13 (0.85,1.49)	1.00 (0.83,1.20)	1.14 (1.03,1.26)*	1.20 (0.90,1.60)
Being hit by moving objects	1.33 (1.06,1.67)*	1.22 (1.05,1.42)*	1.13 (1.04,1.22)*	1.49 (1.18,1.88)*
Body stressing	1.02 (0.87,1.18)	1.05 (0.94,1.15)	1.05 (0.99,1.11)	1.27 (1.08,1.48)*
Heat, electricity and other environmental factors	0.89 (0.49,1.63)	0.89 (0.60,1.32)	1.39 (1.14,1.69)*	2.18 (1.27,3.73)*
Chemicals and other substances	0.61 (0.32,1.17)	0.74 (0.49,1.13)	1.24 (1.01,1.52)*	1.81 (1.00,3.27)*
Mental stress	0.83 (0.50,1.40)	0.89 (0.63,1.26)	1.05 (0.87,1.26)	1.11 (0.64,1.92)
Vehicle incidents and other	1.16 (0.70,1.90)	1.28 (0.92,1.77)	1.19 (0.99,1.41)	2.38 (1.44,3.95)*
Nature of injury				
Group A: Intracranial injuries	1.43 (0.46,4.38)	1.30 (0.61,2.73)	0.80 (0.53,2.73)	0.62 (0.19,2.03)
Group B: Fractures	0.86 (0.55,1.33)	0.86 (0.64,1.16)	1.21 (1.03,1.42)*	1.45 (0.91,2.31)
Group C: Wounds, lacerations, amputations and internal organ damage	1.38 (1.11, 1.71)*	1.21 (1.05,1.40)*	1.10 (1.02,1.18)*	1.30 (1.05,1.61)*
Group D: Burn	0.47 (0.24,0.90)	0.66 (0.43,1.02)	1.32 (1.06,1.63)*	2.34 (1.27,4.31)*
Group E: Injury to nerves and spinal cord	1.35 (0.17,10.50)	0.69 (0.16,3.01)	1.48 (0.63,3.48)	0.73 (0.06,8.77)
Group F: Traumatic joint/ligament and muscle/tendon injury	1.13 (0.98,1.30)	1.12 (1.02,1.23)*	1.05 (0.99,1.10)	1.24 (1.06,1.44)*
Group G: Other injuries	0.97 (0.63,1.52)	0.98 (0.74,1.31)	1.12 (0.96,1.30)	1.36 (0.89,2.06)
Group H: Musculoskeletal and connective tissue diseases	0.98 (0.75,1.27)	1.03 (0.86,1.22)	1.06 (0.96,1.16)	1.31 (0.99,1.71)
Group I: Mental diseases	0.82 (0.49,1.37)	0.88 (0.63,1.25)	1.03 (0.85,1.24)	1.07 (0.62,1.84)
Group J: Digestive system diseases	1.07 (0.41,2.75)	1.15 (0.61,2.13)	1.05 (0.75,1.48)	1.47 (0.54,4.02)
Group K: Skin and subcutaneous tissue diseases	1.56 (0.71,3.41)	1.36 (0.80,2.28)	1.47 (1.12,1.92)*	3.15 (1.42,6.98)*
Group L: Nervous system and sense organ diseases	0.86 (0.50,1.48)	0.91 (0.63,1.32)	1.07 (0.87,1.30)	1.20 (0.67,2.15)
Group M: Respiratory system diseases	0.41 (0.05,3.19)	0.79 (0.22,2.73)	1.43 (0.80,2.56)	5.66 (1.06,30.31)*
Group N: Circulatory system diseases	5.33 (0.29,97.0)	2.74 (0.44,16.80)	1.18 (0.49,2.83)	1.59 (0.14,18.01)
Group O: Infectious and parasitic diseases	0.59 (0.10,3.56)	0.51 (0.16,1.63)	1.99 (1.00,3.95)	2.61 (0.35,19.01)
Group R: Other claims	0.27 (0.04,1.71)	0.39 (0.11,1.37)	0.65 (0.36,1.20)	0.21 (0.04,0.99)*

Abbreviations: CI: confidence interval; RR: relative risk. *p<0.05

a. All temperatures were compared with the optimum temperature of 25.0 °C
b. The 1st percentile of temperature (12.6 °C)
c. The 10th percentile of temperature (15 °C)
d. The 90th percentile of temperature (33.1 °C)
e. The 99th percentile of temperature (40.6 °C)
f. NEC: not elsewhere classified

Attributable risk of occupational injury/illness due to temperature

The estimated temperature-related burden on WC claims is shown in Table 4.4. Overall, 10,876 or 4.9% (95% CI: 2.5–7.2%) of the total claims were associated with hot and cold temperatures. The attributable fraction to heat (i.e. temperatures above the OT) was 2% (95% CI: 1.1–2.9%), while cold (i.e. temperatures below the OT) was responsible for most of the injury burden with a total attributable fraction of 3.3% (95% CI: 0.6–5.8%). Moderate heat and cold (i.e. temperatures between OT and the 97.5th percentile, and temperatures between OT and the 2.5th percentile, respectively) accounted for a higher fraction of injuries, while contributions by extreme temperatures (either hot or cold) were small.

Table 4.4 Estimated attributable fractions (%) and associated 95% empirical confidence intervals (eCIs) for heat and cold effects on daily workers' compensation claims due to injuries and illnesses over a lag of 6 days in Adelaide metropolitan area, 2003–2013.

Claim characteristics	**All claims**	**Injury claims**	**Illness claims**
Temperature category	**Attributable Fraction (%)**	**Attributable Fraction (%)**	**Attributable Fraction (%)**
Overall[a]	4.85 (2.48,7.25)	5.31 (2.76,7.67)	2.62 (−5.89,10.29)
Total cold[b]	2.74 (0.22,5.23)	3.28 (0.57,5.77)	−0.79 (−9.83,7.30)
Extreme cold[c]	0.24 (0.01,0.47)	0.29 (0.04,0.54)	−0.12 (−0.95,0.61)
Moderate cold[d]	2.49 (0.21,4.75)	2.99 (0.52,5.22)	−0.67 (−8.88,6.68)
Total heat[b]	2.11 (1.21,2.98)	2.03 (1.12,2.95)	3.42 (0.67,6.06)
Moderate heat[d]	1.50 (0.83,2.16)	1.43 (0.75,2.14)	2.57 (0.50,4.58)
Extreme heat[c]	0.60 (0.37,0.81)	0.59 (0.37,0.81)	0.84 (0.17,1.47)

[a] Overall burden of claims is the sum of cold and heat contributions.
[b] Total burden of claims is the sum of moderate and extreme contributions.
[c] Extreme cold was defined as temperatures lower than 2.5th percentile; extreme heat was defined as temperatures greater than the 97.5th percentile.
[d] Moderate heat was defined as temperatures between optimum temperature and the 97.5th percentile; moderate cold was defined as temperatures between optimum temperature and the 2.5th percentile.

4.3.4.3 Sensitivity analyses

Results similar to those found using T_{max} were obtained using composite predictive thermal indices, i.e. AT, HX, UTCI and WBGT (Figure B5, Appendix B2).

4.3.5 Discussion

Despite major advancements in workplace health and safety, limited research exists in Australia on how hot and cold temperatures affect injury occurrence in the workplace. This study has shown that: (i) ambient temperatures accounted for almost 5% of WC claims, with most of this burden attributable to cold temperatures; (ii) exposure to extreme temperatures (hot and cold) are associated with the greatest risk to occupational health and safety (OHS), but moderate temperatures (that are more common) have the greatest burden (i.e. highest proportion of injuries); and (iii) temperature-related risks apply to indoor as well as outdoor workers.

As mechanisms of temperature exposure can lead to both acute and chronic outcomes,[50, 152, 408] all compensation claims (accepted by the insurer) for both WRIs and illnesses were used in this study, consistent with similar studies.[45, 145, 146] Our results support a non-linear relationship between daily T_{max} and total WC claims best described as a J-shaped curve, such that the risk of combined injury and illness claims increases at both hot and cold temperatures with the effect being more apparent at higher temperatures. This is particularly evident for injuries and for outdoor industries. These findings are similar to those of previous studies.[45, 122, 135, 147, 184, 185, 401] This evidence of nonlinearity in our study is also consistent with findings from other Mediterranean climates[185, 401] despite potential differences in labour markets and industries. In contrast to our study, some previous studies[122, 135] including one from Adelaide[45] have described a reverse U-shaped relationship with a decline in injuries at extreme temperatures possibly due to the use of adaptive protective measures such as ‘ceasing work’ at a certain threshold temperatures in hot weather.[45] However, compliance with such policies, in reality, is unknown as there is no mandatory regulations or guidelines for maximum workplace temperatures in Australia.[171]

The time lag for the effects of cold and heat in our study differed in that the effects of cold appeared after a three-day lag and lasted longer, while that of heat were acute and immediate. The delayed cold effects are in line with population health studies,[6, 10] and our findings that heat exposure has immediate occupational health consequences align with previous findings.[45, 127]

Albeit complex, the underlying explanations behind the occurrence of injury/illness in non-optimal thermal conditions is likely to be related to physiological mechanisms whereby the body is unable to cool or warm itself to maintain its internal temperature.[3] Exposure to hot and cold temperatures can also cause thermal discomfort resulting in adverse behavioral effects, such as disorientation, impaired judgment, loss of concentration, reduced vigilance, carelessness and fatigue.[50, 152] This may affect workers' physical, cognitive and psychomotor performance, and may reduce their capability to take protective measures such as staying hydrated or moving to shaded areas during hot weather, or adjustment of clothing during cold weather. The combination of this reduced performance and the ability to follow protective measures can increase the risk of occupational injuries.[45, 132] Chronic conditions such as respiratory diseases and skin diseases can also be exacerbated by factors associated with extreme temperatures.[152, 409]

Susceptibility to work-injuries/illness can be influenced by a range of factors related to the characteristics of the worker, the work being undertaken, and workplace characteristics. Our findings showed no gender differences for injury claims during hot temperatures whereas previous studies[45, 127] have found significant associations between high temperatures and injuries among male workers only. However, a study in Melbourne, Australia[132] reported an association between injuries and T_{min} for female workers. Females are highly represented in indoor industries with regulated environments and comprise less than 40% of the workforce in the male dominated 'temperature-sensitive' industries that mostly involve outdoor work.[255]

Our findings showed young workers (15–24 years) had a higher risks of temperature-related claims, consistent with previous literature.[45, 127, 145, 185] Several factors, including insufficient training, lack of competency in the tasks assigned and the strenuous nature of jobs assigned to these workers, may be contributing factors[45] to the overall high risk of injuries in this age group. Young workers may also have limited experience which may contribute to their susceptibility to injuries. However, we also found that experienced workers (more than one year of experience) were also vulnerable to injuries at high temperatures. This may be due to their 'self-confidence' by which they ignore, underestimate or misjudge any hazards irrespective of their age.[301]

We found an increased risk of WRIs and illnesses in both outdoor and indoor industries at moderately and extremely hot temperatures, with the pattern being more consistent for outdoor sectors. This is in line with the findings of previous studies[127, 185, 190] while a study in Adelaide[45] reported significant effects only in outdoor industries. Workers in some non-air conditioned indoor workplaces (e.g. foundries and kitchens) have process-generated heat exposure and high ambient temperatures may augment the temperature-related health risks. Unexpectedly, increased risks of WRIs and illnesses were also found during hot temperatures for occupations where work is carried out in regulated indoor climates, aligning with the findings of a similar study.[132] This could be due to the relatively lower levels of acclimatisation to heat which may render workers susceptible to hot conditions outdoors.[410-412]

As for cold, our results showed an increased risk of WRIs and illnesses restricted to workers in the manufacturing industry and food factory workers, which supports previous evidence showing workers in these industries in other countries are at risk in cold temperatures.[152, 185, 400, 408]

Approximately 5% of the total WC claims in this study could be attributed to temperature. This estimate is higher (2.7%) than those reported by Martinez-Solanas et al. in Spain.[185] Extremely hot or cold temperatures contributed to less than 1% of all injuries which is also consistent with Martinez-Solanas et al.[185], while milder temperatures, which occurred on the majority of days, accounted for around 4% of all injuries. Moderately cold temperatures accounted for 2.5% of all injuries. This is a unique finding as most research has focused heavily on the adverse effects of extreme heat on workers. Our findings suggest that the broader effects of temperature on OHS should be considered with injury prevention being a year round focus.

There are limitations to this study. First, our results are specific to one city with a temperate climate, where the claim risk was lowest at 25 °C, and may not be generalisable to other locations. Second, we used data from one meteorological monitoring station which may not adequately cover the spatial variations of ambient temperatures within the study region. Ambient temperature was used as a surrogate of individual levels of heat exposure thus introducing ecological bias in the exposure estimates as workers' actual exposure on the day of their injury is unknown.

Furthermore, an assumption has been made that workers' place of temperature exposure was the workplace. Exposure misclassification can only be addressed by using personalised temperature and physiological indicators measurement which is emerging as a direction for future research.[413] Third, we did not control for relative humidity, in line with recent concerns about its suitability in epidemiological and environmental health research due to its strong diurnality and seasonality.[414] However, our sensitivity analysis using AT, WBGT, HX, HI and $UTCI_{max}$ (see supplementary material, Figure B5, Appendix B2) yielded similar results to those gained using daily T_{max}, lending support to the finding that no single temperature metric based on highly correlated weather data is superior to others.[288] Fourth, stratifying workers' temperature exposure based on industrial sector level has its limitations due to the considerable heterogeneity in exposures to workers within any one industry. Although we attempted to refine this by using occupational level classifications, this does not obviate the need for individual-level data on the workers' actual task, location and level of exposure on the day of injury for precise exposure assessments. Fifth, our results are based on metropolitan areas (urban environments) which limits generalisability to rural and remote areas (non-urban environments) that tend to have a greater proportion of some high risk industries such as agriculture and mining. Further research to evaluate the impact of temperature on WRIs and illnesses in rural and regional areas is warranted. Additionally, it is known that occupational injuries are often underreported; nevertheless, compensation claims data provide a valuable source of data on occupational health. The relatively small number of claims and hence wide confidence intervals calculated in some stratified analyses is acknowledged, and dictates cautious interpretation of the results. Lastly, the use of 'all accepted claims' as the outcome variable includes injuries and illnesses which may have resulted from short-term or long-term occupational exposures. The data also included both acute and chronic outcomes as we were unable to differentiate between these. These issues may have introduced some bias with the use of a CCO study design.

Despite these caveats, the strengths of this study should be noted. It is one of the first comprehensive studies to assess the impact of both cold and hot temperatures on WRIs and illnesses in Australia using a statistical approach suitable for the exploration of both the nonlinear pattern of exposure-outcome associations and lag structure simultaneously. Second, we have explored influencing factors such as worker, nature of work and workplace characteristics that may govern the occurrence of occupational injuries. Third, this study also measures the proportion of injury burden attributable to non-optimal temperatures.

4.3.6 Conclusion

Our study suggests that both cold and hot temperatures increase the risk of WRIs and illnesses with milder temperatures having the greater burden than extreme temperatures. The degree of occupational injury risk associated with non-optimal temperatures varies according to the nature of work being undertaken and the workplace environment. These may have important public health implications for the prevention of occupational injuries especially for those vulnerable subpopulations at greater risk. It is widely accepted that particular industries such as ‘construction’ and ‘agriculture’ are exposed to the effects of the thermal environment, but our findings suggest that other industries are also affected, particularly in hot weather which our findings suggest, poses a greater problem than cold weather. This is of particular concern as the number of hot days is projected to increase. The broader impacts of temperature highlighted by this study present a challenge that is multi-faceted, with potential consequences for workers, supervisors, and policymakers. Regulators and governments need to engage with workplaces to discuss and develop targeted injury prevention measures that take into account specific risks to workers during hot and cold weather.

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Conflict of Interest: The authors declare that they have no conflict of interest.

*****End of published paper*****

4.4 CHAPTER SYNOPSIS

This chapter consisted of a study that focussed on evaluating the risk, susceptibility and attributable burden of WRI concerning ambient temperatures in Adelaide, a city with a temperate climate. The findings suggest that a positive relationship exists with WRI increasing with daily temperatures with the greatest risk at the extremes but moderate contributing most of the burden. The findings highlight that the risk of WRI is not limited to outdoor occupations alone or heavy demanding occupations but also includes some indoor workers and medium demanding occupations as well. Therefore, prevention strategies need to be inclusive of broader temperatures and not be limited to extremes heat and outdoor workers. The next chapter consists of a study that extends the evidence from Adelaide to three other major Australian capital cities, namely, Brisbane, Melbourne, and Perth.

05

Chapter 5: Geographical Variation in Risk of Work-Related Injuries and Illnesses Associated with Ambient Temperatures: A Multi-City Case-Crossover Study in Australia, 2005–2016

5.1 PREFACE

The study (Study 2) presented in this chapter is the second of two studies in this thesis that address the first and the third objective. While the previous study examined the impact and quantified the associated burden of ambient temperatures on the risk of WRI in Adelaide, this study uses the same methodology for three other Australian capital cities (Melbourne, Brisbane and Perth) which have different climates.

This study is the first to investigate the relationship between ambient temperatures and WRI in Perth and Brisbane, and to quantify the associated burden in all three cities in Australia.

This paper has been published in the Journal of Science of the total environment as: Varghese BM, Barnett AG, Hansen A et al. Geographical variation in risk of WRIs and illnesses associated with ambient temperatures: A multi-city case-crossover study in Australia, 2005–2016. Sci Total Environ. 2019; doi:10.1016/j.scitotenv.2019.06.098.

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Name of Principal Author (Candidate)	Blesson Mathew Varghese		
Contribution to the Paper	B Varghese contributed to the study concept, method and analysis approach, gained ethics approval, extracted the data and performed data analyses, interpreted the data, prepared and submitted the manuscript and made corrections based on reviewer's comments and resubmitted the manuscript for publication.		
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Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	12/8/19

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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5.3 PUBLICATION

5.3.1 Abstract

Background: The thermal working environment can have direct and in-direct effects on health and safety. Ambient temperatures have been associated with an increased risk of occupational injuries but it is unknown how the relationship can vary by weather, location and climate.

Objectives: To examine the relationship between ambient temperatures and work-related injuries (WRIs) and illness compensation claims in three Australian cities: Melbourne and Perth (temperate climate) and Brisbane (subtropical climate) in order to determine how hot and cold weather influences the risk of occupational injury in Australia.

Methods: Workers' compensation (WC) claims from each city for the period 2005–2016 were merged with local daily weather data. A time-stratified case-crossover design combined with a distributed lag non-linear model was used to quantify the impacts of daily maximum temperature (T_{max}) on the risk of WRIs and illnesses.

Results: Compared to the median T_{max}, extremely hot temperatures (99^{th} percentile) were associated with a 14% (95% CI: 3–25%) increase in total WC claims in Melbourne, but there were no observed effects in Brisbane or Perth, with the exception of traumatic injuries that increased by 17% (95% CI: 3–35%) during extreme heat in Perth. For extremely low temperatures (1^{st} percentile), there was a protective effect in Brisbane (RR 0.89; 95% CI: 0.81–0.98), while no effects were observed in Melbourne or Perth.

Conclusion: The relationship between injury and ambient temperature appears to be variable depending on location and climate. In general, WRIs and illnesses appear to be more common at higher temperatures than lower temperatures. Adopting adaptation and prevention measures could reduce the social and economic burden of injury, and formulating effective measures for dealing with high temperatures should be prioritised given the predicted increase in the frequency and intensity of hot weather.

5.3.2 Introduction

Over the last few decades, numerous studies have evaluated the impacts of temperature extremes on human health and interest in assessing this relationship as a response to projected climate warming continues to grow.[5, 9] Exposure to extreme weather events such as heatwaves are associated with increased mortality and/or morbidity rates.[8, 9, 16, 415] Several episodes of extreme weather events, for example, heatwaves in Chicago (1995), Europe (2003), Russia (2010) and Australia (2009 and 2014) have led to an increased awareness on the adverse health effects and have resulted in development of interventions and/or strategies targeted at specific population groups.[20-22, 416] These specific population groups identified to be at-risk includes the elderly, children, those with chronic morbidities, lower socio-economic status, and those living in densely populated cities.[5, 12] In the context of a warming climate, the higher mean temperatures, increased summer temperature variability, and frequent, more intense, and longer duration of heatwaves worldwide are likely to exacerbate the health impacts of heat exposure with social and economic implications.[417]

Many studies have examined the health risks related to temperature extremes and epidemiological studies in particular, have contributed to the understanding and evidence of the potential adverse effects and associated risks of climate-related events on human health, and have identified the above mentioned populations of concern who are more at-risk. These epidemiological studies have described the relationship between ambient temperature and mortality/morbidity as a U-, V- or J-shaped curve, whereby mortality and morbidity rise progressively above or below a moderate temperature range, often referred to as the minimum mortality/morbidity temperature (MMT).[10] However, the effects of temperature, show geographical heterogeneity whereby cities with colder climates have generally greater heat effects while warmer cities have greater cold effects, reflecting population adaptation to local climate.[6]

An additional group at risk of adverse health consequences of temperature extremes is workers. In the occupational setting, interest in investigating the impacts of temperatures on workers' health and safety, particularly high temperatures, has been increasing since the fourth assessment report (2005–2007) of the Intergovernmental Panel on Climate Change (IPCC) where rising heat was first raised as a concern for workplaces.[29, 33, 50, 397, 398] In addition to heat-induced illnesses, work stress, physical discomfort and losses in work capacity and productivity, cumulative exposure to hot and cold temperatures at the workplace can place workers at risk of accidents/injuries.[29, 50, 397] Results of several experimental studies point towards an effect on accidents and injuries through diminished human performance due to factors such as fatigue, loss of alertness, lack of coordination and altered judgment, loss of dexterity and general discomfort.[50]

Most of the existing epidemiological studies have examined the association between temperature extremes and work-injuries using workers' compensation (WC) claims data. Studies in Italy,[122, 184] Canada,[127] China,[183, 190] Thailand[42] and the US,[43, 44, 135, 189] that mostly focussed on extreme heat show an increasing risk for injuries at higher temperatures, but that the association varies depending on the type of work and work location. Evidence regarding cold temperatures is limited to a small number of studies in Italy,[401] the US[400, 402, 403] and Spain.[185] The latter study assessed the effects of heat and cold and estimated that 2.7% of all occupational injuries were attributable to non-optimal ambient temperatures, corresponding to an estimated 0.67 million person-days of work lost every year. The estimated annual economic burden to non-optimal ambient temperatures (both heat and cold) was estimated to be 370 million Euros or 0.03% of Spain's Gross Domestic Product (GDP).[185] Besides the specific economic burden related to occupational injuries due to non-optimum temperatures, various studies have also estimated an economic burden ranging between 0.1% and 0.5% of GDP from reduced work capacity and productivity related to heat stress.[29, 238, 418, 419]

Whilst studies[127, 135, 184, 185, 190] in different locations as mentioned above have examined the role of temperatures on occupational injuries, their results might not be generalisable to cities with different climate and population characteristics. There is a need to identify workers at-risk of injuries from thermal environments to provide an evidence base for developing local population and climate-specific workplace interventions and preventive measures to ease the impact of projected increased risks from extreme temperatures. This is important on the basis of climate change scenarios with average temperatures projected to increase by 0.6–1.5 °C by 2030, with fewer cold extremes and more heat extremes.[404]

Australian workers experience a range of climates varying from warm and humid in the north of the country, through to cool and temperate in the south.[420] Australian studies of the adverse health effects of ambient temperatures on work-related outcomes have been mostly related to heat and based on the temperate climatic cities of Adelaide[45, 145, 146, 421, 422] and Melbourne.[132, 188, 423] Evidence is currently lacking for other cities with a subtropical or tropical climate. Furthermore, there are no comparisons of work-related injuries (WRIs) and illnesses at moderately and extremely high-temperatures, and at cold temperatures. In this paper we examine: 1) the link between ambient temperatures and WRIs and illnesses in three major Australian cities with differing climates and experiences of extreme weather events; 2) the risk profile of workers in these cities; and 3) the attributable risk of WRIs and illnesses due to cold and heat.

5.3.3 Materials and methods

5.3.3.1 Study setting

This study includes capital cities of three states in Australia, namely Melbourne (Victoria), Brisbane (Queensland) and Perth (Western Australia). Melbourne (37°81'S, 144°96'E) is on the southern east coast of Australia and is the country's second largest city with a mild temperate climate with warm summers and cool wet winters.[424] During summer (December–February) the average daytime daily maximum temperature (T_{max}) is 25.6 °C while in winter (June–August) the average T_{max} is 14 °C.

Brisbane (27°46'S, 153°02'E) is on the central east coast of Australia and is a sub-tropical city characterised by warm to hot weather for most of the year. The hottest months (December–February) can be very humid (average relative humidity of 65%

to 70%) with average T_{max} of 29.3 °C, while winter is mostly mild and dry (average T_{max} 21.3 °C).

Perth (31°95'S, 115°86'E) is on the southern west coast and is characterised by a mix of warm temperate and typical Mediterranean climate with mild winters (average T_{max} 18.4 °C) and hot dry summers (average T_{max} 30.8 °C).[286]

These three cities combined comprised 37.4% or 9.4 million of Australia's estimated resident population in 2018 (Melbourne: 4.9 million, Brisbane: 2.4 million, Perth: 2.1 million) with an estimated employed labour force of 4.1 million.[425]

5.3.3.2 Data sources

Workers' compensation (WC) claims data

The data included all accepted workers' daily WC claims for WRIs and illnesses (as determined by the insurer) lodged between 1 July 2005 and 30 June 2016 in the three cities. All injuries regardless of their severity (minor or major) were included, although those that occurred during commuting to and from work were excluded, as they are not compensable in all jurisdictions. These data were extracted from the National Dataset for Compensation Based Statistics (NDS3) collected by Safe Work Australia (SWA). The NDS3 is an amalgamation of case-level data supplied each year by jurisdictional WC schemes. Details about this database are provided elsewhere.[72] As effects of temperature are likely to be higher in those carrying out physical work and in outdoor environments, we used industrial classifications following the work of Xiang et al.[45] to categorise workers as working in either 'outdoor industries' or 'indoor industries'. Additionally, as in our previous study,[422] we also categorised the physical job demands (strength) and the potential workplace temperature exposures at the occupational level using a validated cross-walk approach that has been described elsewhere.[132]

Meteorological data

Weather data including daily T_{max}, daily minimum temperature (T_{min}), daily mean temperature (T_{mean}), relative humidity, wind speed and solar radiation were obtained from the Australian Bureau of Meteorology. A single established weather station was selected to represent the weather conditions in each city, in line with previous studies.[278, 283, 285]

5.3.3.3 Study design

We investigated the impact of ambient temperature on WRIs and illnesses using a time-stratified case-crossover (CCO) approach. This study design, where each case is their own control,[357] is appropriate in occupational epidemiology[426] for studying acute outcomes related to transient environmental risk (e.g. temperature). The CCO design also controls for seasonal changes and long-term trends in injury risk that are unrelated to temperature. In contrast to similar studies[132, 188] and other mortality/morbidity studies[362, 363] that use a monthly strata of 28 days, we chose a short strata (control period) of seven days. Several factors such as labour strikes, power outages, change in work setting, practice and/or tasks undertaken, and vacation periods may affect week-to-week numbers of workers.[132] Therefore, a shorter window than 28 days was needed to account for these week-to-week changes in the number of workers. In our strata, a case day (date of injury) is compared to six other referent days (days when the injury did not occur) within the same calendar week (Sunday to Saturday). Using this approach we examined the impact of ambient temperature on WRIs/illnesses by three domains: work, worker and work environment characteristics.

5.3.3.4 Statistical modelling

The time-stratified CCO study design was combined with the distributed lag non-linear model (DLNM) to model the non-linear and delayed effect of temperature.[234, 375, 422] The city-specific exposure-response and lag-response relationship between ambient temperature and WRI were both modelled with a natural cubic spline with three degrees of freedom (df) for temperature and two df for lagged effects.[422] The maximum lag was set to six days as the longest possible delay between temperature exposure and WRIs.

We included relative humidity in the models, as Brisbane has a hot and humid climate during summer and higher humidity levels may lead to over-heating of the body due to slower evaporation of sweat.[427]

Tests of modelling assumptions were undertaken, including checking the residuals for normality, outliers and autocorrelation, and collinearity checks using the variance inflation factor. The initial check of residuals led to the modelling of ‘first day of the financial year’ (1 July) and ‘New Year’s day’ as separate variables. Models were also adjusted for day of the week, ‘Christmas Day’, and other public holidays using binary indicator variables. These adjustments controlled for a reduction in worker numbers on weekends and holidays. All modelling choices and selection of df were determined using the Akaike Information Criterion.[234, 428]

The median value of daily T_{max} for each city over the study period was used as the centring value (baseline temperature) for calculating RRs at the 1st (extreme cold), 10th (moderate cold), 90th (moderate hot) and 99th (extreme hot) temperature percentiles in line with previous studies.[10, 185, 337, 338, 422, 429]

Several sensitivity analyses were used to test the robustness of the above modelling choices for the CCO design combined with the DLNM model. These included: varying the df for temperature and lag dimensions, excluding relative humidity, and varying the temperature indices by using Apparent Temperature (AT), Humidex (HX), Heat Index (HI), Wet Bulb Globe Temperature (WBGT) and Universal Thermal Comfort Index (UTCI).

Attributable risk

We calculated the number of injuries attributable to temperature and the population attributable fraction using a previously defined method.[236] In short, the total number of claims attributable to temperature (AN) in each city was calculated using the minimum T_{max} in each city as the reference temperature to find the number of claims that could be avoided if the temperature remained at its coldest. The minimum T_{max} in each city represents the lowest point on the exposure-response curve, is in line with previous studies[10, 236] calculating attributable mortality/morbidity risks of temperature. The ratio of AN with the total number of claims gives the population attributable fraction (PAF). Empirical 95% confidence intervals (CIs) were obtained for PAF and AN through 5000 Monte Carlo simulations.[236]

5.3.4 Results

5.3.4.1 Descriptive

Between 1 July 2005 and 30 June 2016, a total of 798,831 accepted WC claims were reported in the three cities: i.e. Melbourne: 258,379, Brisbane: 260,730 and

Perth: 279,722. Across the cities, the claimants were predominantly males (66%) and aged between 35 and 54 years (47%). About 51% of claims occurred in the 'manufacturing' (18%), 'healthcare and social assistance' (13%), 'construction' (10%) and 'retail trade' (10%) industries. In Brisbane and Melbourne, more than half of the claims were 'major' (57%) involving a week or more of workdays lost, while in Perth the majority of claims were minor i.e. less than a week of workdays lost (66%). The majority of the claims (91%) were injury-related while 9% were illness-related. Over half of the claims (56%) were due to musculoskeletal injuries, followed by traumatic injuries and fractures (34%). Table B5, Appendix B3 summarises the characteristics of WC claims.

Over the years 2005–2016, the daily average T_{max} was 21.1 °C (range 9.2–46.4 °C) for Melbourne, 26.4 °C (range 12.6–40.2 °C) for Brisbane, and 25 °C (range 12.8–44.4 °C) for Perth. The mean and median (50th percentile) values of daily T_{max}, T_{min} and T_{mean} were higher in Brisbane, while Melbourne had the highest maximum temperatures. The average daily relative humidity ranged from 64% in Melbourne to 70% in Brisbane (Table 5.1).

Table 5.1 Summary statistics of daily weather variables for Brisbane, Melbourne and Perth, 2005–2016.

City	Meteorological indicator	Mean	Min.	Max.	Percentiles					
					1st	10th	50th	90th	99th	IQR
Brisbane	Daily T_{max} (°C)	26.4	12.6	40.2	17.7	21.4	26.8	31	34.7	5.7
	Daily T_{min} (°C)	16.4	2.6	26.5	6.2	10	16.9	22	24.5	7.4
	Daily T_{mean} (°C)	21.4	10.7	31.5	13.1	16	21.8	26.3	28.9	6.4
	Daily Rh (%)	69.5	19.8	98	39.1	57.3	70	81.7	91.8	11.1
Melbourne	Daily T_{max} (°C)	21.1	9.2	46.4	11.4	14.2	20.0	29.9	38.9	8.4
	Daily T_{min} (°C)	11.9	0.6	28.6	3.5	6.6	11.7	17.5	22.4	6
	Daily T_{mean} (°C)	16.5	6.4	35.5	8.4	10.8	16	23.4	29.4	7.1
	Daily Rh (%)	63.8	19.1	100	33	49.5	64.1	78.2	88.6	15.4
Perth	Daily T_{max} (°C)	25	12.8	44.4	15.3	18	23.8	34.2	40.1	9.1
	Daily T_{min} (°C)	12.9	−0.7	29.7	2	5.9	13.1	19.5	23.8	7.4
	Daily T_{mean} (°C)	18.9	7.4	35.4	9.6	12.7	18.3	26.3	31.2	7.9
	Daily Rh (%)	64.7	20.5	95.2	30.8	44.1	66.8	81.2	90.3	19.7

Note: IQR: inter-quartile range.

5.3.4.2 Exposure-response relationship

Overall

The cumulative association between daily T_{max} and WRIs and illnesses presented as RR for each city, is shown in Figure 5.1. There was a heterogeneous pattern between cities in the effects of heat, with increasing injury risk at the extremes, while cold effects were similar in each city with decreasing injury risks at the coldest extremes.

Relative to the median, increasing T_{max} in Melbourne was associated with an increase in injury risk, with RRs of 1.05 (95% CI: 0.99–1.10) for moderately hot (90th percentile) and 1.14 (95% CI: 1.03–1.25) for extremely hot (99th percentile) temperatures. In other cities the corresponding RR for injuries for moderately hot and extremely hot temperatures were 0.96 (95% CI: 0.93–1.01) and 0.98 (95% CI: 0.89–1.09) in Brisbane, and 0.98 (95% CI: 0.93–1.04) and 1.01 (95% CI: 0.93–1.11) in Perth, respectively. In Brisbane and Perth, we observed a 'comfort zone' of temperature (above the 50th percentile of T_{max}) where injury risks were decreased (RRs <1), before increasing (RRs >1) at the upper temperature range of 37 °C and 37.5 °C in Brisbane and Perth, respectively. Protective associations were observed on cold days in Brisbane, with a RR of 0.89 (95% CI: 0.81–0.98), at the 1st percentile versus relative to the median T_{max}. A non-significant risk reduction was seen on cold days in the other cities compared to the median T_{max}, with corresponding RRs of 0.99 (95% CI: 0.90–1.09) in Melbourne and 0.96 (95% CI: 0.88–1.05) in Perth, respectively.

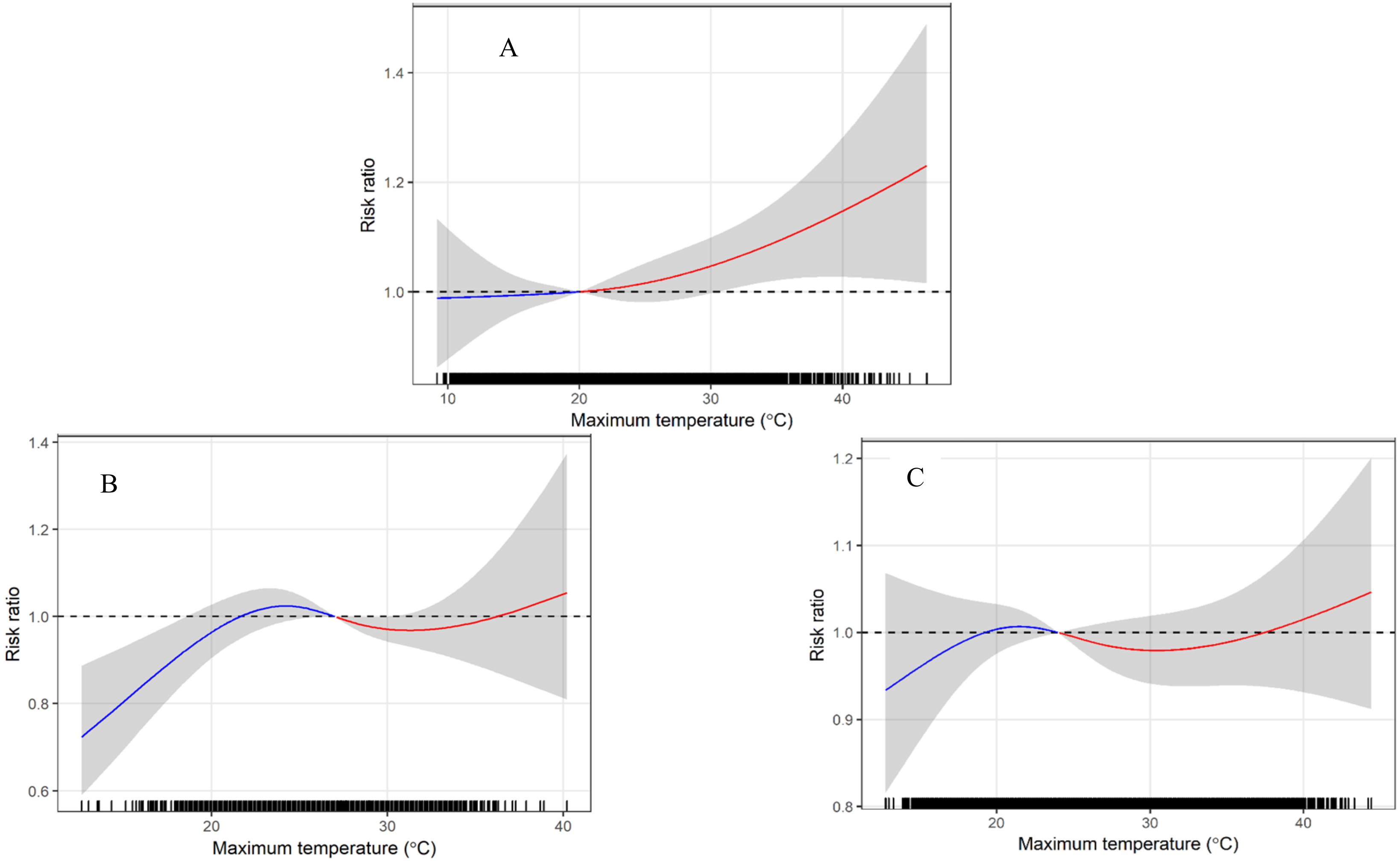

Figure 5.1 Relative risks of workers' compensation claims associated with daily maximum temperature (°C) relative to median T_{max} of (A) 20 °C in Melbourne, (B) 27 °C in Brisbane and (C) 24 °C in Perth, using data from 1 July 2005 to 30 June 2016.

The effects of ambient temperatures on claims stratified by workers' demographics, work and work environment characteristics for Melbourne are shown in Table 5.2. In Melbourne, young workers (RR 1.18, 95% CI: 1.03–1.36) and those in 'regulated indoor climates' (RR 1.07, 95% CI: 1.01–1.14) had higher risk of WRIs and illnesses on moderately hot days (90th percentile vs median T_{max}). Increased risks of WRIs and illnesses during extremely hot temperatures (99th percentile) were observed for female workers (RR 1.27, 95% CI: 1.07–1.15), those aged 25–34 years (RR 1.25, 95% CI: 1.01–1.55), workers who are not an apprentice/trainee (RR 1.14, 95% CI: 1.03–1.26) and workers 'in a vehicle or cab' (RR 1.34, 95% CI: 1.10–1.63). Workers in 'indoor industries' and in 'medium-demanding' occupations were susceptible to both moderately and extremely hot temperatures with the highest mean RR observed for 'transport, postal and warehousing' industry (RR 1.59, 95% CI: 1.18–2.13, results not shown).

Supplementary Table B6, Appendix B3 shows corresponding effects of ambient temperatures on claims in Brisbane and Perth where there was no statistically significant changes in risk for most subgroups. Industry-specific analysis showed higher RRs during extremely hot temperatures for 'agriculture, forestry and fishing' (RR 1.91, 95% CI: 0.72–5.03) and 'transport, postal and warehousing' (RR 1.37, 95% CI: 0.99–1.90) in Brisbane, and 'electricity, gas and water' (RR 1.53, 95% CI: 0.70–3.37) in Perth; however, these were not statistically significant (results not shown).

Consistent with the overall pattern observed at cold temperatures in Melbourne, workers in 'medium-demanding' occupations and 'indoor' and 'outdoor' industries had lower risk of WRIs and illnesses relative to the median T_{max} (Table 5.2), while in Brisbane 'male workers', those aged 15–24 years, workers in 'outdoor' industries and 'heavy-demanding' occupations had lower risk (Table B6, Appendix B3). No change in risks was observed in Perth for any of these subgroups (Table B6, Appendix B3).

Injury and illness characteristics

In Melbourne, claims with the injury characteristics classified as 'falls, trips and slips of a person' increased during moderately and extremely cold temperatures (RR 1.11; 95% CI: 1.00–1.22 and RR 1.24; 95% CI: 1.01–1.52, respectively, results not shown), while those due to 'being hit by moving objects' increased during moderately and extremely hot temperatures (RR 1.14; 95% CI: 1.01–1.29 and RR 1.33; 95% CI 1.03–1.71, respectively, results not shown). Claims due to 'heat, electricity and other environmental factors' increased during moderately hot temperatures (RR 1.63; 95% CI: 1.09–2.45), while those due to 'mental stress' increased during extremely hot temperatures (RR 1.54; 95% CI: 1.01–2.32, results not shown). In Brisbane no specific types of injuries were significantly increased during hot temperatures, while in Perth traumatic injuries increased during extremely hot temperatures (RR 1.17; 95% CI: 1.02–1.35, results not shown). By further stratifying the traumatic injuries data for Perth, we found that workers who were not an apprentice/trainee were at risk at moderately hot (RR 1.15, 95% CI: 1.05–1.27) and extremely hot temperatures (RR 1.31, 95% CI: 1.10–1.55), while workers in the construction industry (RR 1.61, 95% CI: 1.09–2.39), retail trade industry (RR 1.60, 95% CI: 1.07–2.38) and 'medium-demanding' occupations (RR 1.54, 95% CI: 1.22–1.93) were at risk during extremely hot temperatures (results not shown).

Table 5.2 Relative risks for workers' compensation claims in hot and cold temperatures stratified by claims characteristics in Melbourne metropolitan area, 2005–2016 (RR with 95% CI).

Exposure[a]	Extreme cold[b]	Moderate cold[c]	Moderate heat[d]	Extreme heat[e]
Claim severity				
Minor claims	0.82 (0.68, 0.99)	0.88 (0.80, 0.96)	1.15 (1.04, 1.27)	1.17 (0.95, 1.44)
Major claims	1.05 (0.94, 1.17)	1.03 (0.97, 1.09)	1.02 (0.96, 1.07)	1.12 (1.02, 1.26)
Gender				
Male	1.04 (0.92, 1.17)	1.02 (0.95, 1.08)	1.03 (0.97, 1.10)	1.06 (0.93, 1.21)
Female	0.90 (0.77, 1.05)	0.95 (0.88, 1.03)	1.06 (0.98, 1.15)	1.27 (1.07, 1.50)
Age group (years)				
15–24	1.14 (0.86, 1.50)	1.02 (0.89, 1.16)	1.18 (1.03, 1.36)	1.15 (0.86, 1.53)
25–34	1.05 (0.85, 1.29)	1.02 (0.92, 1.13)	1.08 (0.96, 1.20)	1.25 (1.01, 1.55)
35–54	0.96 (0.84, 1.09)	0.98 (0.92, 1.05)	1.02 (0.94, 1.09)	1.12 (0.97, 1.29)
>55	0.91 (0.73, 1.15)	0.95 (0.85, 1.07)	1.01 (0.90, 1.14)	1.05 (0.82, 1.33)
Worker experience				
Apprentice/Trainee	1.06 (0.51, 2.17)	1.02 (0.72, 1.45)	0.97 (0.66, 1.41)	0.87 (0.40, 1.87)
Other	0.98 (0.90, 1.09)	0.99 (0.94, 1.04)	1.05 (0.99, 1.10)	1.14 (1.03, 1.26)
Potential workplace temperature exposure				
Regulated indoors	0.95 (0.89, 1.02)	0.98 (0.92, 1.03)	1.07 (1.01, 1.14)	1.04 (0.98, 1.11)
Unregulated indoors and outside	0.66 (0.32, 1.35)	0.75 (0.40, 1.39)	0.73 (0.38, 1.42)	0.99 (0.49, 2.00)
In a vehicle or cab	0.86 (0.70, 1.05)	1.00 (0.84, 1.20)	1.02 (0.85, 1.23)	1.34 (1.10, 1.63)
Multiple locations	0.94 (0.85, 1.06)	1.03 (0.93, 1.13)	0.96 (0.87, 1.07)	0.99 (0.88, 1.11)
Physical demands				
Limited (≤5kg)	0.94 (0.78, 1.13)	0.95 (0.90,1.00)	1.03 (0.98, 1.09)	1.06 (0.87, 1.30)
Light (5–10kg)	0.92 (0.75, 1.14)	0.99 (0.94,1.06)	1.00 (0.94, 1.06)	0.99 (0.80, 1.24)
Medium (10–20kg)	0.96 (0.82, 1.13)	0.94 (0.90, 0.98)	1.05 (1.01, 1.09)	1.23 (1.03, 1.47)
Heavy (>20 kg)	1.17 (0.94, 1.45)	1.01 (0.95,1.07)	1.01 (0.95, 1.07)	1.24 (0.98, 1.55)
Industry				
Indoor	0.95 (0.90, 1.01)	0.97 (0.94, 0.99)	1.04 (1.01, 1.07)	1.06 (1.01, 1.12)
Outdoor	0.84 (0.72, 0.99)	0.92 (0.86, 0.99)	0.96 (0.89, 1.04)	0.96 (0.82, 1.14)

Abbreviations: CI: confidence interval; RR: relative risk. Shaded cells indicate statistically significant results.
All temperatures were compared with the median T_{max} of 20.0 °C

a. The 1st percentile of temperature (11.4 °C)
b. The 10th percentile of temperature (14.3 °C)
c. The 90th percentile of temperature (29.9 °C)
d. The 99th percentile of temperature (38.9 °C)

Population attributable fraction (PAF)

The PAFs for WC claims attributable to temperature were 1.9% (95% CI: 10.3, 13.4%) in Melbourne, 26.5% (95% CI: 10.2, 40.1%) in Brisbane and 5.7% (95% CI: 6.1, 16.9) in Perth (Table 5.3). The corresponding number of claims attributed to temperatures in these cities for the whole study period (11 years) was calculated to be 5,137 claims in Melbourne (467 claims/year), 69,442 claims in Brisbane (6,312 claims/year) and 16,467 claims in Perth (1,497/year).

Table 5.3 Attributable risk numbers (AN) and population attributable fractions (PAF) and 95% CIs using the lowest T_{max} in Melbourne, Brisbane and Perth, 2005–2016.

Exposure / City	Reference Temperature	AN n (95% CI)	PAF % (95% CI)
Melbourne	9.2 °C	5137 (−27,478–34,923)	1.98 (−10.3,13.4)
Brisbane	12.6 °C	69,442 (27,967–104,649)	26.51 (10.2,40.1)
Perth	12.8 °C	16,467 (−17,959–46,612)	5.71 (−6.1,16.9)

5.3.4.3 Sensitivity analyses

Similar estimated effects were obtained for the range of sensitivity analyses, including other temperature metrics (supplementary material, Table B7, Appendix B3). It should be noted that during extremely cold temperatures in Brisbane a protective effect was found when using T_{max} (and other indices) as the exposure variable, whereas elevated risk ratios were found when using T_{mean} or T_{min}. Varying the df for T_{max} and lag dimensions did not substantially change any results (results not shown).

5.3.5 Discussion

In this study, the associations between ambient temperature and WRIs and illnesses were explored and quantified using WC claims data from three Australian cities with differing climates. Our results provide both supporting and new evidence regarding the occupational impacts of hot and cold temperatures.

The key findings can be summarised as follows. Firstly, the exposure-response relationships varied between the cities, particularly in Melbourne where a stronger effect of increasing temperatures (moderate and extreme) was found. In contrast, claims increased only slightly in Brisbane and Perth when temperatures were close to, or above the reference level of extreme hot temperatures (99th percentile). Secondly, cool to cold temperatures (moderate and extreme) were associated with lower risks of overall claims in all three cities, with Brisbane showing a large protective association. However, specific injuries due to ‘falls, trips and slips’ increased on cold days in Melbourne. Thirdly, worker subgroups vulnerable to injuries during warm or hot weather were not those in heavy physically demanding occupations and working outdoors, as expected, but were those in ‘medium’ strength occupations and those working in ‘regulated indoors’ and ‘vehicle or cab’ environments. Finally, the burden of claims attributable to temperatures appears to be considerably higher in a sub-tropical location than temperate locations.

The differences in risks across the cities warrants further investigation, because it suggests that there are location or population-specific factors that influence the impact of temperature on workers’ health. This is in contrast to studies examining temperature and mortality risk in Australia, which have reported a similar relationship for Brisbane, Melbourne and Sydney.[9, 10] It is possible that these differences are related to workplace factors; for example, although there exists harmonised model workplace health and safety (WHS) legislations, there are variances in how they are implemented and enforced across states and territories.

Furthermore, there are likely differences between the cities in relation to industry or employment profiles, which may also contribute to differences in the exposure-response curves.

Our finding of a stronger heat effect on workers' claims in Melbourne is consistent with previous studies[132, 188] in this city and also with a previous study in Adelaide,[422] which also has a temperate climate. The different relationship to that observed in Brisbane and Perth may be due to climatic or non-climatic factors. Melbourne is situated at a higher latitude than Perth and Brisbane, with a cooler climate overall, yet more variable temperatures in summer. These factors may contribute to the increased sensitivity of workers, who may be less acclimatised to high temperatures. Health effects have been reported to be greater in other cities with cooler climates but higher temperature variability in summer.[378, 430] Our results for Melbourne are consistent with this observation, and suggest that, at least for extreme hot temperatures, these factors matter. Although we do not know the prevalence of workplace air-conditioning, Melbourne has a lower prevalence of any type of household air-conditioning and higher prevalence of heaters than Brisbane and Perth based on reports by the Australian Bureau of Statistics (ABS).[257] This indicates that adaptation to cold may be better than to heat in Melbourne. However, the role of individual physiological and behavioural adaptations in this study were not explored due to the ecological study design and lack of such data within the WC database. Further investigation is needed in order to disentangle and identify factors that may have contributed to the observed heterogeneity in the heat effects.

The worker subgroups most vulnerable to hot days in Melbourne included: 'workers who are not an apprentice/trainee', 'female workers' and 'young workers'. These findings are largely similar to those reported by previous studies[45, 422] with some notable variations. Although several studies[45, 135] have shown male workers to be at greater risk due to their occupational profiles, our results indicate a pronounced effect for female workers during moderately and extremely hot days. Industrial sectors with mostly indoor activities, which have a higher proportion of female workers showed stronger heat effects than industries with mostly outdoor activities.

The finding that outdoor workers were not at elevated risk in Melbourne was unexpected as it contrasts with previous studies,[45, 145, 422] and suggests the existence of heat stress policies, better acclimatisation status or greater awareness of risks posed by hot weather have likely reduced the risks for those working in industries with mostly outdoor activities. Consistent with the study of McInnes et al. (2017)[132] we found that workers in ‘regulated indoor climates’ and ‘in a vehicle or cab’ but not in ‘unregulated indoor and outside’, had increased risks of injury. Although a regulated indoor climate includes work carried out in air-conditioned environments, occupational health problems may arise in workers acclimatised to cooler workplaces if the air-conditioning system fails as they may have reduced capacity for physiological regulation to higher temperatures.[410] It is also possible that workers may not be indoors all the time, thereby being subject to the effects of heat stress and injury when required to work outdoors. Similarly, ‘vehicle or cab’ environments may not necessarily be air-conditioned, and drivers may need to spend considerable time outside of the vehicle. Furthermore, it is also important to note that the ‘unregulated/regulated indoor’ and ‘vehicle or cab’ classification of work environments is a crude measure of workers’ potential temperature exposure.

Our finding of an association between T_{max} and medium physically demanding occupations in Melbourne resonates with a study in Quebec[127] and Adelaide[422] but contrasts with a previous study in Melbourne,[132] where associations were observed only for heavy physically demanding occupations. These findings emphasise that the level of physical strength required by the occupation and other personal risk factors such as acclimatisation and awareness of the health risks of hot weather may be important effect modifiers for injuries on hot days for those working primarily indoors or in industries with mostly indoor activities.

The lack of a significant association between hot temperatures and claims in Brisbane was an unexpected finding, as this city experiences higher levels of humidity on summer days. This finding contrasts with a study in Guangzhou, China, a city with similar climate to Brisbane.[190] Humidity limits evaporation, a major heat loss mechanism, and this would be expected to place workers at greater risk of injuries than in locations where humidity levels are comparatively low (Melbourne and Perth). However, the role of humidity did not seem to influence our results, either when controlling for it with T_{max} or its inclusion in composite indices (e.g. WBGT), possibly because the Brisbane working population is likely acclimatised to high temperatures and humidity in summer.

There appears to be a broader ‘comfortable working zone’ in terms of temperature in Brisbane and Perth, where the risk of WRIs and illnesses is lower. As previously mentioned, this possibly indicates adaptation to local climatic conditions either through physiological, technological and or behavioural acclimatisation of the workers,[12, 352, 430, 431] or more effective occupational WHS practices. However, once temperatures rise above the ‘comfortable working zone’, the risk ratios were somewhat elevated (albeit non-significantly) at extreme temperatures (37 °C in Brisbane and 38 °C in Perth). This suggests that workers in Brisbane and Perth are still likely to be affected by extreme heat in their climatic region. This is clearly evident in our finding that 'traumatic injuries' increased by 17% during extreme hot days in Perth. Previous studies in Adelaide, a city with comparable climate to Perth, reported that traumatic injuries such as 'wounds, lacerations and amputations' and 'burns' increased during high temperatures and heatwave periods.[145, 422] Similar to studies in Adelaide, the at-risk worker subgroups for traumatic injuries during extremely hot temperatures in Perth were those in the construction industry, workers in medium-demanding occupations, and workers who are not an apprentice/trainee.

In contrast to the effects of heat, our results indicate that injuries appear to be reduced during cold days in all cities. This protective effect at cold temperatures contrasts with a recent study in Spain,[185] where a U-shaped curve was found between ambient temperature and risk of occupational injuries. Our results do indicate that 'falls, trips and slips' increased in Melbourne during moderate and extreme cold days, which is in agreement with other studies.[400, 401] It should also be noted that elevated risks at extremely cold temperatures were apparent when T_{min} was used as the exposure variable in Brisbane. T_{min} is a more effective indicator of low overnight and early morning temperatures, and these are likely to impact those who work non-traditional workhours.

Regarding the numbers of claims that could be attributed to temperature, we found that overall PAFs of WRIs and illnesses was considerably lower in Melbourne and Perth, despite the increased risk of WRIs and illnesses in Melbourne at extremely hot temperatures. The high PAF for Brisbane likely occurs because of the much lower risk of WRIs and illnesses is at the lowest temperature, compared to which every day is associated with an increased risk.

Study limitations

This study has a number of limitations. The retrospective ecological nature of the study confines our ability to deduce the causal association of ambient temperature with WRIs. Consistent with other ecological time-series and CCO studies, we relied on temperature data from an outdoor weather station as a surrogate for personal exposure, which fails to account for the spatial and temporal variations of ambient temperatures in workplaces. This introduces misclassification of exposure, as the temperatures to which workers were exposed before the injury may not necessarily reflect that measured at the weather station. Additionally, the claims data analysed in this study are limited to workers who had ‘accepted compensation claims’ and excludes rejected claims and injuries for which no claim was lodged. Thus, the use of an administrative dataset not intended for research purposes does not capture the total burden of WRIs and illness for the general labour force. Lastly, this study is focussed on three cities of Australia, two with a temperate climate and one with a sub-tropical climate. This limits generalisability of findings, and further investigations are needed for other cities in Australia with tropical climates that may have different effects to that observed in the study sites.

Despite these caveats, this study has a number of strengths. The findings have characterised the relationships between ambient temperature and occupational injuries in three large Australian cities in different climatic zones, and quantified the associated attributable burden. Consistent definitions, study periods, procedures and statistical methods were used for each city thereby enabling direct inter-jurisdictional comparisons. A further strength is the use of flexible DLNM, combined with a time-stratified CCO study design that accounts for (i) the non-linear, delayed effects of daily ambient temperatures, and (ii) the lack of denominator information. The inclusion of all claims including those classified as 'minor' and 'major' is a further strength of this study.

Our findings have public health implications in the context of a warming climate. RCP4.5 scenarios predict that among the three study sites, the predicted annual temperature rise and annual number of days above 35 °C and 40 °C for 2030 and 2090 is highest in Brisbane followed by Perth and Melbourne.[109] These projections and our findings indicate that location and climate-specific targeted intervention strategies are needed to inform location-specific action WHS plans for hot weather. It is also possible that the results from this study could be extended to other cities with similar climatic conditions to support the development of extreme weather plans. Future studies using qualitative methods could be conducted to provide more in-depth analysis and exploration of the many complex factors that contribute to heat or cold related injuries, and how they may differ by worker populations and location.

5.3.6 Conclusion

Our study contributes to the growing body of research documenting the relationships between occupational health risks and ambient temperatures. Our results confirm that high ambient temperatures pose a risk for workers' health and safety by increasing the occurrence of WRIs in Melbourne, especially at hot extremes. Although exposure to hot temperatures appears to have a lesser effect on work injuries in Brisbane and Perth, the burden attributable to temperature appears to be higher in sub-tropical Brisbane. Our results indicate that cooler day time T_{max}

temperatures are associated with reduced risks to workers in all three cities. While workers' health and safety should be a priority at all times of the year, our results suggest that there should be particular attention as temperatures increase.

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*****End of published paper*****

5.4 CHAPTER SYNOPSIS

Chapter 5 presented evidence of how daily ambient temperatures affect WRI in three of Australia's larger cities. The findings suggest that the overall relationship between ambient temperature and WRI vary by location and climate, with a stronger effect of increasing temperatures (moderate and extreme) in Melbourne, a city with temperate climate. Cooler daytime maximum temperatures were associated with reduced risks to workers in all three cities, with Brisbane showing a greater reduction in risk. The avoidable burden of temperature on occupational health was therefore higher in subtropical Brisbane than in Melbourne and Perth with temperate climates.

Summary of Section B

Section B comprised Chapters 4 and 5 and addressed the research question ‘what is the epidemiology of heat-related injuries’ from a daily outdoor ambient temperature perspective, using WC claims data. The evidence presented in this section suggests that ambient temperatures have an impact on WRI, however this varies across cities, with a stronger heat effect in Adelaide and Melbourne for overall WRI and for traumatic injuries in Perth, while cooler daytime temperatures were associated with reduced risks in Brisbane. Together the findings from these two studies may have implications for informing policy-makers and relevant stakeholders (industry, union organisations, employers, and regulators) on injury prevention strategies to protect workers’ health and safety. This is particularly relevant in the context of a warming climate.

SECTION C: HEATWAVES AND WORK-RELATED INJURIES

Overview of Section C

Section C consists of two chapters. Chapters 6 and 7 collectively examine the impacts of heatwaves of varying severity on WRI using a time-stratified CCO study design. Chapter 6 reports on the analysis of WC claims data in Adelaide, while Chapter 7 reports on the analysis from Brisbane, Melbourne, and Perth.

06

Chapter 6: Heatwave and Work-Related Injuries and Illnesses in Adelaide, Australia: A Case-Crossover Analysis using the Excess Heat Factor as a Universal Heatwave Index

6.1 PREFACE

Chapter 6 presents the results of a study that addresses the second and third objective by examining the effects of heatwaves (or extended periods of heat) on WRI in Adelaide. Similar to Chapter 4, WRI were identified from the Tabulator dataset. Heatwaves were defined using EHF, a relatively new metric that normalises heatwave severity across locations with different climates. In addition to the WC data, this study also used work-related ambulance call-outs and also compared the predictive ability of EHF to a previously used heatwave definition based on T_{max}.

This study is the first in the literature to assess the impacts of heatwaves on WRI using EHF and has been published in the journal of International Archives of Occupational and Environmental Health as:

Varghese BM, Hansen A, Nitschke M et al. Heatwave and WRIs and illnesses in Adelaide, Australia: using the Excess Heat Factor (EHF) as a universal heatwave index. Int Arch Occup Environ Health. 2019; 92(2):263–72. doi:10.1007/s00420–018–1376–6.

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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

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6.3 PUBLICATION

6.3.1 Abstract

Purpose: Heatwaves, or extended periods of extreme heat, are predicted to increase in frequency, intensity and duration with climate change, but their impact on occupational injury has not been extensively studied. We examined the relationship between heatwaves of varying severity and work-related injuries (WRIs) and illnesses. We used a newly proposed metric of heatwave severity, the Excess Heat Factor (EHF), which accounts for local climate characteristics and acclimatisation and compared it with heatwaves defined by daily maximum temperature.

Methods: WRIs and illnesses were identified from two administrative data sources: workers' compensation (WC) claims and work-related ambulance call-outs for the years 2003–2013 in Adelaide, Australia. The EHF metrics were obtained from the Australian Bureau of Meteorology. A time-stratified case-crossover regression model was used to examine associations between heatwaves of three levels of severity, and: WC claims; and work-related ambulance call-outs.

Results: There was an increase in work-related ambulance callouts and WC claims during low and moderate severity heatwaves as defined using the EHF, and a non-significant decline during high severity heatwaves. Positive associations were observed during moderate heatwaves in WC claims made by new workers (RR 1.31, 95% CI: 1.10–1.55), workers in medium-sized enterprises (RR 1.15, 95% CI: 1.01–1.30), indoor industries (RR 1.09, 95% CI: 1.01–1.17), males (RR 1.13, 95% CI: 1.03–1.23) and labourers (RR 1.21, 95% CI: 1.04–1.39).

Conclusions: Workers should adopt appropriate precautions during moderately severe heatwaves, when the risks of WRIs and illnesses are increased. Workplace policies and guidelines need to consider the health and safety of workers during heatwaves with relevant prevention and adaptation measures.

Keywords: Workers' compensation claims; Case-crossover design; Heatwaves; Occupational Health; Worker safety

6.3.2 Introduction

The detrimental effect of temperature upon human health assessed in terms of increased mortality and morbidity is well established.[5] Major heatwaves (extended periods of unusually high temperatures) have been associated with an increased health burden in populations over recent years. For example, heatwaves in Australia in 2009[20, 432, 433] and Europe in 2003[18] have drawn increasing interest among researchers, governments and policy makers. The majority of health research has predominantly focussed on the general population, while the occupational health effects have been largely overlooked despite their potential economic costs and impact on quality of life.

The direct effects of extreme heat on workers' health was evident during the 2003 heatwave in France where a considerable number of deaths occurred in those of working age (15–64 years). This age group has also been found to be at risk in Australia where a 37% increase in mortality was reported during a record-breaking 2009 severe heatwave in Adelaide, South Australia.[20] Apart from elevating the risk of symptoms leading to heat-related illness (HRI) and in severe cases, death, there is increasing evidence that high ambient temperatures could increase the risk of occupational injuries.[42, 43, 45, 122, 127, 132, 135, 188] The occurrence of work-related accidents during high temperatures may be attributed to multiple factors that can compromise workplace safety, including physical discomfort, decreasing psychomotor performance, fatigue and reduced alertness arising from heat exposure.[29, 33, 41] Consecutive days of very high temperatures can have significant health impacts on workers with physical fatigue carrying over into the following days, thus increasing the risk of injuries.

To the authors' knowledge, only three Australian studies have investigated the impact of sustained high ambient temperatures on workers' health and safety.[145, 146, 188] Two studies[145, 146] did not find any statistically significant difference in overall injury claims between heatwave and non-heatwave periods, although a 6.2% increase in claims was observed for outdoor industries.[145] An increased risk of injury was observed in Melbourne, Australia during two and three consecutive days of hot (but not extreme) weather, with a 15% increased injury risk when the daily maximum temperature was above 33 °C.[188] Given that the frequency, duration, and intensity of heatwaves are predicted to increase in the future due to climate change,[417] it is imperative to better understand how heatwaves might affect workers directly or indirectly in order to inform public health policies that can help minimise the risks.

One of the key challenges presented for heatwave studies relates to heatwave definitions, as currently there exists no standardised definition.[16, 182, 434] Most studies[435-437] have defined heatwaves utilising a combination of duration (≥2, ≥3 or ≥4 days) and intensity (95th or 97.5th percentiles of temperature). Different temperature metrics have been used (e.g. minimum/mean/maximum temperature or Apparent Temperature, Humidex and Heat Index), while some studies have used extended definitions exploring characteristics such as early or late season heatwaves.[325, 438, 439] As a result, it is difficult to make consistent statements on both the current and future health impacts using these different definitions.

In this context, the Australian Bureau of Meteorology (BOM) recently introduced a map-based heatwave forecasting service using the Excess Heat Factor (EHF) metric based on average daily temperatures.[182] Recent studies that have used the EHF as an exposure metric in the assessment of health impacts have found it to be a useful heatwave indicator.[285, 287, 440-442] The EHF is also becoming widely used internationally due to its applicability in both tropical and temperate regions, and as such is included in the World Health Organization (WHO) and World Meteorological Organization (WMO) guidance documents on warning systems.[443]

With the association between heatwaves and occupational injuries not well established, this study aimed to characterise the relationship between heatwaves of varying severity as defined using the EHF, and work-related injuries (WRIs) and illnesses in Adelaide, using two data sources: workers' compensation (WC) claims data and ambulance data. We hypothesise that EHF-defined heatwaves are associated with an increased risk of WRIs and illnesses.

6.3.3 Materials and methods

6.3.3.1 Study site

Adelaide, the capital city of the state of South Australia, is the fourth largest Australian city covering an urban area of 3,258 km^2 with a population of 1.6 million. The city has a temperate climate with mild winters and hot, dry summers.

6.3.3.2 Data sources

Workers' compensation (WC) claims data

Compensation claims data for the period from 1 July 2003 to 30 June 2013 were aggregated by 'Return to Work SA', a government agency that manages the prevention and compensation of occupational accidents and diseases in South Australia. The dataset covered all reported and active claims in the Adelaide metropolitan area defined as the suburbs encompassing postcodes 5000–5200. The data included details on worker characteristics (age, gender, type of work, industry), injury and illness information (agency, mechanism, type and body location) and outcome details (hospitalisations, deaths, days lost from work and total expenditure). More details about this data are described elsewhere.[45, 145, 146, 301] For the purposes of this study, we used all accepted compensation claims (comprising WRIs and illnesses) as the outcome variable in line with previous studies.[145, 146]

Ambulance call-outs

Ambulance services in Adelaide are predominantly provided by the South Australian Ambulance Service (SAAS). Data pertaining to ambulance call-outs (excluding between hospital transfers) logged between 1 July 2003 and 30 June 2013 were examined. For the purposes of this study, we selected only SAAS callouts coded as 'work-related/industrial'.

Meteorological data

The BOM provided the climate data for the study period, including daily maximum and minimum temperatures (T_{max} °C, T_{min} °C) and relative humidity (%) from the Kent Town weather station (023090), considered to best represent the Adelaide metropolitan area.[21, 45, 145, 272, 441]

6.3.3.3 Heatwave definitions

Heatwaves (HW) were defined using the EHF definition according to Nairn and Fawcett.[182] EHF captures the HW intensity based on a three-day averaged daily mean temperature (T_{mean}) consisting of two components: the significance index and the acclimatisation index. These are referred to as the Excess Heat Indices (EHIs) and are calculated as:

$$EHI_{sig}=(T_i+T_{i+1}+T_{i+2})/3-T_{95} \qquad (1)$$

$$EHI_{accl}=(T_i+T_{i+1}+T_{i+2})/3-(T_{i-1} + \ldots + T_{i-30})/30 \qquad (2)$$

The comparison of the three-day averaged T_{mean} to the 95th T_{mean} percentile and average T_{mean} over the previous 30 days generates the above EHIs. The product of equations (1) and (2) gives EHF as:

$$EHF=EHI_{sig}\times\max(1, EHI_{accl}) \qquad (3)$$

Days with a positive EHF indicate the existence of heatwave conditions and the severity level of such events are expressed as an EHF severity index (EHF_{sev}) calculated as:

$$EHF_{sev}=EHF\div 85^{th}\text{ percentile of all positive values} \qquad (4)$$

Days when EHF_{sev} is between zero and one, and greater than one, indicates heatwaves of ‘low’ and ‘severe’ intensity, respectively, whereas those greater than three are identified by the BOM as an ‘extreme’ heatwave.[182] Thus, EHF is primarily based on the local climate and on daily temperature, and accounts for the significance of consecutive hot days and acclimatisation. Other heatwave characteristics such as intensity, frequency and duration are represented, making

EHF useful for forecasting heatwaves.[182] Additionally, the effects of relative humidity that play a considerable role in human response to heat are also indirectly factored in the formula with the use of T_{mean}. Further details on EHIs and EHF (e.g. development, calculation and usage) are described elsewhere.[182]

The EHF and EHF severity data for the Kent Town monitoring station were supplied by the BOM as a gridded dataset using low resolution (0.25°×0.25°, approximately 25×20 km) operational daily temperature analyses. Generally heatwave severity is classified as above by the BOM. However, as there were very few days of EHF_{sev} ≥3 during the study period, for our purposes extreme HW days were included within the high-severity category that we defined using a lower criterion (EHF_{sev} ≥2) as described below. Hence, we used the following EHF_{sev} categories (HWD1):

- No heatwave: daily EHF_{sev} ≤0
- Low-intensity: daily EHF_{sev} >0 and <1
- Moderate-severity: daily EHF_{sev} ≥1 and <2
- High-severity: daily EHF_{sev} ≥2

Additionally, we also used a definition (HWD2) using T_{max} of ≥3 consecutive days with daily T_{max} ≥35 °C (as in previous studies) for comparison.[21, 145, 272]

6.3.3.4 Study design and analysis

A time-stratified case-crossover (CCO) study design was used to assess the association between heatwave severity and the outcome variables of interest. In CCO design each ‘case’ serves as their own control and time-invariant confounders and seasonal patterns are controlled for.[357] In this study, the ‘cases’ are accepted WC claims or reported ‘work-related ambulance call-outs’. Heatwave exposure in the ‘case period’ was compared with the exposures during the ‘control period’ (other days within the strata when the case did not occur). A seven-day strata was utilised to adjust for week to week changes in worker numbers.

Risk periods were pre-defined heatwave days of varying severity and the referent period was all non-heatwave days. Key confounding factors taken into account include: seasonality, day of the week and public holidays. To control for seasonality we restricted the analysis to the warm-season (October–March) and adjusted for public holidays with three separate indicator binary variables (Christmas Day, New Year’s Day and other public holidays). To model the well-known pattern in workers’ activity during the week, the days of the week were modelled using an independent binary variable for each seven-day window except the reference day (Friday). We fitted the CCO design using a generalized linear model (GLM) assuming a Poisson distribution. Results are presented as risk ratios (RR) with 95% confidence intervals (CIs) for the number of daily WC claims and work-related ambulance call-outs during heatwave periods of low-intensity, moderate and high severity, compared with non-heatwave periods in the warm-season. Additionally, stratified analysis by worker (age group, gender), work (industry, occupation), and work environment characteristics (work site location, size of business) was conducted to identify vulnerable subgroups. We also investigated lagged effects (days 1 and 2) of EHF_{sev} on total WC claims and work-related ambulance call-outs. As we found no evidence of a marked lagged effect, these are not presented in the results section.

6.3.3.5 Cross-validation

The predictive ability of each HW definition was assessed using a 50-fold cross-validation. Details of this technique are given elsewhere.[444] The benefit of using this robust model selection technique is that more realistic predictions can be obtained for future studies with the inference being less tailored to the dataset in which this procedure is applied.[288] We randomly removed one day from the seven-day strata throughout the study period and then ran the GLM regression models 50 times. Standard errors were then created by comparing the actual number of claims to the predicted values with the smaller root mean square error indicating the better prediction of the model.

All analysis was carried out using the R statistical software version 3.2.3, with the ‘season’ package used to fit the CCO design.[355]

6.3.4 Results

6.3.4.1 Descriptive statistics

Within the Adelaide metropolitan region during the period of 1 July 2003–30 June 2013, there were 224,631 (76.1%) accepted WC claims of which 111,254 (49.5%) occurred during the warm-season (October–March). Males accounted for 66.4% of the claims and approximately two-thirds (69.5%) of claims were for people aged 25–54 years. On the other hand, there were 5,910 (0.6%) work-related ambulance call-outs out of a total of 931,786 ambulance call-outs during the same time frame of which half (2,987) occurred during the warm-season.

There were 118, 19 and 7 days defined using the EHF (HWD1) as low-intensity, moderate and high-severity heatwaves, respectively. The corresponding three-day mean T_{max} during these heatwave days were 35.1 °C, 38.2 °C and 41.1 °C. By contrast, using the T_{max} definition of heatwaves (HWD2), there were 106 heatwave days.

6.3.4.2 Association between heatwave and work-related injuries and illness

Total effects

There was an increase in WC claims during low-intensity and moderate-severity heatwaves and a non-significant decline during the high-severity heatwaves (Figure 6.1A). The RR during moderate-severity heatwaves was 1.08 (95% CI: 1.01–1.17) for overall WC claims and 1.10 (95% CI: 1.02–1.19) for injury claims. By contrast the RR for illness claims was 1.13 (95% CI: 1.03–1.25) during low-intensity heatwaves. However, based on HWD2, there were no statistically significant difference detected in WC claims between heatwave and non-heatwave periods.

A similar trend was observed for work-related ambulance callouts with an increase in call-outs during low-intensity and moderate-severity heatwaves and a decline during high-severity heatwaves (Figure 6.1B). The corresponding RR during moderate-severity heatwave was 1.21 (95% CI: 0.81–1.81) for work-related ambulance call-outs.

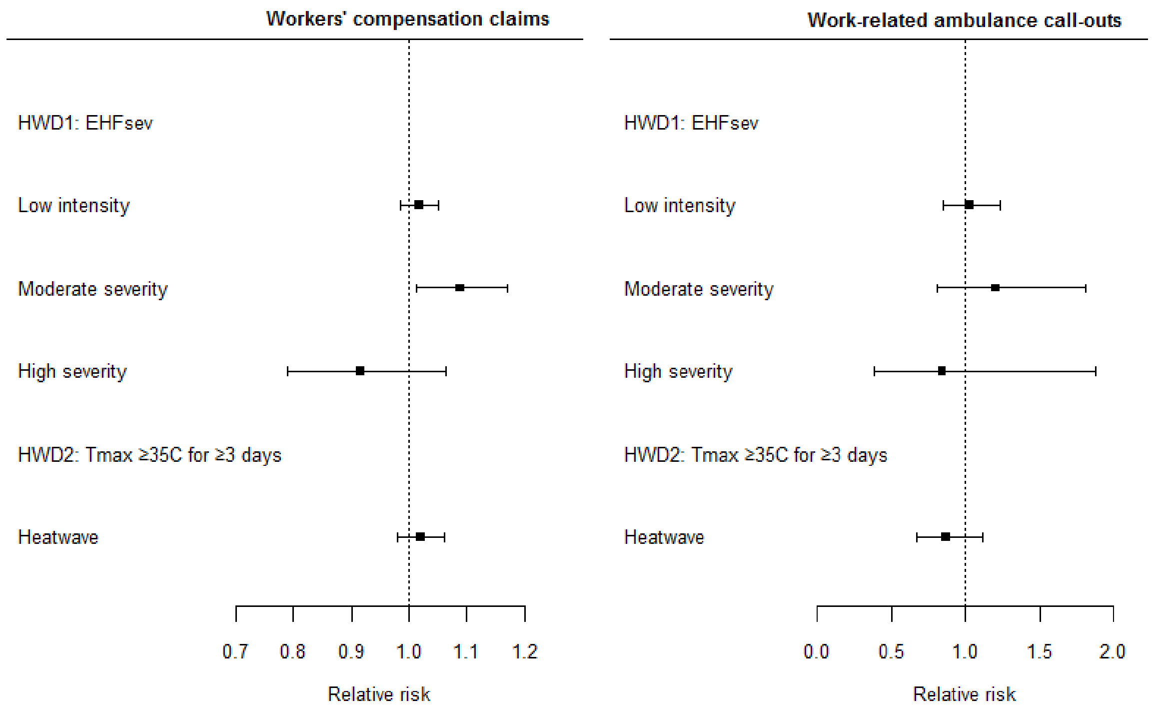

Figure 6.1 Association between heatwave severity and work-related injuries and illnesses, Adelaide metropolitan area, October to March 2003 to 2013. (A) workers' compensation claims; (B) work-related ambulance call-outs.

6.3.4.3 Effect estimates by workers' demographics, work and work environment characteristics

Tables 6.1 and 6.2 show the effect estimates for WC claims by workers' demographics and work environment characteristics. Male workers had a statistically significant increase of 13% (95% CI: 3–23%) in overall claims during moderate-severity heatwaves, while no significant change was observed for female workers. No particular age group showed any significant increase in claims during heatwave periods (Table 6.1).

Regarding work experience, new workers (those with less than 1 year of experience at the time of the claim) showed a statistically significant increase in claims during moderate-severity heatwaves of 31% (95% CI: 10–55%). By contrast, there was no statistically significant increase in claims for experienced workers. Considering the industries, ‘indoor industries’ showed a statistically significant increase in claims overall during moderate-severity heatwaves (RR 1.09, 95% CI: 1.10–1.17), while ‘outdoor industries’ showed elevated risks, but not statistically significant risks (RR 1.05, 95% CI: 0.83–1.34). In particular, an increase of 8% (95% CI: 1–16%) was observed for claims among workers in the ‘manufacturing industry’ during low-intensity heatwaves (Table 6.1).

Positive associations were also observed during moderate-severity heatwaves for workers in medium-sized enterprises i.e. businesses with 20–199 employees (RR 1.15, 95% CI: 1.01–1.30), labourers (RR 1.21, 95% CI: 1.04–1.39), workers exposed to electrical hazards (RR 1.43, 95% CI: 1.15–1.79) and those working in dangerous locations (RR 3.17, 95% CI: 1.38–7.26). Injuries occurring between 12 and 2pm increased during moderate-severity heatwaves (RR 1.39, 95% CI: 1.13–1.70) and this was also evident using the HWD2 definition (RR 1.11, 95% CI: 1.02–1.21). Also, there was a two-fold increase in injuries occurring between 6 and 8pm during high-severity heatwaves (Table 6.2). Notably, there was an increase in claims observed among workers from worksites located in the outer suburbs, while those in the CBD had no increased risk.

Table 6.1 Effect estimates (Risk ratios) for the associations between workers' compensation claims and heatwave severity in Adelaide, October to March 2003 to 2013.

Exposure	**Risk ratio (95% CI)**			
	HWD1			**HWD2**
Claim characteristics	**Low intensity**	**Moderate severity**	**High severity**	
All claims	1.01 (0.98,1.04)	1.08 (1.01,1.16)	0.91 (0.78,1.06)	1.02 (0.98,1.06)
Injury claims	1.02 (0.96,1.03)	1.10 (1.02,1.19)	0.92 (0.78,1.07)	1.02 (0.98,1.07)
Illness claims	1.13 (1.03,1.25)	0.90 (0.70,1.15)	0.97 (0.58,1.63)	0.94 (0.82,1.07)
Gender				
Female	0.98 (0.92,1.03)	0.99 (0.87,1.13)	0.76 (0.58,1.02)	1.01 (0.94,1.08)
Male	1.03 (0.99,1.07)	1.13 (1.03,1.23)	0.99 (0.82,1.18)	1.02 (0.97,1.07)
Age group				
15–24	1.00 (0.92,1.08)	1.15 (0.97,1.36)	0.89 (0.63,1.25)	1.08 (0.98,1.18)
25–34	0.99 (0.92,1.06)	1.11 (0.95,1.30)	1.14 (0.84,1.54)	1.00 (0.91,1.09)
35–54	1.01 (0.96,1.06)	1.08 (0.97,1.20)	0.88 (0.70,1.09)	1.01 (0.95,1.06)
>55 years	1.07 (0.98,1.16)	0.97 (0.78,1.18)	0.87 (0.57,1.31)	1.02 (0.91,1.13)
Worker experience				
Experienced worker	1.02 (0.98,1.05)	1.04 (0.96,1.13)	0.87 (0.74,1.03)	1.01 (0.97,1.06)
New worker	0.99 (0.91,1.07)	1.31 (1.10,1.55)	1.13 (0.79,1.61)	1.03 (0.94,1.14)
Industry location				
Outdoor	1.04 (0.94,1.16)	1.05 (0.83,1.34)	1.38 (0.78,2.31)	1.11 (0.98,1.27)
Agriculture, Forestry, Fishing & Hunting	0.95 (0.66,1.37)	1.29 (0.57,2.88)	0.11 (0.01,1.05)	0.98 (0.62,1.54)
Construction	1.06 (0.94,1.19)	1 (0.76,1.31)	1.46 (0.79,2.71)	1.06 (0.92,1.23)
Electricity, Gas & Water	0.88 (0.6,1.29)	1.48 (0.65,3.35)	2.53 (0.43,14.89)	1.46 (0.92,2.30)
Mining	1.21 (0.81,1.82)	1.13 (0.47,2.69)		1.77 (1.03,3.02)
Indoor	1.01 (0.98,1.04)	1.09 (1.01,1.17)	0.88 (0.76,1.03)	1.01 (0.97,1.05)
Communication	0.61 (0.16,2.37)	1.50 (0.14,16.23)		0.34 (0.06,1.91)
Community Services	0.97 (0.92,1.03)	1.13 (0.99,1.29)	0.84 (0.63,1.13)	1.05 (0.98,1.13)
Finance, Property & Business Services	1.08 (0.93,1.25)	1.24 (0.91,1.69)	0.66 (0.36,1.19)	1.04 (0.87,1.25)
Manufacturing	1.08 (1.01,1.16)	1.08 (0.93,1.26)	1.01 (0.76,1.33)	1.01 (0.93,1.10)
Public Administration & Defence	1.10 (0.91,1.34)	1.21 (0.77,1.90)	1.06 (0.46,2.46)	0.93 (0.73,1.19)
Recreation, Personal & Other Services	0.93 (0.82,1.07)	1.17 (0.89,1.55)	0.84 (0.42,1.69)	0.85 (0.72,1.01)
Transport & Storage	1.05 (0.92,1.19)	0.88 (0.64,1.21)	0.82 (0.42,1.62)	0.95 (0.80,1.12)
Wholesale & Retail Trade	0.99 (0.92,1.07)	1.02 (0.86,1.20)	0.88 (0.63,1.23)	1.06 (0.96,1.17)
Occupations				
Managers	0.95 (0.79,1.14)	0.99 (0.67,1.47)	0.79 (0.31,2.04)	0.83 (0.65,1.06)
Professionals	0.91 (0.82,1.02)	1.10 (0.85,1.43)	0.64 (0.35,1.17)	1.08 (0.95,1.24)
Technicians & trade workers	1.04 (0.97,1.11)	1.06 (0.91,1.23)	0.90 (0.66,1.23)	1.03 (0.94,1.12)
Community & personal	0.97 (0.89,1.05)	1.13 (0.93,1.37)	0.94 (0.62,1.41)	0.92 (0.83,1.03)
Clerical & administrative	1.06 (0.92,1.22)	0.86 (0.62,1.20)	0.80 (0.40,1.61)	0.96 (0.80,1.15)
Sales workers	0.84 (0.74,0.96)	0.99 (0.75,1.31)	1.38 (0.83,2.30)	1.04 (0.88,1.21)
Machinery operators & drivers	1.07 (0.99,1.15)	1.02 (0.86,1.22)	0.91 (0.65,1.29)	1.08 (0.98,1.19)
Labourers	1.08 (1.02,1.16)	1.21 (1.05,1.40)	0.89 (0.66,1.20)	1.06 (0.97,1.15)

Notes: Shaded cells denote statistically significant differences based on the 95% CI; HWD1 based on EHF intensity and HWD2 based on Tmax of 35 °C for ≥3 consecutive days.

Table 6.2 Risk ratios of workers' compensation by work environment characteristics by heatwave severity in Adelaide metropolitan area, October to March 2003 to 2013.

Exposure	**Risk ratio (95% CI)**			
	HWD1			**HWD2**
Work environment	**Low intensity**	**Moderate severity**	**High severity**	
Size of business				
Small (<20 employees)	1.01 (0.93,1.10)	1.12 (0.93,1.35)	0.90 (0.63,1.29)	0.98 (0.88,1.10)
Medium (20–200 employees)	1.05 (0.99,1.11)	1.15 (1.01,1.30)	0.72 (0.56,0.94)	1.04 (0.97,1.12)
Large (>200 employees)	0.99 (0.95,1.03)	1.03 (0.93,1.14)	1.06 (0.86,1.31)	1.01 (0.96,1.07)
Worksite location				
Adelaide CBD	0.99 (0.91,1.06)	1.14 (0.96,1.35)	1.27 (0.87,1.85)	0.98 (0.89,1.08)
Adelaide Inner suburb	1.01 (0.97,1.05)	1.08 (0.98,1.18)	0.74 (0.61,0.89)	0.99 (0.94,1.05)
Adelaide Outer suburbs	1.05 (0.98,1.13)	1.05 (0.89,1.23)	1.36 (1.01,1.83)	1.11 (1.02,1.21)
Workplace hazards				
Dangerous chemical substances	1.10 (0.96,1.26)	1.09 (0.81,1.46)	0.97 (0.50,1.89)	1.10 (0.92,1.31)
Equipment, machinery, tools	0.90 (0.72,1.12)	1.18 (0.71,1.94)	1.80 (0.74,4.42)	0.90 (0.69,1.17)
Electricity	0.98 (0.88,1.08)	1.43 (1.15,1.79)	0.75 (0.47,1.20)	1.05 (0.92,1.20)
Dangerous locations	0.68 (0.44,1.06)	3.17 (1.39,7.26)	5.31 (0.70,40.13)	1.13 (0.68,1.87)
Multiple hazards	1.05 (0.99,1.11)	1.07 (0.94,1.23)	0.88 (0.68,1.15)	1.04 (0.97,1.12)
Time of injury				
00.00–01.59	1.07 (1.01,1.15)	0.93 (0.79,1.09)	0.77 (0.56,1.06)	0.85 (0.77,0.93)
02.00–03.59	1.15 (0.85,1.55)	0.83 (0.36,1.91)	0.79 (0.16,3.94)	1.02 (0.71,1.47)
04.00–05.59	1.06 (0.77,1.45)	0.67 (0.29,1.53)	1.06 (0.30,3.79)	0.85 (0.58,1.27)
06.00–07.59	0.97 (0.85,1.12)	1.30 (0.98,1.74)	1.14 (0.60,2.16)	1.26 (1.06,1.49)
08.00–09.59	0.98 (0.90,1.06)	1.12 (0.94,1.34)	1.04 (0.72,1.48)	1.07 (0.97,1.18)
10.00–11.59	0.99 (0.92,1.07)	1.04 (0.88,1.24)	1.19 (0.83,1.69)	1.03 (0.94,1.14)
12.00–13.59	0.99 (0.90,1.08)	1.39 (1.14,1.70)	0.58 (0.36,0.92)	1.16 (1.03,1.31)
14.00–15.59	1.06 (0.97,1.16)	1.14 (0.93,1.40)	0.86 (0.55,1.33)	1.02 (0.91,1.14)
16.00–17.59	0.94 (0.83,1.07)	0.97 (0.72,1.29)	0.78 (0.45,1.34)	1 (0.85,1.18)
18.00–19.59	1.08 (0.90,1.29)	1.03 (0.68,1.55)	2.13 (1.02,4.53)	1.20 (0.96,1.51)
20.00–21.59	1.15 (0.94,1.40)	0.99 (0.63,1.57)	1.16 (0.41,3.28)	1.02 (0.79,1.32)
22.00–23.59	1.04 (0.81,1.35)	1.28 (0.73,2.23)	0.71 (0.18,2.72)	1.19 (0.86,1.64)

Notes: Shaded cells denote statistically significant differences based on the 95% CI. HWD1 based on EHF intensity and HWD2 based on T_{max} of 35 °C for ≥3 consecutive days.

6.3.4.4 Cross-validation

Using cross-validation methods, the two metrics used to define heatwaves (EHF and T_{max}) were found to be similar predictors of heat-related outcomes (Figure 6.2).

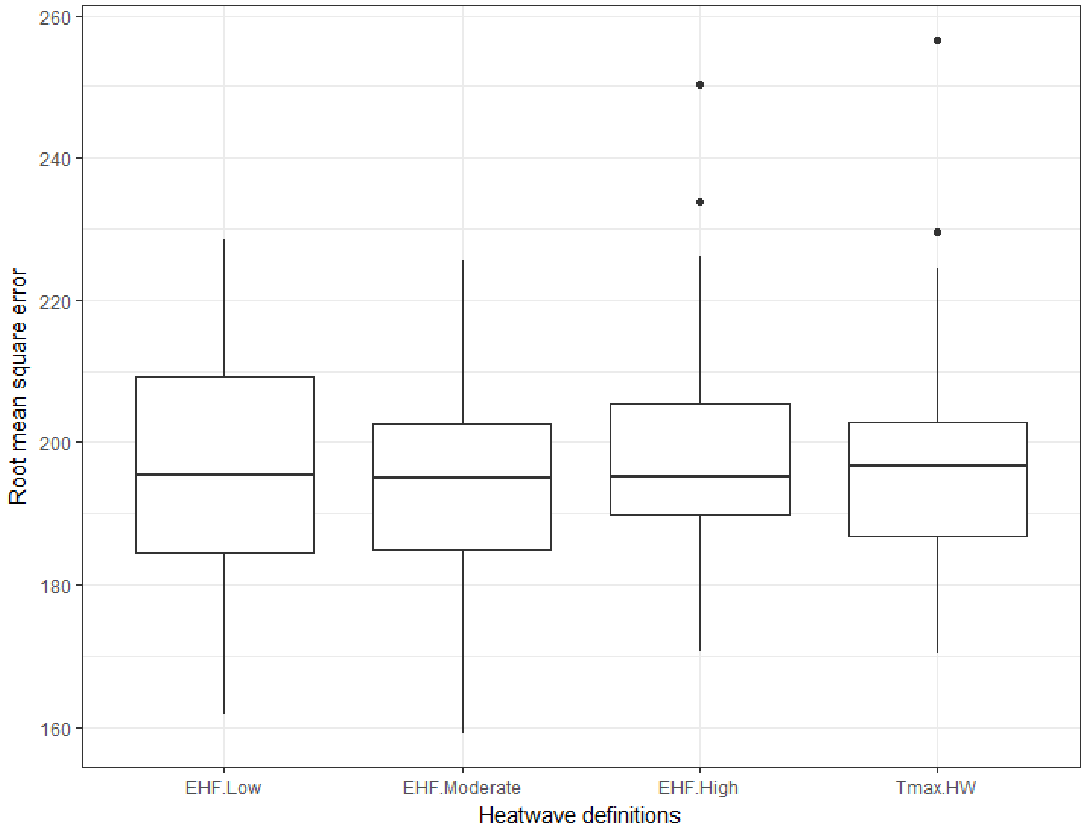

Figure 6.2 Boxplot of root mean square errors comparing the two heatwave metrics.

Note: EHF.Low, EHF.Moderate and EHF.High constitutes HWD1 using EHFsev and T_{max}.HW is HWD2.

6.3.5 Discussion

In this study of the effects of heatwaves on WRIs and illnesses in a temperate Australian city, concordant estimates were obtained using two population-based data sources. To the best of our knowledge, this study is the first of its kind to investigate and provide both supporting and new evidence on how heatwaves of varying severity, as defined using the Australian BOM's updated metric for heatwaves, the EHF may affect workers' health and safety.

This study has yielded several findings. Firstly, there was a consistent increase in WC claims and work-related ambulance call-outs during heatwaves of low-intensity and moderate-severity, and a non-significant decline during high-severity heatwaves. Secondly, moderate-severity heatwaves were significantly associated with an 8.8% increase in WC claims, with the highest effect seen in injury claims, while a nonsignificant 20% increase was observed for work-related ambulance call-outs. These findings differ from previous studies[145, 146] that found no significant increase in claims during heatwave periods. However, the risk estimates were lower and protective in these previous studies which may be explained by the use of a stringent heatwave definition (three or more consecutive days of daily T_{max} of 35 °C). Thirdly, vulnerable groups during moderate-severity heatwaves in this study included male workers, new workers, laborers, those in medium-sized business (20–199 employees), and in industries with substantial indoor work and exposure to electrical hazards. Further, increased risk of WRIs and illnesses was observed during the high-severity heatwaves among workers in worksites located outside the CBD, while workers in the manufacturing industry were at risk even during low-intensity heatwaves.

Elsewhere, previous studies[42, 45, 122, 127, 132, 135, 188] have shown strong but variable evidence for a relationship between high ambient temperatures and occupational injuries, whereby injuries increase in a dose-response manner and decrease above a certain temperature threshold. Indeed, our findings of increasing injury risk during low-intensity and moderate-severity heatwaves which decline during high-severity heatwaves resonate well with this observation. This contrasts with studies on morbidity in the general population using EHF[285, 287, 440, 442] where the greatest impacts were seen with increasing severity of the heatwaves. This could be explained by the operation of workplace protective measures such as work ceasing work or being postponed during extreme temperatures.[45, 146] Further, behavioral changes adopted by workers such as 'self-pacing' to reduce excessive heat strain, along with an increased awareness of heat impacts on health, may be associated with a reduced risk at the higher intensity heatwaves. Since 2009, heatwave warnings which have been implemented in Adelaide have appeared to reduce morbidity in the general population during severe heatwaves,[21] and may have also influenced work practices.

Vulnerable groups identified in this study by gender, occupation, and size of business are similar to those found previously in Adelaide.[145, 146] Lack of acclimatisation to heat and the physical exertion required for the job may make new workers more vulnerable to injuries than those who are experienced.[32, 146] This suggests that an acclimatisation plan should be in place at workplaces along with heat stress training where appropriate for both new and experienced workers. Although urban areas are considered to be at high risk of heat-related health outcomes attributed to the urban heat island effect, this was not evident in our findings. However, worksites located outside CBD identified as 'outer' suburbs had increased risk. This result is likely due to industries being located in the outer suburbs, as there was a more than three-fold increase in the risk of WRI or illness requiring ambulance attendance, in industrialised areas during heatwaves as reported in a study by Hanson et al.[269]

Workers in industries where work is carried out in indoor environments were also found to be vulnerable during moderate-severity heatwaves. However, other studies have shown evidence that outdoor workers in industries such as 'agriculture, forestry and fishing', 'construction', 'mining' and 'electricity, gas and water' are typically at risk. Hot weather adds to the heat burden experienced by indoor workers in environments where there is process generated heat (e.g. foundries, bakeries, smelters, steel mills, glass factories, and furnaces).[33] If the workplace is not adequately cooled or ventilated, the added heat load can potentially compromise workers' health and safety.[33] As efficient cooling methods such as air-conditioners or industrial fans may be impractical in such environments other personal cooling options and adaptive behaviors (e.g. rest breaks, job rotation, and altered work schedule) may need to be considered.

Although our data did not show any significant increase in the risk of health outcomes in outdoor industries, we note the elevation in risks for the electricity, gas and water and construction industries, which increased during moderate and high-severity heatwaves. This is consistent overall with a previous study undertaken in Adelaide.[145] Furthermore, our finding of a three-fold increase in the risk among those working in locations that are classified as being inherently dangerous (using the workers' environmental conditions classification—Human Resources & Skills Development Canada [(228)]), such as construction sites, underground sites and erected support structures, confirms the vulnerability of these industries. The lack of statistical significance at the industry level might reflect the smaller sample size rather than the absence of an effect, and therefore the risks of injuries should not be ruled out.

Our results have the potential to inform unions, industry, and regulators in planning appropriate mitigation strategies for heatwave-related occupational health effects. The current Extreme Heat Plan for South Australia is focused on protecting population health during extreme heat events, which occur less frequently than moderate-severity heatwaves.[445] However, our findings suggest workers are at risk before extreme levels are reached i.e. during the more frequent low and moderate-severity heatwaves. Hence, intervention strategies, policies and heat preparedness plans may need to consider lower thresholds for prevention measures in occupational settings.

Several limitations of this study need to be noted. Exposure misclassification was inherent in this study, as we assumed the entire study site to have the same EHF severity, and that the injury occurred at the workplace. Our results are also limited to one city, which may restrict its generalisability and it is possible that other cities with differing climates and working population characteristics may provide different results. However, the normalising effect of the EHF severity technique design makes severity levels equivalent between locations, despite their differing climates.

Although humidity is not directly included in the EHF calculations, it is indirectly captured by its interaction with daily T_{min}, which may extend its usefulness to humid environments (Adelaide typically has low humidity in summer).[182] Further studies in other geographic areas are thus warranted to validate the EHF metric and its utility in predicting occupational morbidities. This study was focused on the severity of heatwave events and therefore did not explore the effect of heatwave duration. Additionally, the use of administrative data, such as WC claims, is an underestimation of the overall burden and actual risk of injuries related to heatwaves experienced by workers in this region. It is possible that some occupational injuries not listed as a WC claim, may be included in ambulance data, which is known to better capture minor injuries and those occurring among young workers.[241] However, the ambulance data used in this study were broadly coded as 'work-related' and descriptive details of the incidents were not available.

Nevertheless, the concordant estimates obtained from both sources of data is one of the key strengths of this study. In summary, this study extends the work of Xiang et al.[145] by examining the effects of heatwave intensity (using EHF) on WRIs and illnesses, and by using a CCO approach. In addition, we were able to examine factors such as workers' demographics, type of work and work environment characteristics, which may influence the occurrence of WRIs and illnesses. This approach has enabled us to obtain a more detailed picture of how heatwaves can affect workers' health and safety.

6.3.6 Conclusions

The findings indicate that working in hot weather is not only problematic for those working outdoors but also for those working indoors. Male workers and those new to the job appear to be at risk during heatwaves. Heatwave forecasting services may prove useful in the occupational setting to plan for and mitigate the effects of heatwaves on the health and safety of those working in hot conditions. Our data suggest that moderate heatwaves should be considered, in addition to severe heatwaves.

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Compliance with Ethical Standards

Ethical Statement

Ethics approval was obtained from the Human Research Ethics Committees of the University of Adelaide and SA Health.

Conflict of Interest

The authors declare that they have no conflict of interest.

*****End of published paper*****

6.4 CHAPTER SYNOPSIS

Chapter 6 has detailed the findings from the first of two studies focussed on the impacts of heatwaves on WRI. The findings from Adelaide show that WRI increase during moderate-severity heatwaves (as defined by EHF) but not significantly for high-severity heatwaves. The next chapter extends the evidence from Adelaide to Brisbane, Melbourne, and Perth, with different climates.

07

Chapter 7: Characterising the Impact of Heatwaves on Work-Related Injuries and Illnesses in Three Australian Cities using a Standard Heatwave Definition-Excess Heat Factor

7.1 PREFACE

This chapter presents the results of a study that addresses the second and third objective by examining the effects of heatwaves on WRI. Building upon the validated study design and modelling approach in Chapter 6, this study extends the investigation from Adelaide to Brisbane, Melbourne, and Perth.

Similar to Chapter 5, WRI were identified from the NDS3 dataset and heatwaves were defined using EHF, allowing heatwave comparisons between cities with different climates. This study is also unique in that it is the first study in the literature to assess the impacts of heatwaves on WRI using EHF in Brisbane, Melbourne, and Perth.

The study presented in this chapter has been published in the Journal of Exposure Science and Environmental Epidemiology as:

Varghese BM, Barnett AG, Hansen AL et al. Characterising the Impact of Heatwaves on Work-Related Injuries and Illnesses in Three Australian Cities Using a Standard Heatwave Definition—Excess Heat Factor (EHF). J Expo Sci Environ Epidemiol. 2019; [Epub ahead of print]. doi:10.1038/s41370–019–0138–1.

7.2 STATEMENT OF AUTHORSHIP

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Principal Author

Name of Principal Author (Candidate)	Blesson Mathew Varghese		
Contribution to the Paper	B Varghese contributed to the study concept, method and analysis approach, gained ethics approval, extracted the data and performed data analyses, interpreted the data, prepared and submitted the manuscript and made corrections based on reviewer's comments and resubmitted the manuscript for publication.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	12/8/19

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Adrian Barnett		
Contribution to the Paper	A Barnett assisted in the design of the study, data analysis, interpretation of data and results, reviewed and provided feedback on the manuscript		
Signature		Date	12/8/19

Name of Co-Author	Alana Hansen		
Contribution to the Paper	A Hansen contributed to the study concept, assisted in the design of the study, interpretation of data and results, reviewed and provided feedback on the manuscript, evaluated the revised manuscript against reviewers' comments, and supervised the development of work.		
Signature		Date	13/8/19

Name of Co-Author	Peng Bi		
Contribution to the Paper	P Bi contributed to the study concept, assisted in the design of the study, interpretation of data and results, reviewed and provided feedback on the manuscript, evaluated the revised manuscript against reviewers' comments, and supervised the development of work.		
Signature		Date	13/8/19

Name of Co-Author	John Nairn		
Contribution to the Paper	J Nairn provided the gridded EHF data for the three cities, assisted in the interpretation of data and results, reviewed and provided feedback on the manuscript.		
Signature		Date	13/8/19

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7.3 PUBLICATION

7.3.1 Abstract

Background and aims: Heatwaves have potential health and safety implications for many workers, and heatwaves are predicted to increase in frequency and intensity with climate change. There is currently a lack of comparative evidence for the effects of heatwaves on workers' health and safety in different climates (sub-tropical and temperate). This study examined the relationship between heatwave severity (as defined by the Excess Heat Factor (EHF)) and workers' compensation (WC) claims, to define impacts and identify workers at higher risk.

Methods: WC claims data from Australian cities with temperate (Melbourne and Perth) and subtropical (Brisbane) climates for the years 2006–2016 were analysed in relation to heatwave severity categories (low and moderate/high severity) using time-stratified case-crossover models.

Results: Consistent impacts of heatwaves were observed in each city with either a protective or null effect during heatwaves of low-intensity while claims increased during moderate/high-severity heatwaves compared with non-heatwave days. The highest effect during moderate/high-severity heatwaves was in Brisbane (RR 1.45, 95% CI: 1.42–1.48). Vulnerable worker subgroups identified across the three cities included: males, workers aged under 34 years, apprentice /trainee workers, labour hire workers, those employed in medium and heavy strength occupations, and workers from outdoor and indoor industrial sectors.

Conclusion: These findings show that work-related injuries and illnesses increase during moderate/high-severity heatwaves in both sub-tropical and temperate

climates. Heatwave forecasts should signal the need for heightened heat awareness and preventive measures to minimise the risks to workers.

Keywords: Heatwave, Morbidity, Workers health and safety

7.3.2 Introduction

Extreme heat events (heatwaves) represent the most common cause of weather-related deaths in Australia and the US.[32, 103, 110] Individuals are usually acclimatised to their local weather, in physiological, cultural and behavioural terms, within a certain thermal coping range.[8] However, continuing extreme heat with long duration and severity can overstretch limits of tolerance, leading to adverse health outcomes and even death. Effects are typically manifested on the same day, or within a few days, of exposure.[8]

Many studies have examined population health effects of heatwaves in terms of increased morbidity and mortality.[434, 446] Studies have also indicated that workers engaged in strenuous physical activities in hot conditions may be at particular risk of both illness and injury.[145] Cumulative heat exposure can contribute to fatigue, loss of concentration, decline in vigilance, reduced psychomotor performance and reduced use of personal protective equipment (PPE), all of which can increase the risk of work-related injuries (WRIs) and illnesses as outlined in a recent review.[50] These effects can be compounded if there is a lack of relief due to high overnight temperatures. To our knowledge, the impact of heatwaves on work-place injuries has been examined in only five studies to date, with mixed results. Studies in Italy,[184] Adelaide, Australia[421] and Melbourne, Australia[188] have shown an increased risk, while two other studies in Adelaide[145, 146] found no statistically significant increased risk of occupational injuries during heatwaves.

The wider literature on the effects of heatwaves on population health documents several challenges in comparing the effects of heatwaves across different regions.[16, 434, 446] For one, despite the general agreement on heatwaves being periods of prolonged and unusually hot weather, there is no universal definition of a heatwave,[443] as there is no consensus on what defines ‘prolonged’ or excessively hot in different areas and climates.[182] The use of an absolute temperature threshold for every location would be unwise due to factors that may have different impacts in different communities or locations. These include population acclimatisation, adaptation, underlying demographics, meteorological characteristics such as temperature distribution and humidity levels, and extent of urbanisation.[12] For example, temperatures which are considered to be unusually high in tropical or subtropical locations may occur more commonly during hot summers in temperate locations. A variety of heatwave metrics have been used in the literature ranging from temperature only metrics (mean, maximum or minimum temperature), to thermal composite indices that incorporate effects of temperature and humidity (Apparent Temperature or Humidex or Heat Index).[434] Besides this variation, the intensity of heatwaves measured by temperature thresholds (range: 90–99th percentile), and duration of heatwaves in length (2–4 days) also varies according to definition.[435-437]

The lack of a universal heatwave definition can be a challenge for emergency services and government agencies who want to use an indicator that is easily operated and understood by the community they serve. In an attempt to address the lack of a national heatwave definition, the Australian Bureau of Meteorology (BOM) developed a metric called the Excess Heat Factor (EHF) that can be applied consistently across different locations and provide an indication of heatwave severity and intensity.[182] According to this metric, heatwave conditions occur at a location when there is a significant temperature anomaly (both short-term and long-term) specific for that particular location. The EHF index has been used in several studies in Australia[285, 287, 440-442] and elsewhere.[447, 448]These studies suggest that EHF is a useful indicator of heat-health impacts, and therefore a potential heat warning indicator of heat-related occupational injuries and illnesses.[421]

Although several multi-city studies have investigated the relationship between heatwaves and health outcomes (mortality/morbidity) in Australia,[449-452] no research to our knowledge has been conducted to compare the occupational health impacts of heatwaves across different cities. The aims of this study are: (i) to examine the association between workers' compensation (WC) claims data and heatwave exposure (as defined by EHF), for cities with sub-tropical and temperate climates; and (ii) identify vulnerable workers by demographics, type of work (physical demands), occupation and industry of employment and working environment (indoor versus outdoor). With the increasing frequency, duration and intensity of heatwaves across Australia,[417] it is vital to understand the impacts on workers, so that industries can better prepare for the challenges of a warmer climate on occupational health and safety (OHS).

7.3.3 Methods

7.3.3.1 Study area

This study was conducted in three major Australian cities with different climatic characteristics (Brisbane, Melbourne and Perth). Brisbane, the state capital of Queensland, is located on the central eastern coast and has a sub-tropical climate with dry, mild winters and hot, humid summers.[424] Melbourne is located on the southern coast, in the state of Victoria, and has a temperate oceanic climate (i.e. warm summers and cool wet winters) and is also known for its changeable weather conditions. Perth, the capital of Western Australia, is located on the south-west coast of Australia and has a Mediterranean climate with hot, dry summers and cool wet winters.[286] These three cities combined have a population of 8.5 million (or 34% of the Australian population) and a total workforce of about 3.7 million, which is 38% of the total employed workforce in Australia. We restricted our analyses to metropolitan areas in these cities, where the majority of people live and work.[255]

7.3.3.2 Data collection

Workers' compensation (WC) data

In Australia, workers experiencing a WRI or illness are entitled to be supported financially for their medical and health care expenses while they are unable to perform their normal duties. This support is provided by compulsory WC insurance schemes regulated by the relevant jurisdictions. The details of workers making a claim are captured within a jurisdictional database of WRIs and illness for that jurisdiction. The National Dataset for Compensation Based Statistics (NDS3) is compiled by Safe Work Australia, the national regulatory agency, from case-level claims data supplied by each jurisdiction.[72] This dataset contains claims made by the majority of Australian workers, but excludes specific subgroups such as: self-employed and self-insured workers, Commonwealth government employees, military personnel within the Australian Defence Force and police officers in Western Australia.[72, 312]

All accepted WC claims (as determined by the insurer) that occurred in the three Australian states (Queensland, Victoria and Western Australia) between 1 January

2006 and 30 March 2016 were extracted from the NDS3. We included all claims regardless of their severity either as ‘minor’ (<1 week work time lost) or ‘major’ (≥1 week work time lost) claims. Although there are similarities in the way claims are made and recorded across these jurisdictions, there exists some structural and functional differences in policy and practice.[292, 313] For example, claims made while ‘commuting to and from work’ are compensable with restrictions in Queensland, but are not compensable in Victoria and Western Australia.[292] Hence, to establish three comparable jurisdictional-level cohorts, we excluded such claims.

In the NDS3 dataset, each accepted claim includes information on the injured workers age and gender (demographics), industry and occupation (employment), and details of their injury (date, nature, mechanism, body location and agency of injury). However, there is no information on potential workplace heat exposure based on the location of work (outdoor or indoor), the availability of air-conditioning or acclimatisation status or physical demands of the occupation. As outdoor workers were identified to be at higher risk of weather-related heat exposure previously,[145] these workers were identified using two classifications, one at the industrial level and other at the occupational level. Industries were broadly classified as outdoor or indoors based on groupings used by Xiang et al.[145] In an attempt to broadly define occupations and heat exposure levels (e.g. indoor or outdoor), we followed the approach taken by a study in Melbourne[132] whereby a ‘cross-walk’ was performed between the Australian and New Zealand Standard Classification of Occupations (ANZSCO) system[294] and the Canadian National Occupational Classification (NOC) system.[228] This method has been validated previously.[132] The potential classifications of workplace temperature exposures at the occupational level obtained from this cross-walk included ‘regulated indoors’; ‘unregulated indoors and outside'; 'in a vehicle or cab' and 'multiple locations'. Also obtained from this cross-walk were the occupational physical job demands (strength) classified as 'limited'; 'light'; 'medium' and 'heavy'.

Meteorological data

Daily weather data obtained from the Australian BOM included: maximum (T_{max}), minimum (T_{min}), and mean (T_{mean}) temperature data for each city. These data were obtained using the BOM's operational low resolution (0.25°×0.25°) daily temperature analyses. Data were obtained for the following monitoring stations: Brisbane (BOM site number: 040913); Melbourne (BOM site number: 086071) and Perth (BOM site number: 009225). These stations were considered as representative weather stations for these metropolitan areas and have been used in previous studies.[276, 278, 283, 285, 286]

7.3.3.3 Heatwave definition

The EHF is an intensity measure that categorises heatwaves by their severity.[182] The calculation of the EHF is based on a three-day averaged daily T_{mean}, in relation to the 95th percentile of long-term average temperatures, and the recent (prior 30-day) temperatures, for a particular location. This estimate accounts for both historical averages and short-term acclimatisation. EHF intensity is normalised to generate an index of heatwave severity that can be used for comparison between different locations.[182] The details on the calculation of this metric are provided in Appendix B5.[182] We obtained daily gridded EHF and EHF severity data for the BOM monitoring sites mentioned above. We then categorised heatwaves using the following EHF severity levels (EHF_{sev}):

- No heatwave: daily EHF_{sev} ≤0;
- Low-intensity: daily EHF_{sev} >0 and <1;
- Moderate-severity: daily EHF_{sev} ≥1 and <2, and
- High-severity: daily EHF_{sev} ≥2.

However, as there were very few days of EHF_{sev} ≥2 during the study period, we combined the moderate and high-severity HW days (i.e. daily EHF_{sev} ≥1).

7.3.3.4 Study design and statistical analysis

The risk of WRI and illness during heatwave days, defined by EHF_{sev}, compared with non-heatwave days, was assessed using a time-stratified case-crossover (CCO) study design. This approach, whereby each case serves as their own control, was chosen to account for the lack of site-specific denominator data (i.e. the number of workers), as well as its strength in controlling for known and unknown time-invariant individual confounders.[356, 357] In contrast to other studies using a monthly or 28-day strata,[132, 135, 188] we used a shorter seven-day strata to adjust for known weekly changes in worker numbers that arise over a short-period of time due to, for instance, labour strikes, power outages, co-worker absence or changes in work practices.[132, 188] The analyses were restricted to the warm months of each year (November–March) to control for the effects of seasonality.[450] A generalised linear model with a Poisson distribution was used to estimate the relative risk (RRs). Public holidays were adjusted for with three separate binary indicator variables (Christmas Day, New Years' Day and other holidays). Days of the week were adjusted for by including a categorical 'day of the week' variable using Friday as the reference day. RRs with 95% confidence intervals (CIs) are reported for heatwave days of low-intensity, and moderate/high-severity, compared with non-heatwave days during the same warm season. The lagged effects (days 1 and 2) for EHF_{sev} on total WC claims were also explored. As a marked lag effect was not found, these results are not presented.

Ethical clearances were obtained from the ethics committees of The University of Adelaide, the Queensland University of Technology, The University of Western Australia and Monash University.

7.3.4 Results

7.3.4.1 Exposure

The number of heatwave days at each severity level as well as the corresponding three-day average daily T_{max} for each city are in Table 7.1. Melbourne had the highest number of moderate/high-severity heatwave days, while low-intensity heatwave days were highest in Brisbane. The three-day average daily T_{max} during moderate/high-severity heatwave days were highest in Perth (39.9 °C) and Melbourne (37.8 °C).

Table 7.1 Number of heatwave days (n) and corresponding average daily maximum temperatures (ADT_{max}, in °C, for 3 day average) by city, for warmer months (November to March, 2006–2016).

		Heatwave severity*					
		No heatwave		**Low**		**Moderate/High**	
City	**Total**	**n (%)**	**ADT_{max}**	**n (%)**	**ADT_{max}**	**n (%)**	**ADT_{max}**
Perth	1602	1416 (88.4%)	29.3	161 (10.0%)	36.5	25 (1.5%)	39.9
Brisbane	1602	1406 (87.8%)	28.8	173 (10.8%)	32.1	23 (1.4%)	33.9
Melbourne	1602	1419 (88.6%)	24.8	157 (9.8%)	32.8	26 (1.6%)	37.8

Notes: * severity defined on the basis of normalised EHF intensity: No heatwave: EHF_{sev} <0; Low: 0 >EHF_{sev} <1; Moderate/High: EHF_{sev} ≥1.

7.3.4.2 Outcomes

Overall, 746,655 WC claims were reported in the three cities during the study period (1 January 2006–30 March 2016). There were 243,963 (33%) claims in Brisbane, 241,376 (32%) in Melbourne and 261,316 (35%) in Perth. Of these, 11,693 (4.8%), 10,946 (4.5%) and 12,207 (4.6%) occurred during 197, 183 and 186 heatwave days, respectively, as defined by EHF_{sev} (i.e. EHF_{sev} >0). Across the three cities, the majority of claims were among males (66%) and those aged 34–54 years (47%). industries such as ‘manufacturing’, ‘healthcare and social assistance’, ‘construction’ and ‘retail trade’ accounted for about half (51%) of all claims.

7.3.4.3 Heatwaves and workers’ compensation (WC) claims

Overall effect

There was a consistent trend of increasing WC claims with heatwave severity across the three cities. In Brisbane and Melbourne, a small reduction in risk (RR 0.97, 95% CI: 0.94–0.99) was observed during low-intensity heatwaves, while in Perth a null effect (RR 1.01, 95% CI: 0.97–1.02) was observed. However, significant increases in WC claims during moderate/high-severity heatwave days were seen for all three cities with the highest effect estimate in Brisbane (RR 1.45; 95% CI: 1.42–1.48), followed by Perth (RR 1.26, 95% CI: 1.24–1.29), and Melbourne (RR 1.25, 95% CI: 1.22–1.28).

Higher associations were seen for ‘minor claims’ (≤1 week of time-lost) compared with ‘major claims’ during moderate/high-severity heatwaves (Table 7.2).

Effect by workers' demographics, work and work environment characteristics

The results of stratified analyses of claims are shown in Table 7.2. Across the three cities, there were increases in claims during moderate/high-severity heatwaves for almost all worker characteristics, i.e. age, gender and work experience, and consistent with the overall trend, the highest effect was in Brisbane. Also, in all three cities claims were more pronounced during moderate/high-severity heatwaves among male workers, young workers (aged 15–24 and 25–34 years), apprentice/trainees, and workers in labour hire arrangements.

Analysis of work characteristics revealed that moderate/high severity heatwaves affected workers regardless of their work physical demands, with a stronger effect for 'heavy-strength' occupations in Brisbane (RR 1.56, 95% CI: 1.50–1.63) and Melbourne (RR 1.32, 95% CI: 1.26–1.39) and 'medium-strength' occupations in Perth (RR 1.32, 95% CI: 1.28–1.36).

Stratified analyses by work environment characteristics showed significant increase in claims during moderate/high-severity heatwaves whether work was carried out 'mostly outside' or 'inside' based on industry classification (results not shown). Similar effects were also observed when workers were classified based on occupational classifications of workplace temperature exposures as working in 'regulated indoors' or 'unregulated indoors and outside' or 'in a vehicle or cab' (Table 7.2).

Table 7.2 Relative risks of workers' compensation claims by heatwave severity (low and moderate/high) in Brisbane, Melbourne and Perth metropolitan areas during warmer months (November to March, 2006–2016).

Exposure (EHFseverity)*	Perth					Brisbane					Melbourne				
	Non-H/W	Low intensity		Moderate/ High severity		Non-H/W	Low intensity		Moderate/ High severity		Non-H/W	Low intensity		Moderate/ High severity	
	(n)	(n)	RR (95% CI)	(n)	RR (95% CI)	(n)	(n)	RR (95% CI)	(n)	RR (95% CI)	(n)	(n)	RR (95% CI)	(n)	RR (95% CI)
Total	99781	10840	1.01 (0.97–1.02)	1367	1.26 (1.24–1.29)	91199	10381	0.97 (0.94–0.99)	1312	1.45 (1.42–1.48)	88638	9478	0.97 (0.94–0.99)	1468	1.25 (1.22–1.28)
Claim severity															
Minor claims	66064	7053	1.00 (0.97–1.03)	877	1.28 (1.24–1.31)	33574	3729	0.97 (0.92–1.02)	464	1.98 (1.91–2.05)	22401	2407	0.96 (0.91–1.01)	404	1.47 (1.41–1.54)
Major claims	33717	3787	1.01 (0.96–1.05)	490	1.24 (1.20–1.28)	57625	6652	0.97 (0.94–1.01)	848	1.23 (1.20–1.26)	66237	7071	0.97 (0.94–0.99)	1064	1.19 (1.16–1.22)
Gender															
Male	69058	7541	1.00 (0.97–1.03)	940	1.29 (1.26–1.32)	57829	6711	0.98 (0.94–1.02)	844	1.50 (1.46–1.54)	56141	6042	0.96 (0.93–0.99)	949	1.29 (1.25–1.33)
Female	30723	3299	1.01 (0.96–1.05)	427	1.20 (1.16–1.24)	33370	3670	0.96 (0.91–1.01)	468	1.35 (1.30–1.40)	32224	3436	0.97 (0.93–1.01)	519	1.18 (1.15–1.23)
Age group (years)															
15–24	19963	2168	1.01 (0.95–1.06)	254	1.29 (1.23–1.35)	15298	1717	0.94 (0.88–1.01)	221	1.55 (1.47–1.63)	10596	1106	0.96 (0.89–1.04)	186	1.27 (1.19–1.35)
25–34	22217	2361	0.98 (0.93–1.03)	297	1.27 (1.22–1.33)	19312	2284	0.98 (0.92–1.04)	271	1.56 (1.49–1.63)	18113	1947	0.93 (0.88–0.99)	325	1.31 (1.24–1.37)
35–54	42914	4696	1.01 (0.97–1.05)	599	1.26 (1.22–1.30)	43251	4843	0.97 (0.93–1.01)	602	1.42 (1.37–1.46)	44336	4701	0.97 (0.93–1.01)	750	1.26 (1.22–1.30)
>55	14687	1615	1.01 (0.95–1.07)	217	1.21 (1.15–1.28)	13338	1537	0.99 (0.93–1.07)	218	1.30 (1.23–1.37)	15593	1724	1.01 (0.94–1.07)	207	1.18 (1.12–1.24)
Worker experience															
Apprentice/ Trainee	1944	208	1.02 (0.85–1.22)	24	1.35 (1.18–1.56)	2847	332	1.05 (0.88–1.24)	35	1.74 (1.54–1.97)	1634	184	1.01 (0.83–1.23)	20	1.41 (1.21–1.64)
Other	70641	8115	0.99 (0.96–1.02)	1006	1.26 (1.23–1.29)	88209	10030	0.97 (0.94–0.99)	1275	1.44 (1.41–1.47)	86836	9281	0.97 (0.94–0.99)	1446	1.25 (1.22–1.28)

Exposure (EHFseverity)*	Perth					Brisbane					Melbourne				
	Non-H/W	Low intensity		Moderate/ High severity		Non-H/W	Low intensity		Moderate/ High severity		Non-H/W	Low intensity		Moderate/ High severity	
	(n)	(n)	RR (95% CI)	(n)	RR (95% CI)	(n)	(n)	RR (95% CI)	(n)	RR (95% CI)	(n)	(n)	RR (95% CI)	(n)	RR (95% CI)
Labour hire status															
Labour hire worker	1977	209	0.96 (0.81–1.16)	35	1.56 (1.35–1.80)	4447	481	1.01 (0.88–1.16)	51	1.58 (1.43–1.74)	5163	539	0.91 (0.81–1.02)	88	1.52 (1.39–1.67)
Other	2805	294	0.94 (0.81–1.10)	52	1.37 (1.21–1.55)	86589	9878	0.97 (0.94–0.99)	1259	1.44 (1.41–1.47)	83287	8924	0.97 (0.94–0.99)	1379	1.24 (1.21–1.27)
Potential workplace temperature exposure															
Regulated indoors	67993	7350	0.99 (0.97–1.03)	936	1.24 (1.21–1.27)	59879	6860	0.97 (0.94–1.01)	872	1.45 (1.41–1.48)	61695	6595	0.96 (0.93–0.99)	1046	1.25 (1.22–1.28)
Unregulated indoors and outside	1062	125	1.03 (0.82–1.29)	25	1.35 (1.10–1.66)	1139	126	1.01 (0.79–1.29)	14	1.14 (0.93–1.40)	508	45	0.67 (0.46–0.98)	12	1.35 (0.99–1.84)
In a vehicle or cab	5617	608	1.01 (0.91–1.13)	84	1.32 (1.21–1.44)	5904	676	0.96 (0.86–1.07)	90	1.47 (1.35–1.59)	6277	640	0.93 (0.84–1.03)	110	1.21 (1.12–1.31)
Multiple locations	24843	2735	1.01 (0.96–1.06)	319	1.32 (1.26–1.37)	24088	2695	0.96 (0.91–1.02)	336	1.46 (1.40–1.52)	19609	2137	1.01 (0.95–1.06)	297	1.29 (1.23–1.35)
Physical demands															
Limited (≤5kg)	20470	2223	1.02 (0.96–1.08)	257	1.22 (1.16–1.27)	20312	2231	1.01 (0.95–1.07)	275	1.33 (1.28–1.40)	23736	2564	0.98 (0.93–1.04)	386	1.21 (1.17–1.27)
Light (5–10kg)	18565	1993	1.01 (0.95–1.06)	270	1.16 (1.10–1.22)	14881	1719	0.99 (0.93–1.07)	198	1.32 (1.25–1.39)	17501	1930	0.99 (0.94–1.06)	313	1.20 (1.14–1.26)
Medium (10–20kg)	38285	4142	0.98 (0.94–1.02)	543	1.32 (1.28–1.36)	33178	3814	0.96 (0.91–1.01)	491	1.50 (1.45–1.56)	29982	3203	0.97 (0.92–1.01)	490	1.28 (1.24–1.33)
Heavy (>20 kg)	22195	2460	1.02 (0.96–1.08)	294	1.29 (1.24–1.35)	22639	2593	0.95 (0.90–1.01)	348	1.56 (1.50–1.63)	16870	1720	0.91 (0.86–0.97)	276	1.32 (1.26–1.39)

Notes: Shaded cells denote statistically significant differences based on the 95% CI. *severity defined on the basis of normalised EHF intensity: no heatwave (non-H/W): EHF_{sev} <0 (reference category); low: 0 >EHF_{sev} <1; moderate/high: EHF_{sev} ≥1.

7.3.5 Discussion

The principal finding of this study is that the risk of WRIs and illnesses was found to significantly increase during moderate/high-severity heatwaves (EHF_{sev} ≥1) across all three cities, albeit with different effect sizes. Additionally, the worker subgroups impacted by moderate/high-severity heatwaves were fairly consistent across three cities. These findings suggest that even though workers in these cities with different climates may have adapted to their local weather conditions, they may nonetheless be vulnerable to the effects of heatwaves as defined by EHF. Overall our results are consistent with previous occupational health studies[45, 122, 127, 132, 135, 184, 188, 421] suggesting that working in hot conditions can be associated with occupational injuries. Our findings are also in agreement with previous multi-city population health studies[434, 449, 450] where consistent increases in mortality risks were observed in Brisbane, Melbourne and Sydney during heatwaves. However, in Melbourne and Brisbane a significant protective effect of low-intensity heatwaves on WRIs and illnesses was found, while in Perth a null effect was observed. As most of the heatwaves at each location are of low-intensity, people generally have adequate capacity to cope with this level of heat.[182] While we do not have any clear explanation for the protective effect observed, a similar effect of low-intensity heatwaves on mortality has been reported previously.[440]

In this study, the city-specific effect of moderate/high-severity heatwaves on WRIs and illnesses ranged from a 25% increase in Melbourne to 45% in Brisbane. These differences in the size of the effect estimates across the cities might be due to differences in climatic as well as non-climatic factors, such as the demographic characteristics of the workforce, the nature of work-related heat exposure, workplace adaptation measures and responses to extreme heat (e.g. heat policies).[16, 33, 453]

Our finding of the greater risk to workers during moderate/high-severity heatwaves in Brisbane is consistent with previous heat-health studies that have found greater population health impacts (both morbidity and mortality) with more intense and longer duration heatwaves.[277, 363, 453-455] Although the population of Brisbane might be acclimatised to extended periods of warmer temperatures during summer,[277, 453, 456, 457] the rarity of 'unusually' hot days (defined by EHF_{sev}) may explain why they are at risk.[277, 449, 453, 458] Furthermore, being a sub-tropical city, the effects of heat stress can be due to the combined effect of air temperature and humidity. For example, the average relative humidity ranged from 69% to 71% during heatwaves of moderate/high-severity over the warm season. As a result, workers can feel much hotter than the actual environmental temperature when relative humidity is high as it impairs the evaporation of sweat, thus accelerating the increase of body temperature.[3, 427] Impaired sweating is also likely to contribute to decreased grip, possibly leading to injury. Although EHF does not take humidity into account explicitly, its use as a heatwave forecasting service in tropical environments has been previously demonstrated by BOM.[459]

Notwithstanding the differences in exposure metric used, our findings for Melbourne are in general agreement with a previous study,[188] which reported that the risk of serious occupational injuries (up to 10 days of work lost) increased up to the 90th percentile of temperature (33.3 °C) and declined at extreme temperatures. Consistent with previous population health studies in Perth[285-287] that have found significant increases in morbidity and mortality during heatwaves, our study showed that workers are at risk of WRIs and illnesses during moderate/high-severity heatwaves in Perth.

Overall, these findings build upon our previous work in Adelaide[421] where we examined the effects of heatwaves (defined using EHF_{sev}) on WRIs and illnesses in Adelaide, a city with temperate climate in Australia, and found a significant increase in claims during moderate-severity heatwaves (RR 1.08, 95% CI: 1.01–1.17) and non-significant decline during high-severity heatwaves (RR 0.91, 95% CI: 0.78–1.06). The findings from the present study based on moderate/high-severity heatwaves in Melbourne, Brisbane and Perth are similar to those from Adelaide. The effect observed at high-severity heatwaves in Adelaide could be due to the reduced statistical power because of the rarity of such events.

Consistent increases in risks were observed for workers across the three cities regardless of gender, age group and experience. However, pronounced effects were seen amongst males, younger age groups (<35 years), apprentice/trainees and labour hire workers. Reasons for increased susceptibility in males and young workers have been previously discussed in the literature.[45, 127] Young workers, with less experience, are more likely to work in high-risk occupations and/or strenuous work and are less likely to slow down or self-pace. Other possible reasons may include: lack of awareness of workplace rights and responsibilities, workplace peer pressures and low compliance towards preventive measures.[45, 132] In the case of male workers, it is known that they are more likely to work in physically demanding and heat exposed occupations and are also more likely to be risk-takers.[45, 127] Apprentices/trainees may be at risk due to lack of experience, acclimatisation, training and competency. Workers in labour hire arrangements have been shown to be at greater injury risk than 'direct hire' workers due to the type of work assigned and lack of proper workplace health and safety practices. An inquiry into labour hire workers in Victoria has revealed that OHS standards are lower in the labour hire sector where these workers often work in dangerous working environments, without being provided with adequate PPE, supervision, inductions or job-specific training.[460] This highlights the need to especially consider the health and safety of these workers.

To categorise work as indoor or outdoor, we have used two classifications, one at the industrial sector level and the other at the occupational level. Notwithstanding the exposure misclassification inherent in grouping workers according to industrial sectors, we found that indoor as well as outdoor industries were at risk during heatwaves. This contrasts with the findings of Xiang et al.[145] who found only outdoor industries at risk during heatwaves in Adelaide. Outdoor heat may add to the exposure levels in indoor work environments where workers may already be exposed to heat-generating processes (e.g. food preparation/services and manufacturing).[127] A recent study of complaint calls made to the safety regulator in South Australia identified that most of the calls were from indoor workplaces (warehouses, factories and kitchens).[461] On the other hand, limited awareness of heat stress, reduced acclimatisation due to reliance on, or failure of, cooling systems in place may explain why workers in indoor industries with office environments and sedentary work such as 'administrative and support services' and 'professional, scientific and technical services' were at risk.[24, 410, 462] Similar findings have also been reported in Quebec.[127]

Consistent with McInnes et al.[132] using the occupational level classification of work as indoor or outdoor, we found that workers in 'regulated indoors' and 'working in a vehicle or cab' were at increased risk of WRIs and illnesses during moderate/high-severity heatwaves. Besides work location, another important effect modifier in the heat-health relationship is the nature of work undertaken which can be strenuous and repetitive in both outdoor and indoor industries.[33, 408] Indeed, our findings by physical workloads that show workers in medium (somewhat physically demanding) and heavy strength (very physically demanding) occupations are at risk, confirms this observation.

Our findings are of benefit and have implications for policymakers and industry leaders, by highlighting how the risks to workers' health and safety increase during exposure to prolonged and unusual heat across different locations in Australia. A recent review of policies and guidance documents in Australia has revealed that none of the jurisdictional regulators currently have any guidelines or regulations for specific outdoor temperature thresholds at which precautions need to be taken or when work should cease.[171] At the population level, higher thresholds are used for extreme heatwave warnings to avoid message fatigue. However, our findings have shown that occupational injuries and illnesses occur in moderate/high-severity heatwaves (EHF ≥1). This indicates that workplaces should be aware of the potential risks to workers' health and safety during hot as well as extreme conditions. In Australia 'heatwave assessment maps' and 'forecast maps' are provided by the BOM[291] that may be useful for workplaces undertaking risk assessment for predicted periods of hot weather when work may need to be modified or rescheduled.[291]

This study has a number of strengths. To the best of our knowledge, this is the first multi-city study in Australia to compare heatwave effects on WRIs and illnesses using a standard definition of heatwave severity based on local climatic conditions. We have included both major and minor claims. The results provide a more complete picture of how heatwaves affect workers' health and safety by exploring immediate and contributing factors (e.g. those relating to the worker, work undertaken and work environment) to the occurrence of injuries and illnesses.

There are several limitations. First, the study population consisted of workers who had an accepted compensation claim, while rejected or ineligible claims and injuries for which a claim was not lodged, were not included. Therefore, using WC data alone are likely to underestimate the true burden of injuries and illnesses.[293] Nevertheless, the NDS3 dataset provides useful national level data to investigate the epidemiology of occupational injuries. Second, workers' personal exposure to ambient heat was not known as we used data from a single weather monitoring station in each city. This introduces the likelihood of exposure misclassification which typically leads to an underestimation of the risk estimates. Further studies using personalised heat exposure measures are needed to establish precise exposure-response relationships. Furthermore, the EHF metric does not directly incorporate measures of humidity, which was expected to limit its utility in Brisbane. Nevertheless, Nairn and Fawcett[182] have argued that humidity is indirectly factored in the calculation of EHF due to its relationship with T_{min}, in that higher humidity leads to higher T_{min}. From our results, it appears that EHF is a useful metric for both temperate (Melbourne, Perth) and humid (Brisbane) locations. Lastly, cautious interpretation is needed for some results where subgroup sample size was small, and we cannot rule out the possibility of some erroneous inferences due to multiple comparisons.

7.3.6 Conclusions

In conclusion, our results show that WRIs and illnesses increase in both subtropical and temperate locations during moderate/high-severity heatwaves with the greatest effect in Brisbane. The impacts of exposure to prolonged periods of extreme heat are not limited to workers in very physically demanding occupations and outdoor industrial sectors, but also extend to less demanding occupations and indoor industrial sectors as well. In the context of a warming climate, these findings have important implications for workforce policies and practices, suggesting that prevention strategies along with workplace heatwave action plans are needed to prevent heat-related occupational injuries and illnesses.

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*****End of published paper*****

7.4 CHAPTER SYNOPSIS

Chapter 7 presented evidence of how heatwaves of varying severity can affect WRI risk in three Australian cities. The findings show that WRI increase during moderate/high-severity heatwaves (as defined by EHF) in both subtropical Brisbane and temperate Melbourne and Perth.

Summary of Section C

The evidence base presented in the Chapters 6[3] and 7 show that WRI increase during moderate/high-severity heatwaves in both subtropical and temperate climates with a higher effect in subtropical Brisbane. Amongst those most at risk were males, new workers, and labour hire workers. Both outdoor and some indoor work resulted in increased risks of WRI during heatwaves. The evidence shows workplaces need to be mindful of the increased injury risks for workers during heatwave periods.

[3] Note: combining the high-severity heatwave category to the moderate-severity category in Chapter 6 generates similar results to that of Chapter 7 (see Tables B8-B9, Appendix B4 for the updated results).

SECTION D: INJURY EXPERIENCES, MANAGEMENT AND PREVENTION

Overview of Section D

This section of the thesis focusses on better understanding the circumstances underpinning the occurrence of WRI in hot weather. This is in the context that limited understanding exists in the literature on how WRI arise in hot weather and how they can be better prevented. Two chapters are part of this section. Chapters 8 and 9 build upon the epidemiological evidence shown in Sections B and C and present findings from two national online cross-sectional surveys of key stakeholders such as HSPs and HSRs. Participants were questioned on their perceptions of heat and WRI, as well as the determinants, prevention, and management of injuries in hot working conditions.

08

Chapter 8: Determinants of Heat-Related Injuries in Australian Workplaces: Perceptions of Health and Safety Professionals

8.1 PREFACE

Chapters 4–7 presented the findings from epidemiological studies showing how daily ambient temperatures and heatwaves can impact WRI. These studies used WC data acknowledging that not all WRI are captured this way and that the data provide no contextual information as to why WRI occur in hot weather. This chapter aims to fill this gap by better understanding the circumstances underpinning WRI occurrence in workplaces using key stakeholders' perspectives at a national level.

The study presented in this chapter is the first of two studies that address the fourth objective. To the best of the authors' knowledge, this study is the first to have gauged the perceptions of HSPs on heat and WRI across Australia.

This paper is currently in the format of a manuscript submitted for publication.

8.2 STATEMENT OF AUTHORSHIP

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Publication Status	☐ Published ☐ Accepted for Publication ☑ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
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Principal Author

Name of Principal Author (Candidate)	Blesson Mathew Varghese		
Contribution to the Paper	B Varghese contributed to the study concept, method and analysis approach, gained ethics approval, collected the data and performed data analyses, interpreted the data, drafted the manuscript.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	12/8/19

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Alana L Hansen		
Contribution to the Paper	A Hansen assisted in the design of the study, interpretation of data and results, reviewed and provided feedback on the manuscript and supervised the development of work.		
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8.3 PUBLICATION

8.3.1 Abstract

Introduction

Hot environments can lead to adverse health effects and contribute to injuries in the workplace. However, there is limited understanding of the context of heat-related injury occurrence. Gaining the perspectives of occupational health and safety professionals (HSPs) may assist in better characterisation of the issue and inform targeted interventions.

Methods

A national online survey of HSPs was conducted in Australia (2017–2018) to collect data on: their experiences of heat-related injuries in workplaces; current preventive measures; training, policies and guidelines; and their perspectives on barriers for prevention. Results were analysed descriptively and a log-Poisson regression model was used to identify risk factors associated with HSP reported injury occurrence.

Results

Of the total 307 HSP survey participants, 74% acknowledged the potential for increased risk of occupational injuries in hot weather. A variety of injury types and mechanisms were reported, including manual handling injuries, hand injuries, wounds or lacerations, and loss of control of power tools.

Correlates of reported heat-related injuries included: working in the sun without shade; inadequate hydration; too few rest breaks; issues with personal protective equipment (PPE); and poor supervision. Only 42% reported that adequate heat

training was available in workplaces and 54% reported the provision for outdoor work to cease in extreme temperatures. It was acknowledged that the frequency of injuries could be reduced with wider adoption of self-pacing and work/rest regimes. Perceived barriers for prevention included: lack of awareness of physical injury risks, and management concerns about productivity loss and/or deadlines.

Conclusion

The findings indicate a range of potentially modifiable work and organisational risk factors for WRIs during hot weather. More attention to these factors, in conjunction with traditional interventions to reduce heat effects, could enhance injury prevention and labour productivity in people working in hot environments.

Keywords: Occupational health; Workplace heat exposure; Work-related injuries; Perceptions; Safety professionals

8.3.2 Introduction

Current and projected hot weather conditions are a serious concern for public and occupational health.[32, 463] Epidemiological studies have documented increases in morbidity and mortality associated with temperature extremes, especially among infants, young children, the elderly, those with underlying chronic health issues or disabilities and those using certain medications. However, the health risks due to extreme heat are not limited to these traditional vulnerable populations alone, but also extend to workers across a wide range of workplaces.[25, 29, 32]

Heat exposure in the workplace (both high temperatures and heatwaves) is known to cause adverse health effects including physical injury and illness, both acute and chronic, in workers both outdoors and in unregulated indoor environments.[29, 50, 464,

[465] One of the well-documented direct health effects of heat exposure is heat-related illnesses (HRIs) comprising a spectrum of disorders that range from minor heat rash to heat exhaustion and heat stroke, which in severe cases can lead to death.[113] These illnesses have been shown to increase with rising temperatures and during heatwaves.[123, 466, 467] Heat stress also affects workers' thermal comfort and reduces worker performance, work capacity and labour productivity.[29, 468]

Studies using administrative databases such as workers' compensation (WC) claims[45, 127, 132, 135, 145, 184, 185, 190, 421-423, 469] or company injury records[43, 44] and hospital records,[122] have identified subgroups at-risk, which include male workers, young workers, new workers, and those in outdoor and some indoor occupational settings. A range of occupational injuries have also been reported to increase in hot weather including slips, trips and falls, wounds, lacerations and amputations, burns, fractures, and superficial injuries.[42, 127, 145, 185]

However, research on the antecedents or mechanisms of injuries during hot weather is limited.[50, 397] Additionally, the interplay of potential underlying organisational, work and personal factors that might increase the risk of work-related injuries (WRIs) during hot weather is not well-understood. Studies have identified these factors as potential causes of HRIs, but further research is needed to establish whether they play a role in injury occurrence.[120, 178]

Cross-sectional studies assessing risk factors for heat stress-related health effects have primarily surveyed workers from a range of sectors.[115-117, 119, 120, 140, 201, 217, 470-474] Furthermore, perceptions of workers[140, 201] and of occupational hygienists[199] regarding extreme hot weather management in a warming climate have also been explored. However, the risk factors for work injury occurrence was not the focus of these studies.

A range of stakeholders hold occupational health and safety (OHS) roles and responsibilities, including employers and managers, OHS officers, workers themselves, health and safety professionals (HSPs), return to work coordinators and government regulatory bodies.[475] The comprehensive efforts and cooperation of these stakeholders is key for the successful prevention of workplace injuries and illnesses. HSPs encompass a wide range of professional groups such as occupational hygienists, occupational physicians, OHS consultants, safety managers, OHS advisers, officers and managers.[261] Their roles include, but are not limited to, performing work site inspections and evaluations, identification and assessments of risks, providing health and safety training and professional advice, policy and design, and determining ways to anticipate, eliminate, reduce or alleviate hazards.[261] Given their broader role and importance in OHS and the growing concern about OHS risks with rising temperatures, we conducted a survey among HSPs to gauge their perceptions on occupational injuries during hot weather in workplaces they visit or manage.

The purposes of this study were to assess HSP perspectives on: (i) injury experiences in Australian workplaces during hot weather and contributing factors; (ii) current preventive practices; (iii) current levels of training, policies and guidelines; (iv) heat-associated productivity loss; and (v) barriers to injury prevention.

8.3.3 Methods

8.3.3.1 Study design and participants

An anonymous cross-sectional online survey of Australian HSPs was administered from March 2017 to April 2018. HSPs included in this survey were defined as those with a full-time responsibility in managing the health and safety of workers in several workplaces. They included ‘work health and safety consultants’, ‘inspectors’, ‘safety managers’ and ‘trainers’. Recruitment was assisted by Safe Work Australia (the peak national body for OHS in Australia), jurisdictional OHS authorities, and industry and union contacts, who promoted the survey via their websites, newsletters and networks. A brief study description and a link to the online survey were provided to these organisations, with reminder emails.

8.3.3.2 Questionnaire design and measures

The survey questions were developed following an extensive literature review[50] and discussions with experts, and made available online through SurveyMonkey™ (www. surveymonkey.com, San Mateo, California, US) following a pilot test with local HSPs in South Australia (n=10). The opening page of the survey contained the participant information statement and informed consent was sought from all participants prior to commencement of the survey. The final questionnaire comprised seven sections namely: demographics; heat-related injuries/incidents; preventive measures; training; policies and guidelines; barriers; and productivity impact and potential solutions (see the supplementary material for the survey questions in Appendix B6).

Specifically, to determine the perceived frequency of heat-related injuries in workplaces, HSPs were asked the following question based on a 4-point Likert-scale '*In your experience of workplaces, would you say that injuries or incidents caused by (partly at least) hot/very humid weather occur:* (never/rarely/sometimes/often)' This was followed by questions on the types of injuries/incidents, symptoms and outcomes where heat exposure could have been a direct or in-direct contributing factor.

A five point Likert-type scale was used to assess the frequency of currently adopted prevention measures (never/rarely/sometimes/often/always) for outdoor and indoor workers. Respondents were asked their views on the most important work practice for preventing heat stress. Questions asked about the availability and type of training for preventing heat-related injuries/incidents in workplaces the respondents visit/manage. Questions also asked about the existence of a hot weather/heat stress policy, risk assessment tools used in workplaces and perceptions on the barriers for establishing prevention measures for best practice. In the final section, specific questions sought to identify HSPs perceptions on productivity concerns and potential solutions.

8.3.3.3 Data analysis

Quantitative analysis

Data were analysed descriptively in the first instance. Not all questions were mandatory, so the actual number of participants per question was used to estimate the percentages of responses for each item. Underlying factors that may have contributed to injury experiences were assessed using the following themes: work factors and hazards; organisational issues; and types of workers. A dichotomous dependent variable was created to represent the frequency of injury experience as reported by HSPs, by combining ‘sometimes’ and ‘often’ versus ‘never’ and ‘rarely’. The five response categories for the frequency of prevention measures adopted for indoor and outdoor workers were collapsed into two categories: ‘often/always’ and ‘never/rarely/sometimes’ with ‘always/often’ as the reference category.

Bivariate associations between frequency of injury experience (sometimes/often vs. never/rarely) and risk factors (organisational issues, work factors and hazards, types of workers, frequency of prevention measures) were assessed using log-Poisson regression analyses. This approach was chosen over the logistic model to decrease overestimation of the risks so that the results could be expressed as prevalence ratios (PR) with 95% CI, with p-values less than 0.05 considered statistically significant.[476, 477] All data analysis was performed using Stata 15 (College Station, TX).

Qualitative analysis

Participants who responded in the affirmative to the question ‘*Do you think that hot weather contributes to productivity loss?*’ (n=245) were further asked: ‘*What potential solutions to productivity loss during hot weather have been discussed?*’ Open-ended responses were provided by 115 participants and were imported and analysed for textual content in NVivo 11 (QSR International Pty Ltd, Doncaster, Victoria, Australia).

8.3.3.4 Ethical approval

This study was approved by the Ethics committee of the University of Adelaide (approval number: H-2016-085), and ratified by corresponding committees of

Queensland University of Technology, Monash University, and The University of Western Australia.

8.3.4 Results

8.3.4.1 Characteristics of study participants

Table 8.1 shows the demographic characteristics of the 307 participants who completed the online survey. The majority of respondents were males (65%) and 60% of respondents were in the 35–54 years age group. Forty-five percent represented industries with mostly outdoor activities, while 29% were from industries with mostly indoor activities. About 40% and 32% identified as a ‘health and safety professional’ and ‘health and safety manager’, respectively.

Table 8.1 Characteristics of the study population.

Sample Characteristics (n=307[a])	N (%)
State and territory, Australia*	
Eastern (ACT/NSW/Qld/Tas/Vic)	120 (39)
Central (SA/NT)	145 (47)
Western (WA)	41 (13)
Gender*	
Male	198 (65)
Female	106 (35)
Unspecified	2 (0.6)
Age-group*	
18–34 years	42 (14)
35–54 years	184 (60)
55 years and over	80 (26)
Years of experience in health and safety*	
Less than 5 years	33 (11)
5–10 years	105 (34)
11–20 years	104 (34)
More than 20 years	63 (21)
Industry	
Mostly indoor activities	88 (29)
Mostly outdoor activities	139 (45)
Mixed	80 (26)
Current role in health and safety*	
Consultant	31 (10)
Health and Safety Manager	98 (32)
Health and Safety Professional	121 (40)
Inspector	27 (9)
Other (please specify)	27 (9)

Note: * May not total to 307 due to missing values.
Abbreviations: NSW/ACT/Qld/Tas/Vic, New South Wales/Australian Capital Territory/Queensland/Tasmania/Victoria; SA/NT, South Australia/Northern Territory; WA, Western Australia.

8.3.4.2 Heat-related injuries/incidents

Three-quarters (74%) of respondents indicated that injuries or incidents caused by hot/very humid weather occur ‘sometimes’ or ‘often’ in workplaces that they visit/manage. ‘Manual handling’ (musculoskeletal injuries) or ‘joint/ligament injuries’ were the main type of injuries identified by 58% of the HSPs (Figure 8.1A) followed by ‘hand injuries’ (46%) and ‘wounds or lacerations’ (32%), all of which resulted in minor outcomes such as being sent home or days off work (Figure B6A, Appendix B6).

The four most frequently cited causes of injuries were ‘injuries arising from slips, trips or falls’ (46%), ‘injuries resulting from not wearing personal protective equipment (PPE)’ (45%), ‘impaired vision due to fogged safety glasses’ (39%) and ‘loss of control of tools leading to injury’ (38%) (Figure 8.1B). Respondents reported ‘fatigue’ (88%) as the most frequent type of incident or illness in workers during hot weather followed by ‘muscle/heat cramps’ (68%) and ‘severe dehydration’ (64%) (Figure 8.1C) resulting in minor outcomes (being sent home or days off work) and ‘any access to health care’ (ambulance called /visit to Emergency Department / stay in hospital), respectively (Figure B6B, Appendix B6).

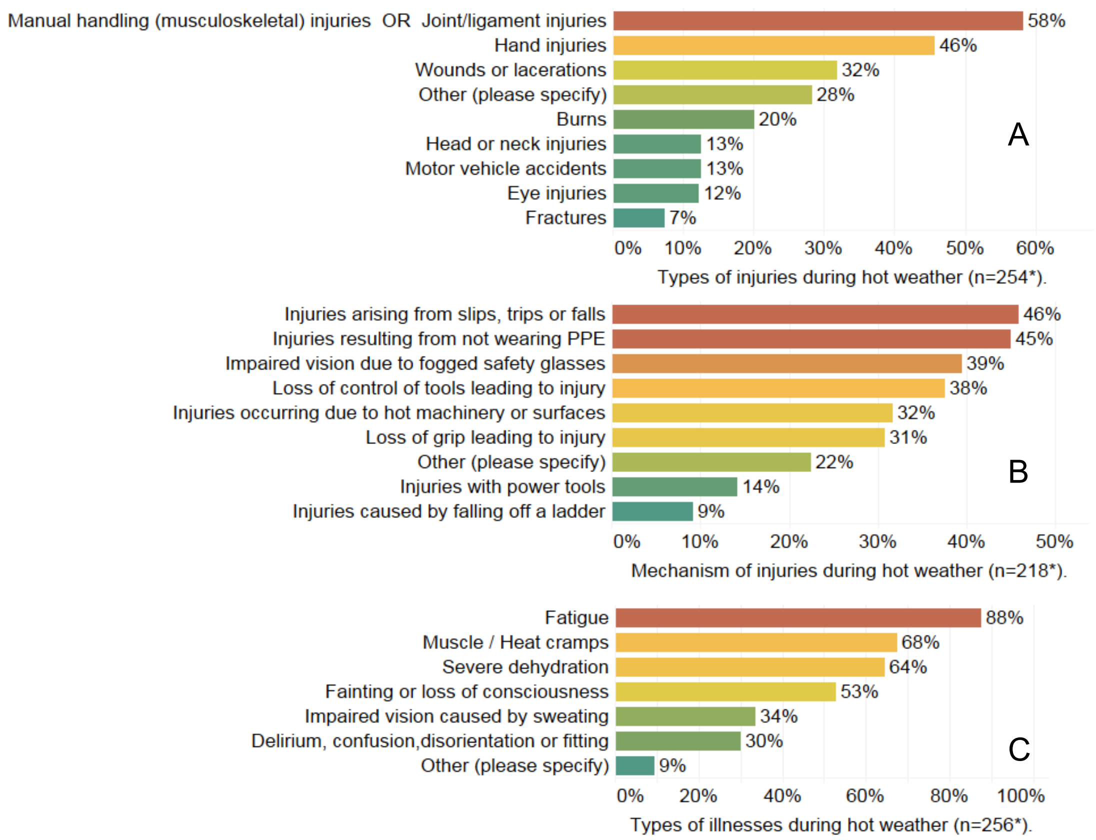

Figure 8.1 Bar chart of (A) types of injuries; (B) mechanism of injuries and (C) types of illnesses during hot weather as reported by respondents. Percentages do not total 100% as multiple responses were allowed.

The major organisational issues for injuries cited by participants were ‘policies not adhered to’ (54%), ‘poor supervision’ (40%) and ‘no health and safety training specifically on heat stress’ (37%) (Figure B7A, Appendix B6). Organisational issues listed under the ‘others’ option included, ‘work design and environment’, ‘culture within the organisation’, ‘management’ and ‘victim-blaming’. Some verbatim examples of organisational issues raised by participants include: ‘aged building design issues’, ‘failure of air conditioning’, ‘poor decision making’, ‘lack of leadership on safety’, ‘culture of not managing hazards’, ‘workers not managing their own risks’, and ‘workers incorrect perception of work pressure’.

The three most frequently cited contributing work factors and hazards for injuries were ‘working in the sun with no access to shade (solar radiation)’ (61%), ‘wearing of PPE leading to higher body temperature' (48%) and 'rushed activity' (46%) (Figure B7B, Appendix B6). Sixty-eight percent and 47% responded that 'workers aged 25–50 years' and 'younger workers (aged up to 24 years)', respectively were most commonly affected by injuries/incidents (Figure B7C, Appendix B6).

8.3.4.3 Preventive measures

In response to a question asking about preventive work practices adopted for outdoor workers during hot weather, the measures most often/always adopted were 'access to cool drinking water (86%)', 'PPE supplied' (85%), and 'sunscreen supplied' (78%) (Figure 8.2A). Most respondents indicated 'use of cool vests' and 'urine specific gravity testing' were measures that were never/rarely adopted, while 'work gets rescheduled to cooler times' and 'shade erected over work area' were adopted 'sometimes'.

For indoor workers, the measures 'fan only cooling' (30%) and 'job rotation' (25%) were adopted sometimes, while 'access to cool drinking water' (94%), 'adequate ventilation' (75%) and 'PPE supplied' (71%) were adopted often/always (Figure 8.2B).

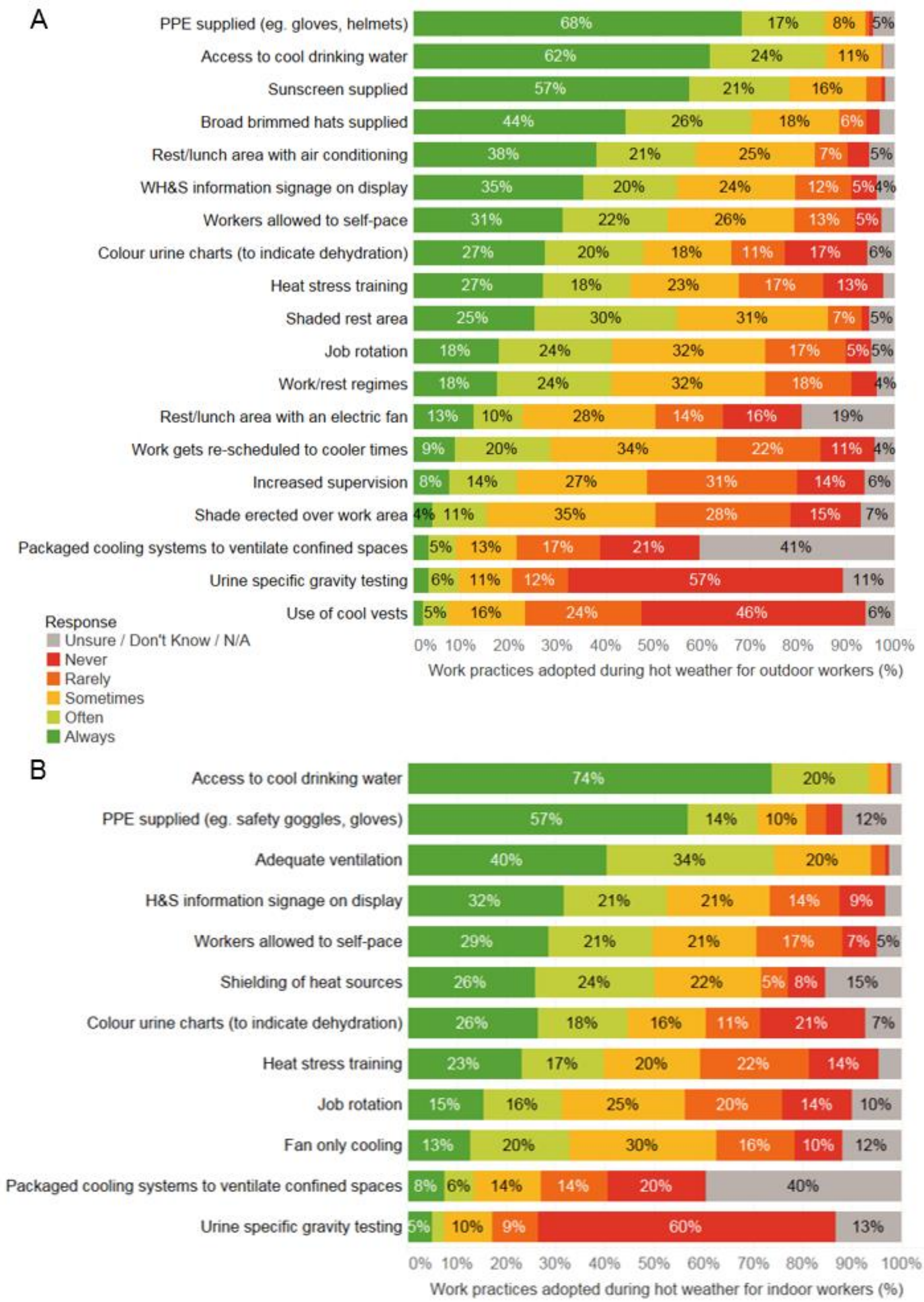

Figure 8.2 Percentages of work practices adopted during hot weather for outdoor (A) and indoor workers (B) as cited by HSPs.

Fifty-five percent of the participants reported that the ‘provision for outdoor work to cease if temperatures are extreme’ was available in workplaces that they visit/manage, with two-thirds (67%) saying that the ‘temperature at which outdoor work ceases’ varies between workplaces and is dependent on other factors including humidity, location and nature of work (Table B10, Appendix B6). With respect to work practices, participants noted that ‘heat stress training’ (22%) and ‘access to cool drinking water’ (19%) were the most important for preventing heat stress in outdoor workers (Figure B8A, Appendix B6).

‘Access to air conditioning or fans’ was often available for indoor workers as cited by 74% of respondents and the most common type of cooling systems in workplaces was ‘refrigerated’ (Table B10, Appendix B6). With respect to work practices for indoor workers, participants noted that ‘heat stress training’ (25%), ‘air conditioning’ (24%) and ‘access to cool drinking water’ (21%) were noted as important for preventing heat stress in indoor workers (Figure B8B, Appendix B6).

8.3.4.4 Training

Forty-two percent of the HSPs reported that training was available for preventing heat-related injuries/incidents in workplaces they manage/visit, while 39% reported that it was available in some workplaces (Table B11, Appendix B6). Fifty-two percent of the respondents said that training was available for supervisors and only 10% reported that supervisors and workers were trained separately (Table B11, Appendix B6).

About two-thirds of the HSPs said that training was conducted ‘annually regardless of job’ and ‘once at induction when starting a new job where heat could be a hazard’ with the majority of the training being provided on site by ‘health and safety professionals' (67%) and 'supervisors' (46%). With respect to the quality of the heat stress training, 45% said that the training provided was 'comprehensive' or 'adequate' while 47% of HSPs reported that this training was not assessed. The main sources of heat stress training information and resources were the 'Employer' (70%) and 'Safety regulator' (24%) (Table B11, Appendix B6).

8.3.4.5 Policies and guidelines

Sixty-three percent of the participants reported that there is a hot weather or heat stress policy in workplaces they visit/manage, and 63% reported that heat stress management is partially implemented (Table B12, Appendix B6). When asked about indicators of heat risk, about half (51%) said that 'air temperature at weather bureau' followed by 'air temperature on site' (45%) were used as measures to indicate heat thresholds in workplaces. With respect to the use of mobile phone device apps to assist in heat stress management, two-thirds of the HSPs (66%) reported that they were not used in workplaces they currently visit (Table B12, Appendix B6).

8.3.4.6 Barriers

The three most important barriers for the prevention of occupational injuries/incidents during very hot weather reported by the HSPs (Figure B9, Appendix B6) was 'lack of awareness of workers that heat can be associated with ill health and injury' (43%), followed by 'management concerns about productivity loss and/or deadlines' (33%) and 'lack of awareness by supervisors of heat hazards' (29%).

8.3.4.7 Productivity and potential solutions

More than half of the participants (52%) indicated that hot weather contributes to productivity loss often, while 44% said it contributes sometimes (Table B13, Appendix B6). When asked how much of a problem productivity is for workers, 58% thought it was a minor problem and 28% thought it was a major problem. Fifty-one percent of the participants reported that potential solutions have been discussed to address productivity loss in workplaces they visit/manage. The most frequent response to an open-ended question on potential solutions was to reschedule work, for example, to include earlier starts, night work or even to cooler months. Other common suggestions were: rotation of workers or tasks; active cooling systems (including air conditioning and fans); and adopting work rest regimes to ensure adequate breaks. The most common responses based on the number of coding references are shown in Figure 8.3.

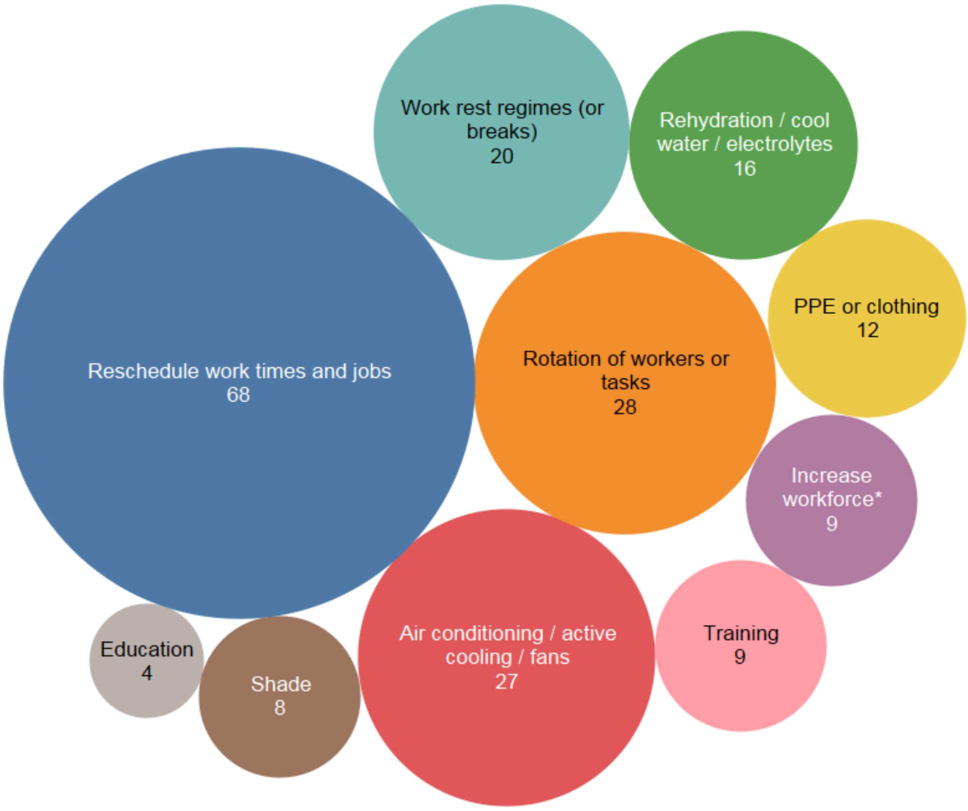

Figure 8.3 Open ended responses to solutions for productivity concerns. Numbers are the coding reference and circles are proportional to the number (n=115).

8.3.4.8 Factors associated with injury experience

Bivariate analyses of the organisational issues and reported frequency of injury experiences indicated a higher prevalence of injuries was associated with: 'workers not being allowed to take breaks as needed'; 'lack of induction'; 'insufficient access to cool drinking water'; 'poor supervision' and 'no health and safety training specifically on heat stress' (Figure 8.4).

With respect to work factors and hazards (Figure 8.5), 'working in the sun with no access to shade (solar radiation)'; 'dangerous locations'; 'wearing of PPE leading to higher body temperature'; 'fire steam and hot surfaces' and 'rushed activity' were identified to be associated with higher frequency of injury experiences as cited by HSPs.

Organisational issues	Injury experiences: Never/Rarely n (%)	Injury experiences: Sometimes/Often n(%)	PR [95% CI]
Policies not adhered to			
No	30 (52.6)	83 (44.1)	Reference
Yes	27 (47.4)	105 (55.8)	1.08 (0.94-1.24)
Poor supervision			
No	42 (73.7)	106 (56.4)	Reference
Yes	15 (26.3)	82 (43.6)	1.18 (1.03-1.34)
No health and safety training specifically on heat stress			
No	43 (75.4)	111 (59.0)	Reference
Yes	14 (24.6)	77 (40.9)	1.17 (1.02-1.33)
Production targets			
No	44 (77.2)	124 (65.9)	Reference
Yes	13 (22.8)	64 (34.0)	1.12 (0.98-1.28)
No policy related to hot weather or hot environments			
No	46 (80.7)	130 (69.1)	Reference
Yes	11 (19.3)	58 (30.8)	1.13 (0.99-1.3)
Workers not being allowed to take breaks as needed			
No	52 (91.2)	130 (69.2)	Reference
Yes	5 (8.8)	58 (30.8)	1.28 (1.14-1.44)
Insufficient access to cool drinking water			
No	50 (87.7)	139 (73.9)	Reference
Yes	7 (12.3)	49 (20.1)	1.18 (1.04-1.35)
Responsibilities not clearly defined			
No	48 (84.2)	142 (75.5)	Reference
Yes	9 (15.8)	46 (24.5)	1.11 (0.96-1.29)
Lack of induction			
No	55 (96.5)	167 (88.8)	Reference
Yes	2 (3.5)	21 (11.2)	1.21 (1.04-1.4)

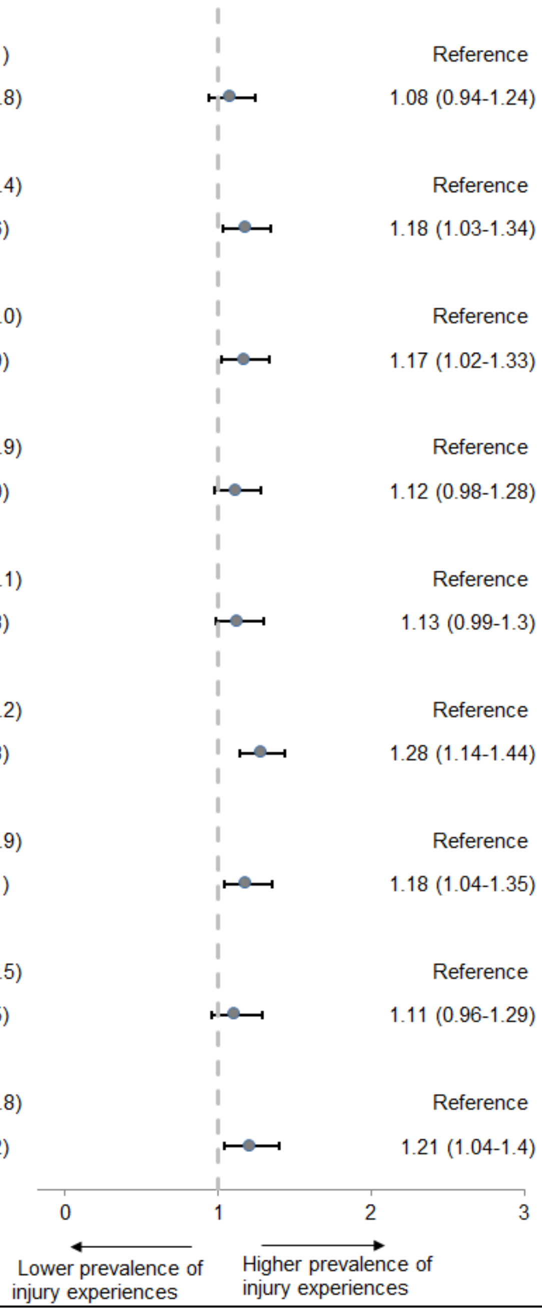

Figure 8.4 The associations between organisational issues cited by HSPs and reported frequency of injury experiences. Prevalence ratios (PRs) and 95% CIs.

Work factors and hazards	Injury experiences: Never/Rarely n (%)	Injury experiences: Sometimes/Often n(%)	PR [95% CI]
Rushed activity			
No	39 (66.1)	95 (50.3)	Reference
Yes	20 (33.9)	94 (49.7)	1.16 (1.01-1.33)
Wearing of PPE leading to higher body temperature			
No	39 (66.1)	90 (47.6)	Reference
Yes	20 (33.9)	99 (52.4)	1.19 (1.03-1.37)
Working in the sun with no access to shade			
No	33 (55.9)	63 (33.3)	Reference
Yes	26 (44.1)	126 (66.7)	1.26 (1.07-1.48)
Working indoors with no air conditioner, fan or adequate ventilation			
No	45 (76.3)	129 (68.2)	Reference
Yes	14 (23.7)	60 (31.7)	1.09 (0.94-1.25)
Equipment, machinery and tools			
No	51 (86.4)	147 (77.7)	Reference
Yes	8 (13.6)	42 (22.2)	1.13 (0.97-1.30)
Electricity			
No	59 (100)	183 (96.8)	Reference
Yes	0 (0)	6 (3.2)	1.32 (1.23-1.42)
Fire, steam and hot surfaces			
No	53 (89.8)	150 (79.4)	Reference
Yes	6 (10.1)	39 (20.6)	1.17 (1.01-1.35)
Dangerous locations			
No	57 (96.6)	162 (85.7)	Reference
Yes	2 (3.4)	27 (14.3)	1.25 (1.10-1.42)

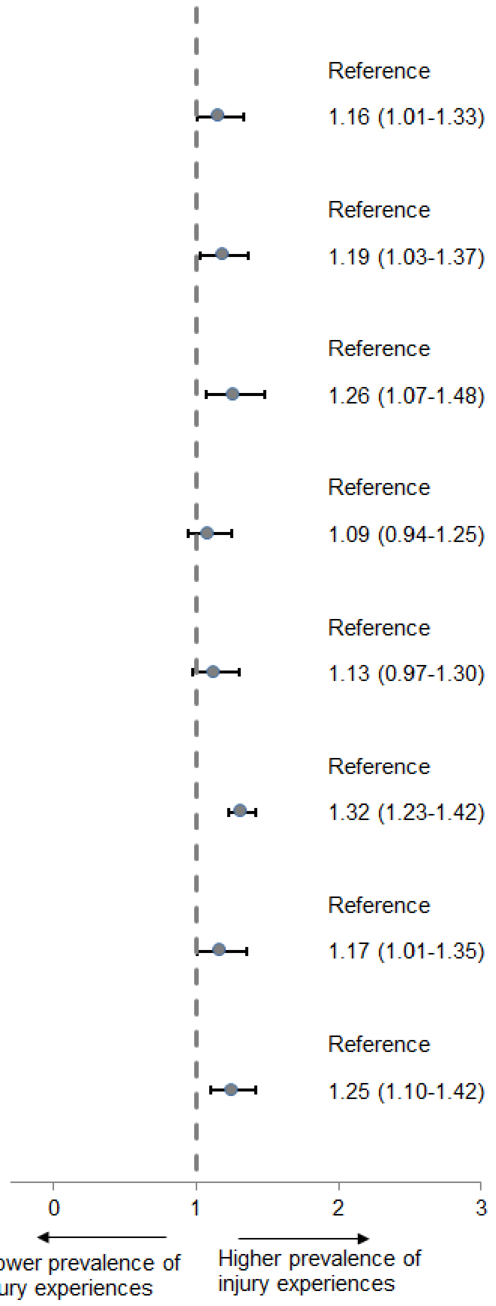

Figure 8.5 Prevalence ratios (PRs) for injury experiences associated with work factors and hazard cited by HSPs.

‘New workers’, ‘young workers’ and ‘workers whose first language is not English’ were identified as workers associated with higher frequency of injury experiences (Figure 8.6). Compared with workplaces where preventive work practices such as ‘self-pacing’; ‘work-rest regimes’ and ‘access to cool drinking water’ are adopted often/always for outdoor workers, the frequency of injury experience (sometimes/often) was higher in workplaces where these measures were adopted never/rarely/sometimes. Similarly, if ‘access to cool drinking water’ and ‘self-pacing’ was adopted never/rarely/sometimes for indoor workers, such workplaces had higher frequency of injury experiences as cited by HSPs (Table 8.2).

Injury experience was reportedly lower in workplaces where air-conditioning or fans were available ‘often’ (reference=‘never’) for indoor workers (PR 0.79; 95% CI: 0.64–0.97) and heat stress management was fully implemented (PR 0.72, 95% CI: 0.59–0.89) compared with workplaces where it has been partially or not at all implemented (results not shown). Workplaces with a hot weather or heat stress policy had lower reported injury experience compared with those that did not (results not shown), however this association was not statistically significant (PR 0.92; 95% CI: 0.77–1.09).

Type of workers	Injury experiences Never/Rarely n (%)	Sometimes/Often n(%)	PR [95% CI]
New workers			
No	47 (81.0)	96 (51.6)	Reference
Yes	11 (18.9)	90 (48.4)	1.32 (1.16-1.51)
Younger workers (aged up to 24 years)			
No	42 (72.4)	88 (47.3)	Reference
Yes	16 (27.6)	98 (52.7)	1.26 (1.1-1.46)
Workers aged 25-50 years			
No	22 (37.9)	56 (30.1)	Reference
Yes	36 (62.1)	130 (69.9)	1.09 (0.92-1.28)
Older workers (aged over 50 years)			
No	38 (65.5)	103 (55.4)	Reference
Yes	20 (34.5)	83 (44.6)	1.1 (0.96-1.26)
Workers whose first language is not English			
No	55 (94.8)	155 (83.3)	Reference
Yes	3 (5.2)	31 (16.7)	1.23 (1.08-1.41)

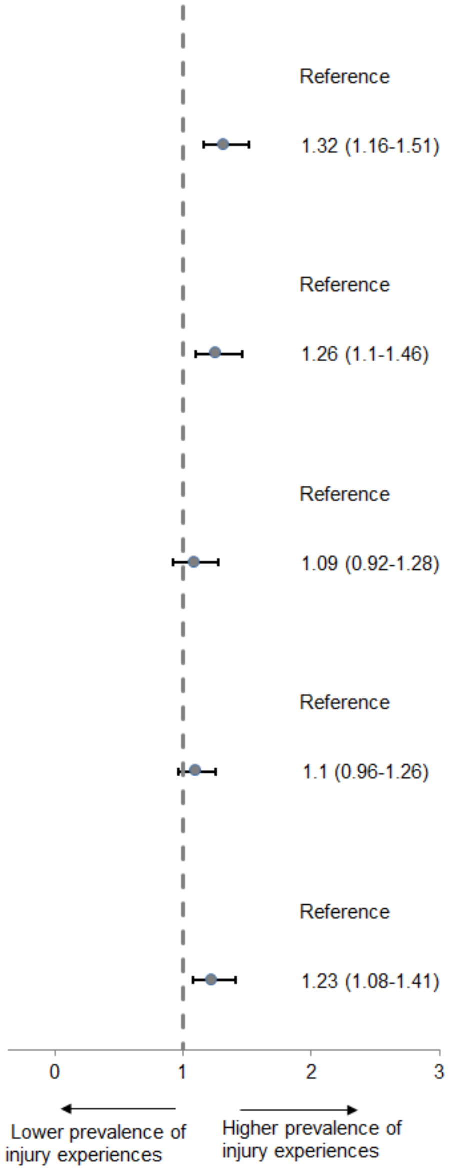

Figure 8.6 Prevalence ratios (PRs) for injury experiences associated by worker factors as cited by HSPs.

Table 8.2 Prevalence ratios (PRs) for frequency of injury experiences (never/rarely vs. sometimes/often) reported by HSPs and prevention measures (never/rarely/sometimes vs often/always).

Frequency of injury experience	**Never/ Rarely**	**Sometimes/ Often**	**PR (95%CI)**	**Injury experience**	**Never/ Rarely**	**Sometimes/ Often**	**PR (95%CI)**
Prevention measure~ for outdoor workers	n(%)	n(%)		**Prevention measure for indoor workers**	n(%)	n(%)	
Access to cool drinking water	59 (27)	158 (73)	1.19 (1.01-1.40) ▲	Access to cool drinking water	59 (26)	168 (74)	1.35 (1.25-1.46) ▲
Broad brimmed hat supplied	47 (27)	129 (73.)	1.04 (0.88-1.22)	Shielding of heat sources	30 (25)	90 (75)	1.04 (0.90-1.22)
PPE supplied	54 (26)	154 (74)	1.13 (0.92-1.37)	PPE supplied	45 (26)	127 (74)	1.10 (0.92-1.30)
Use of cool vests	4 (22)	14 (78)	0.95 (0.73-1.23)	Adequate ventilation	47 (26)	132 (74)	1.09 (0.93-1.27)
Sunscreen applied	56 (28)	142 (72)	1.17 (1.01-1.36) ▲	Fan only cooling	22 (29)	55 (71)	1.08 (0.91-1.28)
WH&S information signage on display	41 (30)	94 (70)	1.15 (1.00-1.34)	Packaged cooling systems to ventilate confined spaces	10 (31)	22 (69)	1.10 (0.85-1.42)
Heat stress training	33 (29)	79 (71)	1.10 (0.95-1.28)	Heat stress training	24 (25)	72 (75)	1.00 (0.85-1.16)
Shaded rest area	40 (30)	95 (70)	1.13 (0.97-1.31)	H&S information signage on display	33 (26)	93 (74)	1.02 (0.88-1.19)
Shade erected over work area	7 (19)	30 (81)	0.89 (0.74-1.06)	Job rotation	24 (32)	51 (68)	1.18 (0.99-1.41)
Rest /lunch area with air-conditioning	43 (30)	102 (70)	1.13 (0.98-1.32)	Workers allowed to self-pace	41 (34)	79 (66)	1.28 (1.10-1.50) ▲
Rest /lunch area with an electric fan	13 (24)	41 (76)	0.97 (0.81-1.17)	Colour urine charts to indicate dehydration	28 (26)	80 (74)	1.01 (0.87-1.18)
Packaged cooling systems to ventilate confined spaces	4 (19)	17 (81)	0.94 (0.74-1.18)	Urine specific gravity testing	4 (22)	14 (78)	0.97 (0.74-1.25)
Workers allowed to self-pace	46 (36)	83 (64)	1.31 (1.12-1.53) ▲				
Job rotation	31 (30)	71 (70)	1.13 (0.97-1.32)				
Increased supervision	14 (27)	37 (73)	1.06 (0.87-1.27)				
Work gets rescheduled to cooler times	20 (29)	49 (71)	1.06 (0.89-1.26)				
Work/rest regimes	34 (34)	67 (66)	1.19 (1.01-1.41) ▲				
Colour urine charts (to indicate dehydration)	27 (23)	90 (77)	0.94 (0.80-1.09)				
Urine-specific gravity testing	5 (22)	18 (78)	0.95 (0.76-1.20)				

Note: ~Prevention measures adopted was coded as ‘Often/Always’ (reference category) vs. ‘Never/Rarely/Sometimes’. ▲ shows statistically significant PR ratio at the 95% CI.

8.3.5 Discussion

Hot weather creates significant OHS concerns particularly for those working outdoors and in non-air-conditioned indoor work environments. The findings described here provide insights into the experiences of work-injuries and incidents sustained during hot weather in Australian workplaces, based on the perceptions of HSPs, who are at the frontline in improving occupational safety and health.

There are several key findings from this study. First, hot/humid weather was acknowledged by the majority of the HSPs as a contributory factor to work-injuries in workplaces they visit/manage. Second, we have identified organisational issues, factors and hazards that are associated with a higher reported frequency of injury experiences. Third, it was evident that administrative and personal controls such as provision of cool drinking water, PPE and sunscreen (outdoor workers) and ventilation (indoor workers) were reportedly the most often/always adopted preventive measure. However, lack of awareness of workers and supervisors, and management concerns around productivity loss and/or deadlines were reported as key barriers for prevention. Fourth, the existence of a hot weather or heat stress policy (62%), provision for outdoor work to cease at temperature extremes (55%), and access to air-conditioning for indoor workers (74%) were reported by more than half of the HSPs. Fifth, heat stress training (42%) and full implementation of heat stress management (28%) was reported by less than half.

To date, studies examining the relationship between hot weather and work-injuries have not identified the mechanisms underlying this relationship.[132, 135, 185, 188] A recent review [50] suggests that it is difficult to isolate ambient temperature as the sole contributory factor for work-injuries, but rather a range of personal, work-related and organisational factors or a combination of these factors as the most likely pathway to heat-related work injuries.

The acknowledgement by 74% of HSPs that injuries or incidents occur in hot/humid weather is concerning as this alludes to a larger problem than reported in studies using WC claims data.[45, 132, 135, 145, 188, 421, 422] This figure is also higher than a previous study conducted in Australia in 2014,[199] where 53% of occupational hygienists reported having investigated circumstances around injuries or illnesses attributed to extreme heat. However, the acknowledgement of heat-related injuries/incidents that occur is not often reflected in the injuries/illnesses reported. This issue of under-reporting of heat-related injuries/illnesses is possibly due to the misunderstanding of the link between heat and health consequences. Furthermore, it is possible that the main causal factor of heat is often not reported—for example, when an individual collapses in the heat it may be attributed to the increased cardiovascular stress.

In the present study, frequently occurring heat-related injuries and symptoms of HRIs often resulted in minor outcomes (sent home/days off work), a notable finding which would not normally be captured using workers compensation claims data. Consistent with previous studies,[145, 185] the types of heat-related occupational injuries frequently reported in this study included ‘manual handling’, ‘hand injuries’ and ‘wound or lacerations’. ‘Fatigue’, ‘muscle/heat cramps’ and ‘severe dehydration’ were the commonly cited symptoms of illnesses, which is consistent with previous cross-sectional studies[115, 116, 119, 120, 201, 215, 221, 224, 474] assessing risk factors for HRIs. These results point towards the contributory role of physiological factors such as fatigue, dehydration and muscle cramps as precursors to the early stages of HRIs and work injuries in hot weather.

Our findings suggest that new workers, young workers (aged 15–24 years) and workers whose first language is not English are more likely to be at risk of heat-related injuries. This result concurs with previous research.[45, 132, 421, 422] The higher risks faced by these groups may be explained by factors such as lack of awareness of hazards, job inexperience, lack of familiarity within the work environment, risk-taking behaviours, and language barriers, and possible cultural factors for workers whose first language is not English.[478, 479] Additionally, these workers often feel uncomfortable raising safety concerns, and may be more likely to push through to impress their managers and other workmates due to job insecurity. In light of these findings, these groups need to be an OHS priority for regulatory bodies and policy makers.

Organisational factors such as poor safety climate and safety practices have an influence on the rates of work injuries in a workplace.[480] The key actors in this space include employers and workers, both of whom have shared responsibility in regards to OHS matters. By legislation, employers are required to protect the health and safety of their workers by ensuring a safe working environment 'as far as reasonably practicable'.[462] In the present study, the organisational risk factors most often reported by HSPs as being associated with a higher frequency of heat-related injuries were: lack of health and safety training and induction, poor supervision, insufficient access to cool drinking water, and workers not allowed to take breaks as needed. This relates to structural factors in the workplace beyond the control of the individual worker that may either directly or indirectly influence the occurrence of injuries. Additionally, it is noteworthy that 62% of HSPs reported the existence of a hot weather policy; however, 'policies not being adhered to' was identified as an organisational issue by 60% of participants. This highlights that having a policy alone does not necessarily translate to solutions, as non-compliance can result in unsafe work environments and increased risk-taking behaviours by workers. Such policies need to be followed up with in-field interactions/discussions by leadership and HSPs in the hotter months to ensure the message is understood and controls embedded.

Work factors related to higher frequency of injuries included working in the sun with no access to shade, work in dangerous locations (e.g. confined spaces), use of PPE, work near hot surfaces and rushed activity. Although the wearing of PPE is necessary to protect workers from hazards, it can be problematic in two ways. First, PPE can be impermeable clothing or clothing with high insulating factors, potentially increasing the risk of heat stress by impeding heat loss to the environment via sweat evaporation, retaining excess heat and moisture and/or increasing the physical effort to perform tasks.[481-484] Second, workers may choose not to wear PPE in hot weather because of feelings of discomfort, poor fit, and inappropriateness for a range of work circumstances. Respiratory protection devices for example can impede adequate fluid intake in hot work environments. This may result in respirators being removed in hazardous environments in order to drink fluids, resulting in exposures. Workers not wearing PPE was cited as a mechanism of injury by HSPs suggesting that the non-use of PPE may be leaving workers exposed to other hazards. Therefore, the choice of the right PPE taking into account the work and work environment, is vital and the improvement of PPE to make it more comfortable in hot weather is needed.

Limiting the work to suit the environment and modifying the environment to suit the work are two approaches that may be used to manage heat stress where practicable. These can be done through the hierarchy of controls to reduce hazards leading to the prevention of work-injuries and illness.[485] In terms of heat hazard, the most effective higher order controls for indoor working environments would be provision of ventilation and mechanical cooling methods i.e. air-conditioning and/or cooling fans, insulation of roofs and walls and shielding of heat sources. For outdoor workers, protection from the sun and the provision of an air-conditioned environment for rest breaks would be most effective. However, these controls could be expensive and impractical depending on the work environment and work settings.

Our findings that the provision of drinking water is the most common method of workplace heat stress prevention in workers (both outdoor and indoor) is consistent with other studies.[140, 199, 201, 226, 486] However, despite access to water, 64% of HSPs cited severe dehydration as a frequent type of incident in workplaces as shown in other studies.[115, 487-490] Although water may be provided in workplaces, workers may still not be drinking enough, perhaps due to the inability to take adequate breaks as needed as reported by HSPs. Alternatively, as other studies have indicated, workers could be starting work dehydrated.[487, 490-492]

The key guidance advice provided by all the eight state and territory WHS regulators in Australia to control heat risk includes ‘reschedule work to cooler parts of the day’, ‘change location of work’, ‘job rotation’ and ‘extra rest breaks in cool area’.[171] The lower frequency of adoption of some of these control measures (e.g. extra rest breaks) indicates the challenge faced by workplaces in terms of expense and the trade-off between labour productivity and worker health. Indeed, more than half of the HSPs (53%) cited that hot weather contributed to productivity losses in workplaces and that solutions to address them have been discussed. This finding is similar to a survey of construction workers where 50% of participants reported slowing down when it is hot.[474] A recent study estimated that the annual costs of heat stress to the Australian economy was US$6.2 billion per year (or US$655 per person) and concluded that wider adoption of prevention measures is warranted to reduce further economic impacts.[238] The solutions raised by HSPs in the open-ended questions included reschedule of work to cooler times of the day and rotation of workers or tasks, while allowing workers to self-pace, and having appropriate work/rest regimes, were the measures identified as being associated with reductions in reported frequency of injury. These measures have been shown to be effective as protective measures for HRIs if engineering solutions are too expensive or difficult to implement.[493]

Provision of training and adequate supervision is another component of heat stress management, but only 42% of HSPs reported the availability of heat stress training in workplaces. Similarly, in a study of workers from South Australia, 43% of participants reported heat-stress training was available.[140] Notwithstanding, it is important to acknowledge the variety of factors operating at multiple levels that may constrain the wider adoption of safe work practices. The lack of awareness by workers that heat can be associated with ill health and injury, as identified by 44% of HSPs, is an important barrier for prevention that needs to be considered. This is consistent with previous studies.[199, 204] It is possible that workers and their supervisors may not be fully aware of the spectrum of health effects which can start with fatigue and dehydration and can progress to increased risk of accidents and heat disorders. Our previous work in Adelaide[422] has shown that occupational injuries increase with temperatures even in moderate ranges (above 25 °C) before reaching extreme levels (35 °C), in both outdoor and indoor settings. Accordingly, workers and their supervisors need to be aware of the health risks of working in hot weather at both moderate and extreme temperatures. Current training programs may need to be modified to include the risks of workplace injuries that can occur at moderate temperatures, and before the occurrence of HRI. It is also important that the training materials are translated or presented appropriately for non-English speaking workers, or those with poor literacy. While there is a need for raising awareness and providing training for workers, supervisors and management teams, it is also important to highlight that each of these groups have a shared responsibility in relation to OHS. Also, as pointed out earlier, training and policies are important but they must be followed up at the work front with interactions/discussions to ensure the importance is recognised and to reinforce the adoption of controls. In summary, a combination of administrative and engineering controls tailored according to individual occupations will be necessary to reduce heat-associated injuries for workers.

The present study has several limitations. First, although the study has attempted to obtain information about the extent and characteristics of occupational injury experiences during hot weather at the Australian national level, we cannot make any claims for generalisability due to the relatively small sample size and non-random sampling design. It is plausible that HSPs who were more interested in the topic may have completed the survey creating a possible selection bias whereby the frequency of injury may be inflated. We cannot calculate a survey response rate because we did not have a sampling frame but instead advertised the survey widely. As a proportion, there were more respondents from Central Australia than from other states. Second, the data are self-reported and the injuries/incidents reported are not validated. Third, despite our extended work[469] showing differences in outcomes for occupational temperature-related injuries according to climate zones, we were unable to carry out region-specific analyses due the relatively small sizes. Despite these caveats, one of the major strengths of the study is that the data collected covers several risk factors that are not normally collected as part of administrative datasets, and the first reported national study of HSPs perspectives on working in hot conditions. Garnering the perspectives of professionals at the forefront of OHS has aided in a better understanding of the underlying causes for the associations between hot weather and injuries.

8.3.6 Conclusion

The results of this study add to the growing body of evidence about the relationship of work injuries and hot weather, and offer additional insights on underlying factors that may explain the increase in risk. Our results highlight that the underlying mechanisms of injury occurrence are likely to be complex and multi-factorial. However, heat related injuries are preventable if adequate attention is given to the working environment and work factors. Translating these findings into proactive preventive action should be given a priority in the context of increasing heat exposure in Australian workplaces.

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Competing interests: The authors declare that they have no competing interests.

*****End of manuscript*****

8.4 CHAPTER SYNOPSIS

Chapter 8 presented the findings of a national survey of HSPs on heat and WRI, their determinants, prevention, and management. The findings point to a range of modifiable work and organisational risk factors for WRI in hot weather. More attention to these factors in conjunction with traditional interventions for heat-induced illness, could enhance workplace injury prevention. The findings also call for more increased awareness of heat as an occupational hazard, particularly with regards to WRI occurrence and modifiable risk factors. The following chapter further examines the risk factors using a similar survey targeting HSRs.

09

Chapter 9: Heat-Related Injuries in Australian Workplaces: Perspectives from Health and Safety Representatives

9.1 PREFACE

The study presented in this chapter also addresses the second objective. This study expands on the findings presented in Chapter 8 by examining the risk factors for heat-related injuries from the perceptions of HSRs. The findings from the study represent an evidence base upon which WHS practices and interventions could be assessed to better the health and safety of workers in hot weather.

Similar to Chapter 8, this study is the first to have garnered the perceptions of HSRs on heat and WRI across Australia.

This paper is currently in the format of a manuscript submitted for publication.

9.2 STATEMENT OF AUTHORSHIP

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Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	12/8/19

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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9.3 PUBLICATION

9.3.1 Abstract

Introduction

Hot weather poses occupational health and safety concerns for people working in hot environments. It is known that work-related injuries increase during hot weather, yet there is an incomplete understanding of the underlying factors.

Methods

A national online survey was conducted in Australia among workplace health and safety representatives (HSRs) to better understand factors contributing to heat-related injuries in workplaces. Risk factors and preventive measures associated with reported injuries were identified using log-Poisson regression models.

Results

In total, 222 HSRs completed the survey. Overall, 43% reported that injuries or incidents caused by hot/very humid weather occur sometimes or often in their workplace. Factors found to be associated with reported heat-related injuries included ‘the wearing of personal protective equipment (PPE)’ which can hinder the loss of body heat, and ‘inadequate resources and facilities’. ‘Piece-rate workers’, and ‘new workers’ were identified as being at high risk. The most frequently adopted preventive measures for outdoor and indoor workers were the provision of PPE (despite some identified issues) and access to cool drinking water. HSRs reported that less injuries occurred in hot weather among outdoor workers if work was rescheduled to cooler times and shade was provided; and in indoor environments

where there was adequate ventilation, heat sources were shielded and workers were able to self-pace.

Conclusion

Organisational issues, workplace hazards, personal factors and preventive measures, are all determinants of heat-related injuries in Australian workplaces. Wider adoption of identified prevention measures could reduce the incidence of heat-related injuries in outdoor and indoor workplaces.

Keywords: Occupational health; Workplace heat exposure; Work-related injuries; Perceptions; Safety representatives

9.3.2 Introduction

Heat exposure (weather-related or industrial) in the workplace is an important occupational health and safety (OHS) concern that has been linked to a range of adverse physical outcomes including fatal heat-related illnesses (HRIs).[29, 201] In addition, heat stress is also known to affect workers' thermal comfort, reduce worker efficiency, compromise work capacity and labour productivity, and increase safety risks.[24, 29, 203, 238, 494]

In the US between 2009 and 2017 there were 327 work-related fatalities and 30,890 non-fatal work injuries and illnesses involving days away from work, that were attributed to exposure to environmental heat.[495] The corresponding figures over the same time-period in Australia show 13 worker fatalities and 12,905 compensated work-related injuries (WRIs) and illnesses involving more than a week of absence from work.[496] However, these official figures only capture reported incidents/injuries where heat exposure was thought to be a contributing factor and so likely underestimate the total burden.[32] Several epidemiological studies have correlated workers' exposure to hot weather with an increased risk of workplace injuries and accidents at higher temperatures and during heatwaves.[43-45, 122, 127, 132, 135, 145, 184, 185, 188, 190, 423, 469] Groups susceptible to heat-related injuries include male workers, young workers, both outdoor and some indoor workers (e.g. warehouse workers) and those carrying out a range of physically demanding work.[33, 50, 397, 465, 468]

While much about the 4Ws (what, who, where and when) of the risks of reported occupational injuries in hot weather is known, currently there is a lack of information on the 'why' and 'how' these occur. This is mainly due to the lack of such information in administrative datasets used in previous epidemiological studies. For example, little is known about factors operating at the workplace level (e.g. organisational factors) and/or preventive practices, which are likely to influence the health impacts experienced by workers during hot weather. Better understanding these underlying risk factors will help identify workplace issues requiring prevention action. This information can guide policy and will support the appropriate provision of resources and prevention efforts.

The adverse health effects of heat (i.e. heat-illnesses and injuries) are preventable.[199, 474, 497] Workplace safety standards and guidance materials have promoted a wide variety of control measures for dealing with heat, including education and training, personal protection, administrative controls and engineering controls.[167] However, there is little information about the extent to which different control measures aimed to mitigate exposure to heat are currently practised in Australian workplaces. This information will be key to promoting effective practice interventions to protect workers.

Under the Model Work Health and Safety (WHS) Act, Australian employers are required to consult with their workers in regards to the prevention, identification and abatement of workplace hazards.[172] This consultation is often done through workplace health and safety representatives (HSRs) who are ‘workers elected or selected for the role to represent the health and safety interests of workers within their workplace’.[263] As HSRs operate at the interface between the employers and workers, they play an integral role in maintaining safer workplaces and can offer valuable perspectives on the physical hazards, conditions and work practices, and other risk factors for heat-related injuries that exist at their workplace.[265] Hence, this study examined the perspectives of HSRs on heat-related injuries with the following objectives: (i) investigate the types of heat-related injuries and their associated risk factors in Australian workplaces during hot weather; (ii) describe and assess the prevention measures adopted for outdoor and indoor workers; (iii) examine the existing levels of training, policies and guidelines; and (iv) identify potential barriers to the prevention of heat-related injuries.

9.3.3 Methods

9.3.3.1 Study design, participants, setting and data collection

This study comprised a national cross-sectional online survey targeting Australian occupational HSRs and workers’ representatives on health and safety committees (hereafter referred to as HSRs). Union officials and/or work site supervisors who have health and safety as a part-time responsibility also completed the survey.

The survey was promoted by Safe Work Australia (peak national body for WHS in Australia), jurisdictional WHS authorities, and industry and union contacts via their websites, newsletters and networks. The anonymous survey was open from March

2017 to April 2018 and was hosted on SurveyMonkey™ (www. surveymonkey.com, San Mateo, California, US).

9.3.3.2 Questionnaire design

The online survey (Supplementary file - Appendix B7) was designed to examine HSRs perspectives and experiences of heat-related injuries/incidents; preventive measures; training; policies and guidelines; and barriers and recommendations for prevention. Development of the survey questions was informed by literature reviews[33, 50] and expert knowledge from a team of 12 experienced researchers. A pilot survey was conducted with HSRs (n=19) after which final amendments were made before the online link was activated.

Section 1 of the survey covered demographic information on: gender; age group; years of experience in health and safety (H&S); main industry of employment, current role in H&S; and size, nature and location (state) of their workplace. Further, worker payment and work operation were characterised by asking HSRs whether their organisation had any workers on piece rates (i.e. being paid per output) and if any workers were under production targets that allowed them to leave work once meeting their target.

Section 2 investigated the perceived frequency of heat-related injuries/incidents by asking participants: '*In your workplace, would you say that injuries or incidents caused by (partly at least) hot/very humid weather occur?*' The participants responded using a 4-point Likert-type scale ('Never'/'Rarely'/'Sometimes'/'Often'). This was followed by questions on the types of injuries and incidents or illnesses where heat exposure could have been a (direct or in-direct) contributing factor and their outcomes.

Section 3 collected information regarding preventive measures for heat-related injuries/incidents in the workplace. To examine the frequency of prevention practices for outdoor and indoor workers, participants were asked about how often particular work practices were adopted during hot weather. Response options used a 5-point Likert-type scales (‘Never’/‘Rarely’/’Sometimes’/‘Often’/‘Always’). This was followed by asking participants to identify the most important work practice for preventing heat stress.

Section 4 contained questions regarding heat stress training, including who is trained, the frequency of training and how training is being conducted. Section 5 contained questions on hot weather policies and guidelines in the workplace, and temperature measures used as an indicator of heat risk.

The final section allowed HSRs to nominate barriers faced in establishing preventive measures in their workplace. Responses to an open-ended question *‘Do you have any suggestions for the prevention of heat-related injuries and health issues in Australian workplaces?*’ do not form part of this analysis.

9.3.3.3 Statistical analysis

To describe the overall study population, descriptive analyses of all variables were conducted. The responses to some questions were dichotomised for analysis due to a small number of responses in some categories, as follows: (1) Responses for measures of occupational injuries were dichotomised to ‘sometimes/often’ and ‘never/rarely’; (2) Responses for prevention practices were dichotomised to: ‘often/always’ to indicate a safer work environment, versus all other responses combined (never/rarely/sometimes).

Perceived frequency of injuries in the HSRs workplace (dichotomised as 'sometimes/often' versus 'never/rarely') was the outcome variable for regression analyses. To assess the magnitude or strength of the associations between reported injury experience and contributing factors, we used the log-Poisson regression expressed as PRs with 95% CIs. This approach was favoured over ORs, as our dependent outcome variable had a relatively high prevalence (>20%) and ORs are often misinterpreted as prevalence ratios.[498, 499] All data analysis was conducted in Stata 15 (College Station, TX).

Ethical approval was obtained from the ethics committees of the University of Adelaide, Monash University, The University of Western Australia and Queensland University of Technology.

9.3.4 Results

9.3.4.1 Demographics

A total of 222 HSRs responded to the online survey. Response fractions to questions varied as survey questions were not compulsory. The demographic characteristics of the HSR sample are summarised in Table 9.1. Nearly two-thirds were male (63%), 57% were between 35–54 years, and 50% were from the eastern states of Australia. The majority of HSRs were from industries with mostly indoor activities (66%), medium-sized businesses (45%), part of a larger organisation (62%), and workplaces without piece rates and production targets (79% and 78%, respectively).

Table 9.1 Demographic characteristics of the HSR respondents (n=222).

Sample Characteristics	n (%)
State and territory, Australia	
Eastern (ACT/NSW/Qld/Tas/Vic)	111 (50)
Central (SA/NT)	96 (43)
Western (WA)	15 (7)
Gender*	
Male	140 (63)
Female	78 (35)
Unspecified	3 (1)
Age-group*	
18–34 years	30 (14)
35–54 years	125 (57)
55 years and over	64 (29)
Years of experience in health and safety*	
Less than 5 years	67 (31)
5–10 years	65 (30)
11–20 years	58 (27)
more than 20 years	27 (12)
Industry	
Mostly indoor activities	145 (66)
Mostly outdoor activities	55 (25)
Mixed	20 (9)
Current role in health and safety*	
Health and safety representative	148 (67)
Other (please specify)	39 (18)
Site supervisor	15 (7)
Union official	18 (8)
Number of employees in workplace*	
Up to 20 employees (small size)	48 (22)
21–201 employees (medium size)	100 (45)
More than 201 employees (large size)	69 (31)
Part of a larger organisation*	
Yes	136 (62)
No	69 (31)
Unsure	11 (5)
Piece rate*	
Yes	8 (4)
No	174 (79)
Unsure	29 (13)
Production targets	
Yes	8 (4)
No	172 (78)
Unsure	32 (14)

Note: n% unless otherwise indicated *May not total to 222 due to missing values. Abbreviations: NSW/ACT/Qld/Tas/Vic, New South Wales/Australian Capital Territory/Queensland/Tasmania/Victoria; SA/NT, South Australia/Northern Territory; WA, Western Australia.

9.3.4.2 Heat-related injuries/incidents

Over a third (43%) of the HSRs reported that injuries/incidents occur ‘sometimes’ or ‘often’ due to hot/very humid weather in their workplace. The three most frequently reported types of injuries/incidents were ‘manual handling’ (musculoskeletal injuries) (55%); HRIs (31%), and hand injuries (26%), while ‘fatigue’ (90%), ‘muscle/heat cramps’ (53%), and ‘severe dehydration’ (49%) were the top three reported type of illnesses (Table B14 and B15, Appendix B7), all of which resulted in minor outcomes (i.e. sent home or days off work) (Figure B10, Appendix B7).

Concerning the types of workers who had incurred heat-related injuries and incidents (Figure 9.1A), HSRs most frequently reported ‘workers aged 25–50 years’ (69%), and ‘older workers (aged over 50 years)’ (55%).

Figure 9.1B shows the most commonly reported work factors and hazards that may have contributed to heat-related injuries and incidents as perceived by HSRs. These were ‘working in the sun with no access to shade’ (56%), ‘wearing of PPE leading to higher body temperature’ (52%), and ‘rushed activity’ (46%).

‘Lack of health and safety training specifically on heat stress’ (55%), and ‘inadequate resources and facilities’ (52%) were the most common organisational issues reported by the HSRs (Figure 9.1C). ‘Other’ responses can be broadly summarised as issues around ‘management’ and ‘culture within the organisation’. Those concerning workplace management issues included ‘poor planning and improper allocation of daily work load’; ‘refusal to have a policy’; ‘failure to accommodate extreme heat events’ and ‘company not wanting to spend money’. Regarding ‘culture within the organisation’, some of the issues raised included, ‘culture of just getting the job done', 'emphasis on cost saving and production targets' and 'low OHS culture'.

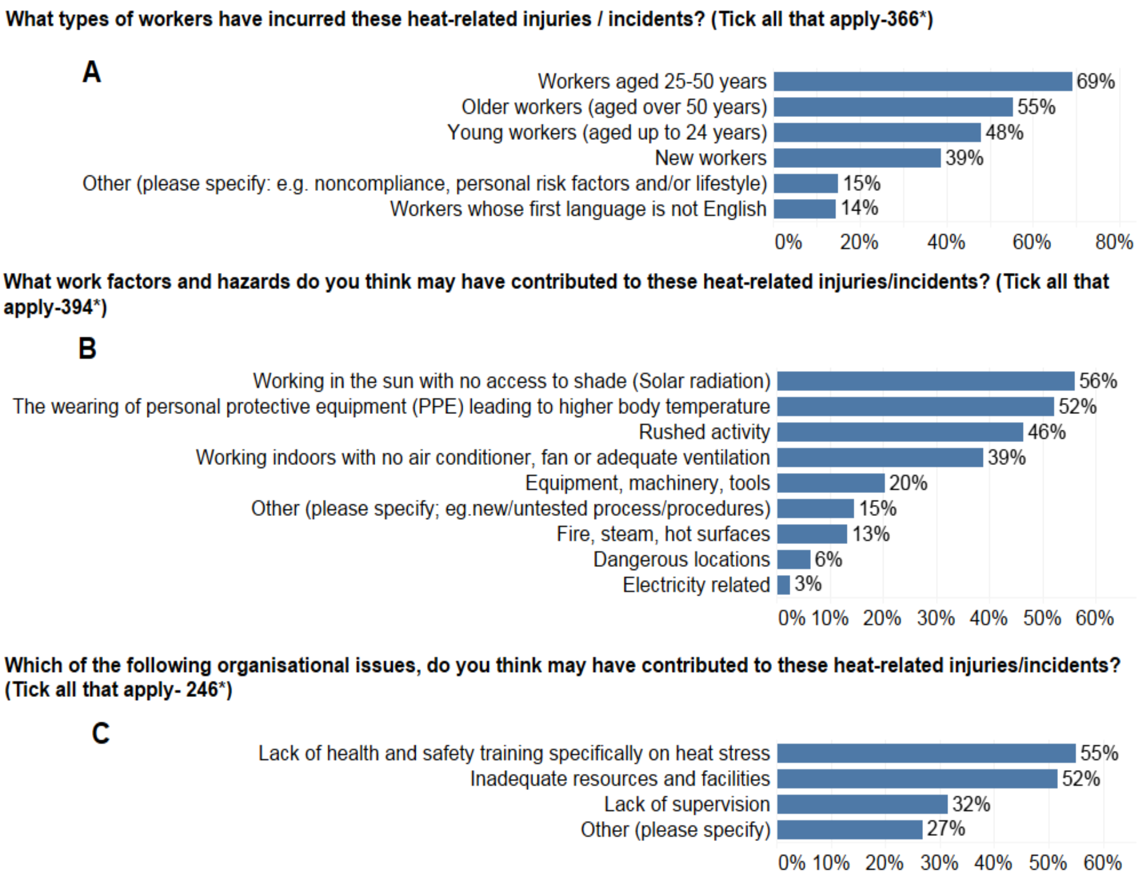

Figure 9.1 Distribution of risk factors that have contributed to heat-related injuries/incidents during hot weather as perceived by HSRs: (A) types of workers; (B) work factors and hazards; (C) organisational issues. * indicates that percentages shown do not add to 100% as multiple responses were allowed.

9.3.4.3 Preventive measures

For outdoor workers the three most common preventive work practices (Figure 9.2A) adopted 'always' during hot weather were 'PPE supplied' (61%), 'sunscreen supplied' (56%), and 'access to cool drinking water' (53%). The least common were 'urine specific gravity testing' and 'use of cool vests' with 68% and 54% of participants indicating they were 'never' adopted. HSRs cited 'outdoor work ceases if temperature is extreme' (23%) and 'access to cool drinking water' (22%) (Figure B11A, Appendix B7) as the most important work practices for preventing heat stress.

About 50% of HSRs (n=87/175) said that there is provision for outdoor work to cease when temperatures are extreme with over a third (i.e. 37/91, 41%) clarifying that the temperature threshold is not based on a specific temperature, but depends on work circumstances (Table B16, Appendix B7).

For indoor workers 'access to cool drinking water' (68%), 'PPE supplied' (54%) and 'adequate ventilation' (42%) were the three most common forms of preventive work practices 'always' adopted, while 'urine specific gravity testing' and 'colour urine charts' were the least commonly adopted (67% and 47% cited 'never', respectively) (Figure 9.2B). When asked about the most important work practice for preventing heat stress in indoor workers, 41% of HSRs cited 'air-conditioning' and 30% 'access to cool drinking water' (Figure B11B, Appendix B7). More than two-thirds (77%) of the participants cited that 'access to air-conditioning or fans' were often available for indoor workers (Table B16, Appendix B7).

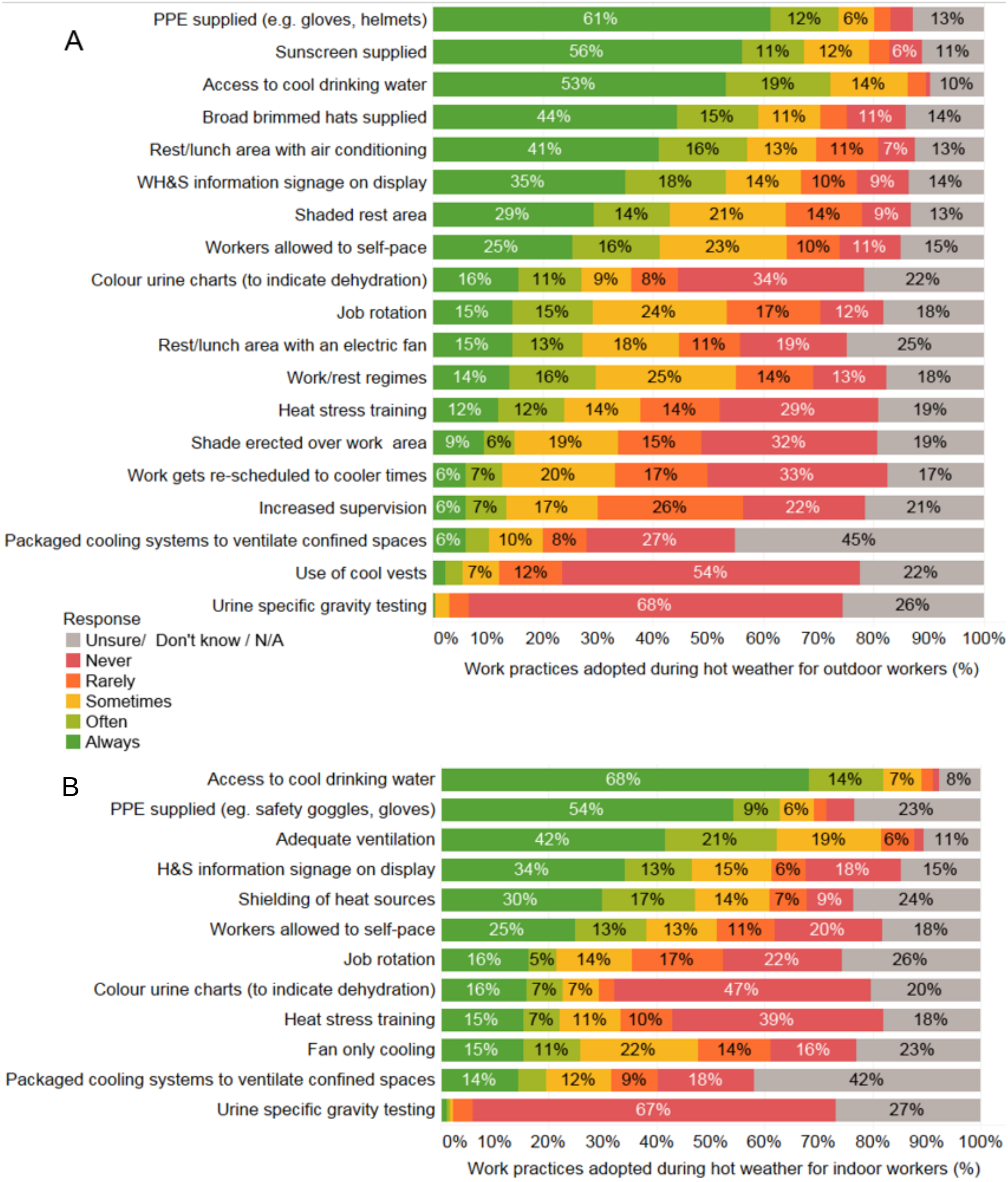

Figure 9.2 Prevention practices adopted for outdoor workers (A) and indoor workers (B) during hot weather.

9.3.4.4 Training

Thirty-five percent of the HSRs said that training to prevent heat-related injuries/incidents in their workplace was available (Table B17, Appendix B7). When asked about the timing of training, 34% of HSRs answered that training was provided ‘annually regardless of job’ followed by 31% claiming it was ‘once only at induction when starting a new job where heat could be a hazard’. Forty percent indicated that HSPs conducted the on-site training, and 40% also indicated this was undertaken by supervisors.

9.3.4.5 Policies and guidelines

More than half of HSRs (58%) stated that a hot weather or heat stress policy existed in their workplace (Table B18, Appendix B7). While 48% of HSRs reported the use of ‘air temperature at weather bureau’ and ‘air temperature on site’ as indicators of heat risk, almost one quarter (24%) were unsure/didn’t know what indicators were being used in their workplace.

9.3.4.6 Barriers

The top three barriers for prevention of heat-related injuries identified by HSRs were: lack of awareness by workers that heat can be associated with ill health and injury (50%), lack of training of workers (31%), and lack of management commitment to protect health and safety (30%) (Table 9.2). Besides these, HSRs also identified the barriers of ‘attitudes to keep working at all costs’ (23%), ‘lack of supervisor awareness’ (23%) and ‘management concerns around productivity loss and/or deadlines’ (23%).

Table 9.2 Barriers for prevention of heat-related injuries as perceived by HSRs ordered by percentage*.

Barriers (n=192)	**n (%)**
Lack of awareness of workers that heat can be associated with ill health and injury	95 (50)
Lack of training of workers	59 (31)
Lack of management commitment to protect health and safety	58 (30)
Attitudes to keep working at all costs	45 (23)
Lack of awareness by supervisors of heat hazards	45 (23)
Management concerns about productivity loss and/or deadlines	45 (23)
Lack of specific heat-related guidelines and regulations	36 (19)
Difficulties in assessing heat risks	29 (15)
Management reluctance to allow workers to slow down or rest as needed	26 (14)
Lack of training of supervisors	24 (13)
Low compliance and implementation of policies	20 (10)
Lack of financial resources	19 (10)
Others	14 (7)

Note: * Percentages shown do not add up to 100% as multiple responses were allowed.

9.3.4.7 Correlates of injury experiences

The log-Poisson regression analysis showing factors associated with injury experiences in hot weather is summarised in Table 9.3. The work factors and hazards associated with higher perceived injury experience were: working in dangerous locations (PR 1.47, 95% CI: 1.04–2.07) and wearing of PPE leading to higher body temperature (PR 1.39, 95% CI: 1.04–1.85). Organisational issues associated with higher reported injury experience were inadequate resources and facilities (PR 1.40, 95% CI: 1.04–1.87). New workers were associated with higher frequency of reported injury experiences (PR 1.34, 95% CI: 1.01–1.76) and HSRs who reported that piece-rate workers existed in their workplace also reported a notably higher frequency of injuries compared with those that did not (PR 1.78, 95% CI: 1.15–2.79, results not shown in table).

Table 9.3 Factors associated with the frequency of injury experience as reported by HSRs.

Injury experience	Never/Rarely	Sometimes/Often	
Work factors and hazards	**n (%)**	**n (%)**	**PR (95% CI)**
Rushed activity	30 (41)	43 (59)	1.10 (0.83–1.45)
The wearing of personal protective equipment (PPE) leading to higher body temperature	29 (35)	53 (65)	1.39 (1.04–1.85) ▲
Working in the sun with no access to shade (solar radiation)	35 (40)	53 (60)	1.19 (0.89–1.58)
Working indoors with no air conditioner, fan or adequate ventilation	25 (41)	36 (59)	1.09 (0.82–1.44)
Equipment, machinery and tools	11 (34)	21 (66)	1.22 (0.91–1.65)
Fire, steam and hot surfaces	7 (33)	14 (67)	1.23 (0.87–1.72)
Dangerous locations	2 (20)	8 (80)	1.47 (1.04–2.07) ▲
Organisational issues	**n (%)**	**n (%)**	**PR (95% CI)**
Lack of health and safety training specifically on heat stress	31 (38)	51 (62)	1.22 (0.91–1.63)
Inadequate resources and facilities	26 (34)	51 (66)	1.40 (1.04–1.87) ▲
Lack of supervision	20 (43)	27 (57)	1.01 (0.74–1.36)
Type of workers	**n (%)**	**n (%)**	**PR (95% CI)**
New workers	20 (34)	39 (66)	1.34 (1.01–1.76) ▲
Younger workers (aged up to 24 years)	32 (44)	41 (56)	1.01 (0.76–1.34)
Workers aged 25–50 years	45 (43)	60 (57)	1.07 (0.78–1.47)
Older workers (aged over 50 years)	32 (38)	52 (62)	1.28 (0.95–1.72)
Workers whose first language is not English	7 (32)	15 (68)	1.27 (0.91–1.76)

Note: Reference for each variable is ‘no’ response to work factors and hazards, organisational issues and type of workers. ▲ indicates statistically significant results based on the 95% CI.

No statistically significant association was seen between the provision for outdoor work to cease when temperatures are extreme, and frequency of injury experiences as reported by HSRs (PR 0.89, 95% CI: 0.64–1.23); or between having a hot weather policy and frequency of injuries (PR 0.69, 95% CI: 0.42–1.23). Access to air-conditioning or fans for indoor workers was associated with reduced frequency of reported injuries (PR 0.58, 95% CI: 0.42–0.81). HSRs reported fewer injuries for outdoor workers in workplaces where preventive work practices such as ‘reschedule of work to cooler times’, ‘shaded rest areas’, ‘shade erected over work area’, ‘self-pacing’ and ‘rest/lunch areas with air-conditioning’ are adopted often or always (Figure 9.3).

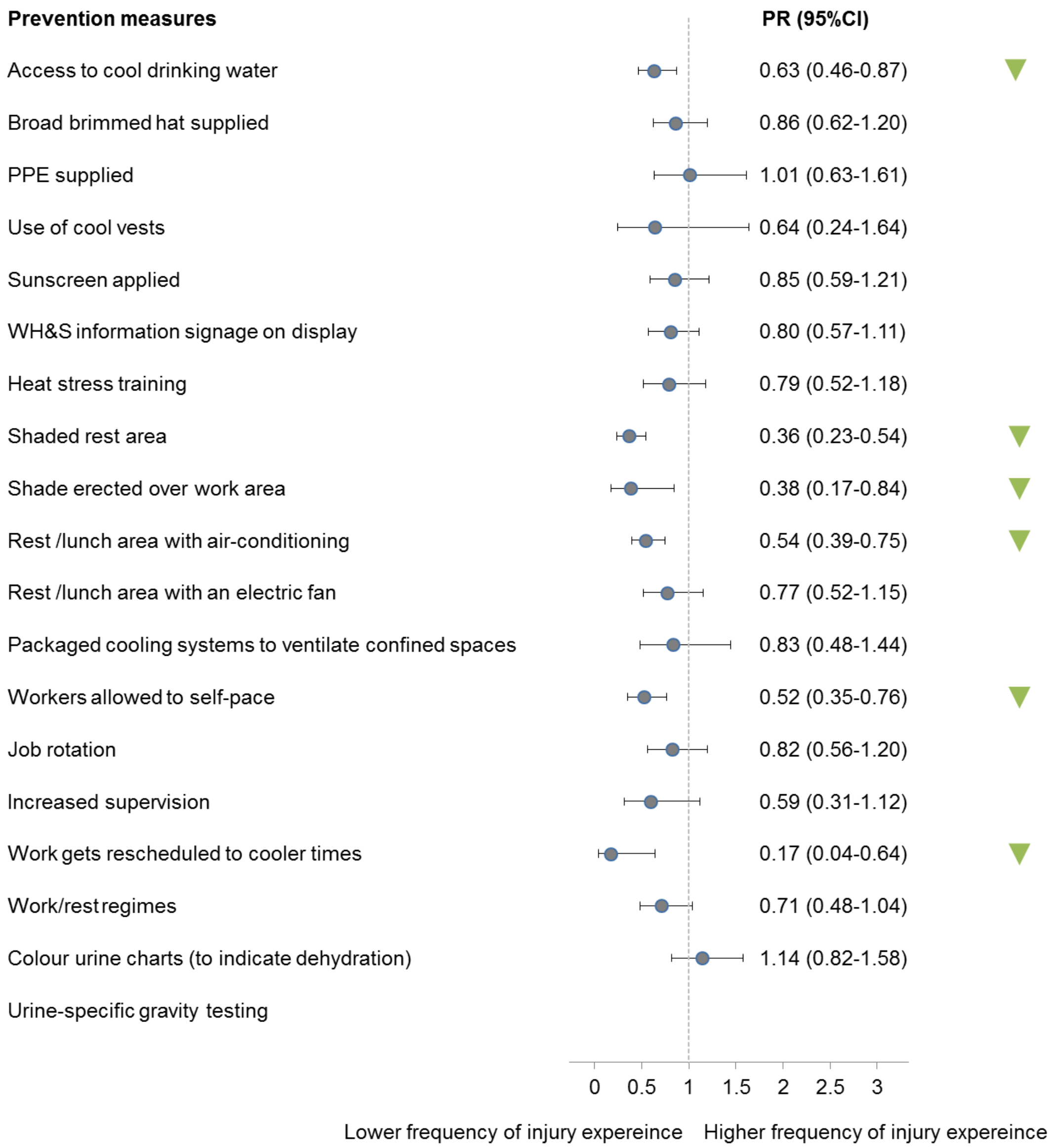

Figure 9.3 Prevalence ratios (PRs) for the frequency of injury experiences (as reported by HSRs) and frequency of prevention measures adopted for indoor workers.

Notes: Reference for each prevention measure is 'never/rarely/sometimes' and frequency of injury experience (never/rarely versus sometimes/often). ▼ shows statistically significant PR based on the 95% CI.

For indoor workers 'self-pacing', 'shielding of heat sources'; and 'adequate ventilation' often or always adopted, were significantly associated with fewer injuries (Figure 9.4).

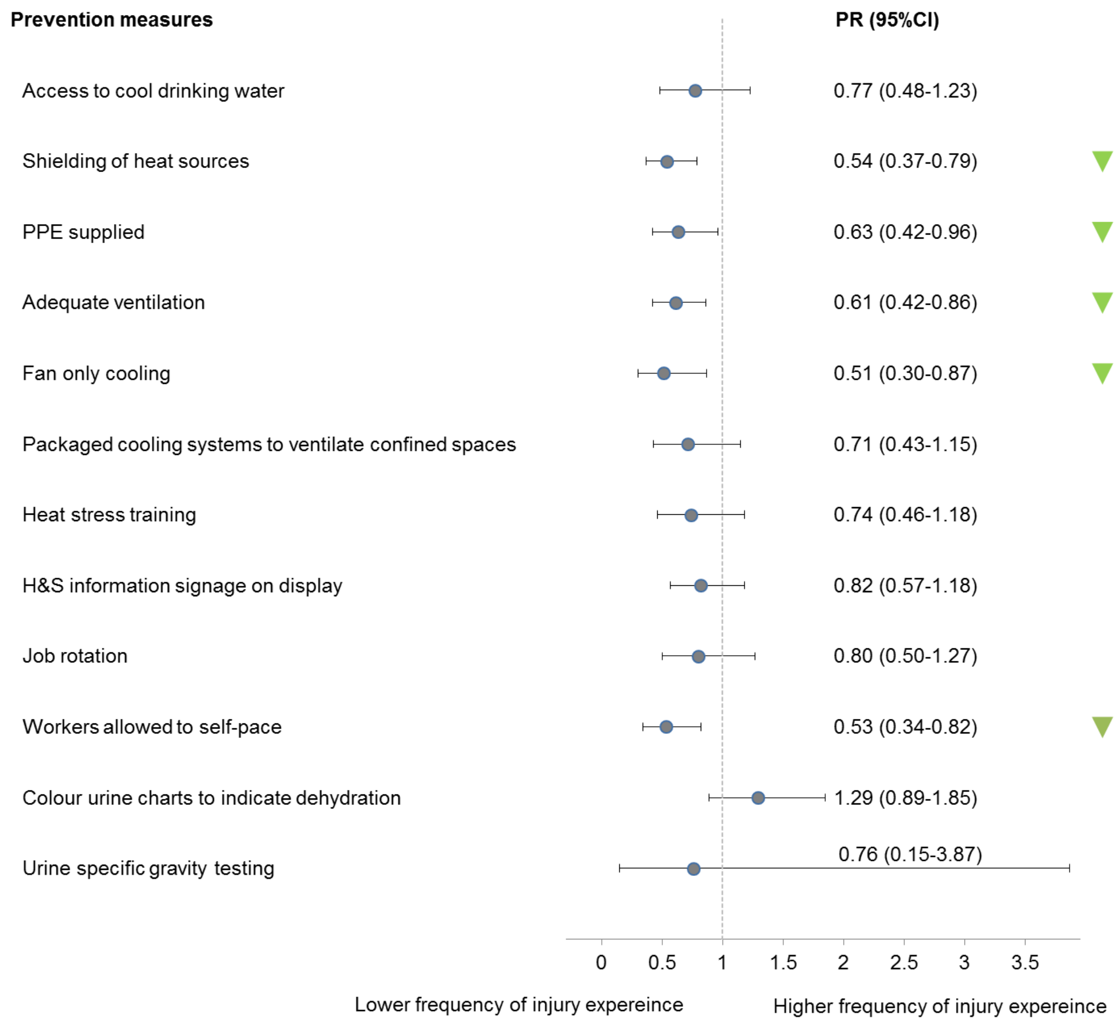

Figure 9.4 Prevalence ratios (PRs) for the frequency of injury experiences (as reported by HSRs) and frequency of prevention measures adopted for indoor workers.

Note: Reference for each prevention measure is 'never/rarely/sometimes' and frequency of injury experience (never/rarely versus sometimes/often). ▼ shows statistically significant PR based on the 95% CI.

9.3.5 Discussion

Our results reveal the hazards of working in hot weather as perceived by HSRs and identify the most common challenges faced by Australian workplaces in regard to dealing with heat-related work injuries. To the best of our knowledge, no previous research has examined the factors underlying injury experiences in hot weather from the perspective of HSRs who are a vital link between employers and employees. Notwithstanding the cross-sectional nature of the data, the breadth and depth of information provided by HSRs sheds light on the importance of the work and the work environment and their effects on workers' health and safety in hot weather.

The key findings from the survey are: (i) 43% of surveyed HSRs recognise the contributory role of hot weather in injury occurrence in their workplace; (ii) the frequency of heat-related injuries and incidents was higher in workplaces with inadequate resources and facilities; and new workers, workers on piece rates and workers wearing PPE were most at risk; (iii) the prevention measures associated with reduced frequency of injuries include a combination of administrative controls (e.g. rescheduling of work to cooler times and self-pacing) and engineering controls (e.g. provision of shielding of heat sources and adequate ventilation); (iv) 58% of HSRs reported a hot weather or heat stress policy in their workplace but only 35% reported heat-stress training was available; and (v) potential barriers for the prevention of heat-related injuries related to lack of awareness and training of workers, and management's lack of commitment to protect workers' health and safety.

The survey indicates that HSR accounts of heat-related injuries/incidents caused by hot or very humid weather may be more prevalent than those reflected in official statistics of WC claims. This finding is of concern as it indicates that heat exposure in the workplace is not a trivial issue and can be overlooked by official statistics on occupational heat-related injuries and HRIs.[32] A similar survey we conducted amongst workplace health and safety professionals (HSPs) (unpublished) together with surveys of occupational hygienists,[199] and workers[140] have also indicated a high prevalence of heat illness or injury in different work settings.

Our analysis suggests that the underlying mechanism of occupational heat-related injuries is multi-factorial, consisting of modifiable factors (organisational and work-related).[50] Although there are no prescribed maximum and minimum temperatures under regulations at which work cease, the WHS legislation legally mandates a 'duty of care' responsibility for employers and managers to protect the health and safety of their workers by ensuring a safe thermal work environment 'as far as reasonably practicable'.[172] This includes identifying and controlling workplace risks, and providing training and supervision. Despite these legal obligations, only 35% of HSRs cited the availability of heat stress training in their workplace. This lack of heat stress training was cited both as a top organisational issue and as the second top barrier for prevention. While WHS training is mandatory, heat stress training is not and this is related to the fact that there are no WHS legislations pertaining to work in hot weather across Australia.[171] Similar Australian studies have shown 43% of workers and 42% of HSPs reported having heat stress training in their workplace and workplaces they visit or manage.[140] Awareness of the work environment and safety issues plays an important part in the prevention of workplace injuries and illnesses. However, lack of awareness of workers about heat risks, which is also linked with the lack or lower frequency of training available in workplaces, was cited as the top barrier for prevention by respondents. While heat stress training was reportedly provided annually in some workplaces, the scope, depth and content of the training was not explored in this study. This makes it difficult to assess its effectiveness in reducing injuries. Providing more heat stress training can make workers aware of the potential risks and provide directions to protect them; however, if workers do not feel empowered, then no level of training will help. This means that there is a need for a comprehensive approach for prevention that is top-down from the management to workers.

Inadequate resources and facilities was identified as another organisational factor reported by HSRs and associated with higher frequency of injuries. This is consistent with previous studies in the US.[464, 500] The lack of resources and health and safety information is an inherent issue for small businesses that can have limited capacity and tighter financial constraints.[501, 502] Also, the lack of management's commitment to protect workers' health and safety poses challenges for effective prevention of injuries. The lack of resources and health and safety information was identified as the third top barrier by HSRs, along with attitudes to keep working at all costs, lack of awareness by supervisors, and management concerns around productivity loss and/or deadlines. All of these issues have also been identified previously[464, 500] and are influential factors in the safety climate of workplaces.

The commonly cited work factors and hazards associated with heat-related injuries and incidents as reported by HSRs were lack of shade, rushed activity, wearing of PPE and working in dangerous locations (e.g. confined spaces). The latter two factors showed an association with an increased reported frequency of injuries and are recognised in the literature as being risk factors for heat-related health impacts.[33, 50, 120, 474] While PPE (e.g. gloves, protective workwear and safety glasses) represents a control measure to reduce workers' exposure to hazards, it can be a competing workplace hazard as it can increase workers' thermal load and act as a barrier for heat loss and evaporative cooling, particularly during very hot days.[474, 482] Therefore, choosing the right PPE for the right work and work environment is crucial.[483]

Workers aged 25–50 years and older workers (>50 years) were cited as groups that were most affected by heat, while ‘new workers’ were found to be associated with an increased reported frequency of injury experiences. Although older workers may be physically more susceptible to injuries, new workers have also been shown to be at higher risk of heat-related occupational injuries and illnesses.[211, 421, 423] Possible reasons include inexperience, inadequate training, and supervision, lack of awareness of rights and responsibilities, and greater exposure to more hazardous jobs.[503, 504] Also, it is likely that new workers feel that they have limited control over their work environments and are likely to prioritise work over safety.[504] This finding highlights the need for workplaces to focus on health and safety awareness in new workers as a priority.

Consistent with the literature,[120, 164, 505] we found that HSRs who reported workers being on piece-rates also reported a higher prevalence of heat-related injuries. Workers who get a pay rate for their output (e.g. number of items made, picked or packed) may tend to ignore the body’s signals to slow down their activity in the heat in order to earn more wages.[135] Piece-rates can therefore be a disincentive to taking breaks to rest and hydrate.[120] This is often found among horticultural workers (e.g. fruit picking) or among textile workers (e.g. garment) where employers rely on piece-rates as mode of compensation to boost productivity.[505]

Regarding the types of injuries experienced by workers during the heat, ‘manual handling’, ‘hand injuries’ and ‘burns’ were the most frequently reported injuries, while ‘fatigue’, ‘muscle/heat cramps’ and ‘severe dehydration’ were the most frequently reported symptoms of HRIs. The similarities in the types of injuries seen by HSRs and those reported previously in ecological studies using workers' compensation claims data[145, 422] confirms that heat exposure in the workplace is a broad occupational health problem.

The core message of the heat illness prevention campaign run by the Occupational Safety and Health Administration (OSHA) in the US was 'water, rest and shade'.[506] Consistent with this message is the guidance provided by the state and territory regulators in Australia; however, there is no legally binding or any active surveillance to ensure the compliance of these practices in workplaces.[171] The control of risks and hazards in the workplace to prevent WRIs is guided by the hierarchy of controls which is mandated by OHS legislation in Australia.[507] The findings from the present study show that most workplaces are not reliant on higher order controls (i.e. elimination/substitution of the hazard, e.g. better designed buildings), as the most often/always adopted prevention measures for indoor workers was access to cool drinking water (82%), adequate ventilation which is an engineering control and PPE (63% each); while for outdoor workers it was PPE (73%), access to cool drinking water (72%) and sunscreen (67%). The adoption of these control measures in workplaces is encouraging, but there is still room for improvement as these measures (except for ventilation) are all lower-order controls. We found that the frequency of injury experiences were lower for outdoor workers in workplaces with shaded rest areas, shade over work areas and rest/lunch areas with air-conditioning and where work was rescheduled to cooler times of the day. It has been shown access to regular breaks and breaks in shaded areas reduces the odds of HRI.[220] On the other hand, provision of fans, shielding of heat sources, adequate ventilation and air-conditioning reduced the frequency of injury experiences for indoor workers.

While reductions in injury experience is expected with adoption of these higher order controls, it is important to acknowledge that these may not be practical and economical, especially in small- and medium-sized enterprises. Additionally, measures like self-pacing were associated with reduced frequency of injury experience for both indoor and outdoor workers. Indeed, self-pacing has been found to be a protective behaviour in reducing the risk of heat stress for those working in hot weather provided that they are well-hydrated and acclimatised.[493, 508] What this means is that the combination of control measures is likely to be more effective than using a single control measure.

Having a temperature-cut off for stopping work, especially outdoor work, is an ongoing debate between employers, workers, experts and regulators, as to date, there is no legislation which specifies maximum temperatures to which workers can be exposed.[171] Certainly in this study HSRs reported that the ceasing of outdoor work and the provision of air-conditioning was most important for outdoor and indoor workers, respectively. In this study, more than half (58%) of HSRs reported the existence of a hot weather or heat stress policy in their workplace; and the provision for outdoor work to cease when temperatures are extreme was cited by half of the HSRs (50%). Further investigation is needed to examine the contents of the policies in place to evaluate their effectiveness. It is also possible that having specific heat-related guidelines and regulations which, if enforced, may encourage employers to be more proactive in fulfilling their responsibilities, as a lack of such guidelines and regulations were cited as one of the top five barriers for prevention by HSRs. While we do not argue for a (sometimes impractical) temperature threshold at which work must stop, it is recommended that there be consideration of solutions to issues that are placing workers at risk of injury in hot working conditions. We would suggest that more training and awareness of workers is needed and that this should be in conjunction with other forms of control.

This study has several limitations that should be taken into account while interpreting the results. While participants were from a broad range of areas, the generalisability of the study findings is limited due to the potential non-representativeness of the participants. It is also likely that HSRs who were interested in the topic may have been more likely to participate in the survey, resulting in selection bias. Another limitation is the cross-sectional design of the study and the self-reporting of HSRs view on injury experiences and preventive measures which may not reflect the true situation. Finally, because of the relatively small sample size, we could not compare responses by states and across different industries.

Despite these caveats, the present study provides an improved understanding of the factors that may contribute to the risk of heat-related occupational injuries and the current prevention measures adopted in Australian workplaces. The targeting of HSRs is a strength of the study, because this group can provide a reflection of their own current workplace experiences and practices. The comprehensive nature of the survey data is also a major strength of this study, and the findings complement the findings of previous epidemiological studies using alternative data sources.

9.3.6 Conclusion

This study advances the current knowledge of how occupational heat exposure may lead to increased risk of injuries by considering the perspectives of HSRs who provide a vital link between employers and workers. The study offers a window into issues that workers face during hot weather that potentially places them at increased risk of occupational injuries. The findings identify several factors operating at the work, organisational and individual level that contribute to the risk of injuries in hot weather, and addressing these factors will be essential for maintaining safe workplaces and keeping workers safe during the heat.

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*****End of manuscript*****

9.4 CHAPTER SYNOPSIS

Chapter 9 presented the findings of a national survey of HSRs on heat and WRI, their determinants, prevention, and management. The findings suggest that organisational issues, as well as workplace hazards, personal factors, and preventive measures are all major determinants of heat-related injuries in Australian workplaces. The results suggest that the burden of heat-related WRI could be reduced by wider adoption of prevention measures such as work rescheduling, self-pacing, provision of shade, and adequate ventilation. The following section is the discussion of the key findings and conclusion of this research.

Summary of Section D

Section D focussed on better understanding the circumstances underpinning the occurrence of WRI in hot weather from the workplace level. This was obtained from surveying two groups of key stakeholders, HSPs and HSRs, who are at the forefront of WHS in workplaces. The next section will bring together the multiple lines of evidence obtained from the research presented from Sections B to D.

SECTION E: USING THE EVIDENCE

What we think, or what we know, or what we
believe is, in the end, of little consequence.
The only consequence is what we do.

John Ruskin (1819–1900)

Overview of Section E

This final section of the thesis consists of two chapters which bring together the findings from Sections B to D. Chapter 10 contains a full discussion, interpretation and evaluation of the research findings with reference to the existing evidence base and literature. Chapter 11 concludes the thesis and reports on evidence-based recommendations drawn from the key research findings to improve and better safeguard workers' health and safety.

10

Chapter 10: Discussion

10.1 PREFACE

This chapter brings together the evidence obtained throughout this PhD research. Section 10.2 provides an overview and recap of the research background, along with the objectives set out in this research. Section 10.3 covers the key findings and an overview of the key discussion points in five sub-sections (10.3.1–10.3.5). The overall significance of the research is described in Section 10.4, followed by issues related to the findings in Section 10.5. The overall strengths and limitations of the work undertaken and the challenges faced are presented in Sections 10.6 through to 10.8. The key implications from this research are summarised in Section 10.9; and Section 10.10 concludes this chapter with suggestions for future research, followed by the chapter synopsis in Section 10.11.

10.2 OVERVIEW OF THE RESEARCH

This research has examined the impacts that environmental heat exposure has on workers' health and safety, assessed mainly in terms of WRI. The overall research aimed to better characterise the association between heat and WRI, thereby contributing to new evidence in order to inform national injury prevention policy and guidance in Australia in the context of a warming climate.

This research has been scoped around four objectives (as mentioned in Chapter 1) and shown in Table 10.1.

Table 10.1 Summary of research objectives and the chapters in which they are addressed.

Research objectives	Chapters
1. To examine the effect of ambient temperatures and risk of WRI recorded in WC data from four Australian capital cities with diverse climates.	4–5
2. To assess to what extent heatwaves of varying severity affect the risk of WRI recorded in WC data from four Australian capital cities.	6–7
3. To identify workers at-risk during high temperatures and heatwaves.	4–7
4. To better understand the nature of heat-related injuries in Australian workplaces, the potential risk factors, and prevention measures being employed to reduce the effects of heat stress; and to characterise the potential barriers faced in workplaces for injury prevention.	8–9

As discussed in Chapter 3, the first three objectives relate to answering the 4Ws in the epidemiology of WRI associated with hot weather (What, Who, Where and When), and the last objective mainly addresses the 'Why' and 'How' these injuries occur in workplaces, and the solutions for prevention. Four studies were conducted to address Objectives 1–3 and two studies were conducted to address Objective 4. Although each of these studies have their own research questions, they are all interconnected by common themes that overall lead to a better understanding of the heat-work injury phenomenon.

Two data sources were utilised in order to obtain a more comprehensive understanding of the issue under investigation. These were the WC claims data, and the surveys data, the latter of which complemented the former by uncovering the stakeholder perceptions of the determinants of heat-related injuries, their prevention and management. While previous research has generally considered the heat-WRI relationship, this is the first time that many facets of the issue of WRI associated with hot working conditions has being systematically assessed at a national level in Australia. This has been made possible through the use of multiple lines of evidence and flexible, complex and modern quantitative approaches.

The relationship between heat exposure and WRI was examined using two BOM exposure metrics: T_{max} and EHF-defined heatwaves. The former metric is a standard way of examining the impact, while the latter is a new way of classifying the varying severity of heatwaves.

While assessing WRI from high temperatures and heatwaves was the major aim of this thesis, analysis using T_{max} throughout the year also generated evidence for cold temperatures, the impact of which has not been previously explored in Australia. Although this additional aspect was discussed within Chapters 4 and 5, to keep with the overall aims and objectives of this thesis, the results for hot temperatures and heatwaves will be the main focus of this Discussion section.

10.3 KEY FINDINGS OF THE RESEARCH

The key findings from the overall research are summarised in Table 10.2 and discussed further in Sections 10.3.1–10.3.5.

At a higher level, the key findings may be broadly interpreted as follows;

1. Working in heat is a clear and significant health and safety hazard for workers as shown by an increase in WRI claims (Chapters 4 to 7) and in surveys of health and safety professionals and health and safety representatives (Chapters 8 and 9).

2. The relationships between heat and WRI are complex, and depend not only on the temperature (Chapters 4 and 5), but also on the location (Chapter 5), whether a heatwave is occurring (Chapters 6 and 7), the characteristics of the work (Chapters 4-9), policies and practices in the workplace (Chapters 6-9), and characteristics of the workers themselves (Chapters 4-9).

3. The novel statistical methods used in this research (Chapters 4-7) produced robust results which agree broadly with previous literature (Chapter 2) and with the findings of the surveys (Chapters 8 and 9).

Table 10.2 Summary of key findings, corresponding data sources and relevant chapters.

Key findings	Data sources	Chapters
1) Both hot and cold temperatures are associated with increased risk of WRI in Adelaide, and the increase in WRI is apparent at moderately and extremely hot temperatures.	WC	4
2) Extremely hot temperatures were associated with greatest risks, but a relatively small absolute burden of WRI. Most injuries are attributable to moderately hot temperatures.	WC	4
3) The relationships between ambient temperatures and WRI vary by location and climate; however generally, higher maximum temperatures are likely to be associated with an increase in WRI.	WC	5
4) The impact of heatwaves (as measured by EHF) on WRI is consistent across the study sites with an increased risk of WRI during moderate/high-severity heatwaves as compared to non-heatwaves.	WC	6–7
5) Working in heat is a clear and significant health and safety hazard for workers, as acknowledged by stakeholders.	Surveys	8–9
6) Fatigue and dehydration are perceived possible pre-cursors to WRI in hot weather.	Surveys	8–9
7) The use/non-use of PPE is a perceived contributory factor to heat-related injuries	Surveys	8–9
8) Lack of awareness and heat stress training often exists among workers and there can be a perceived lack of effective safety leadership in some workplaces.	Surveys	8–9
9) Many workplaces are reliant on administrative controls and some of these measures have the perceived potential to reduce WRI in hot weather.	Surveys	8–9
10) Workers at higher risk of heat-related injuries include males, young workers, non-English speaking workers, labour-hire workers, new workers, and those in outdoor and some indoor industrial sectors, or in medium and heavy strength occupations.	WC Surveys	4–9

The following section presents the above key findings which are discussed in the following order. Key findings (1)–(4) from the analysis of the WC claims data are discussed in Sections 10.3.1–10.3.3, followed by key findings (5)–(9) from the surveys of HSPs and HSRs in Section 10.3.4. Key finding (10) is an integration of findings from the two main data sources and is discussed in Section 10.3.5.

10.3.1 Relationship between ambient temperature and work-related injury claims

Two studies[422, 469] (Chapters 4 and 5) were conducted to investigate the effects of temperature exposure on the occurrence of WRI in four Australian capital cities namely; Adelaide, Melbourne, Brisbane and Perth. The results have been discussed in detail in Chapters 4 and 5 and the three key points related to findings (1)–(3) stated above, are discussed below.

The first key finding is that both hot and cold temperatures were associated with increased risk of WRI in Adelaide and that injuries increase both at moderately and extremely hot temperatures. In Adelaide, a city with temperate climate, a non-linear relationship or J-shaped curve was observed between WRI and daily T_{max} with the risk of WRI increasing above and below an optimum temperature of 25 °C. In comparison to 25 °C, moderately hot (90th percentile, i.e. 33 °C) and extremely hot (99th percentile, i.e. 40 °C) temperatures were associated with an 8% and 30% increase in overall claims, respectively, while moderately cold (10th percentile) and extremely cold (1st percentile) temperatures were associated with an 8% and 10% increase in WRI, respectively.

The second key finding is that most of the temperature-attributable injuries can be attributed to moderately hot temperatures (1.5%), whereas the contribution of extremely hot temperatures, which were associated with the greatest risks, was relatively small (0.6%). The higher attributable burden on moderately hot days reflects the greater number of such days as compared to extremely hot days that occur rarely. Almost 5% of total WRI were attributable to ambient temperatures (hot or cold) and notably, moderate temperatures accounted for a substantial higher fraction of injuries than extreme temperatures (4% versus 1%, respectively).

The third key finding is that the relationships between temperature and WRI vary by location and climate across the study cities. There is clear evidence of an effect of hot temperatures on WRI in Adelaide and Melbourne where increases were seen at both moderately and extremely hot temperatures, while in Perth this effect was limited to traumatic injuries. In the case of Brisbane, cooler temperatures reduced the risk, suggesting that temperatures above the mean still pose significant safety risks. Notably, not finding a statistically significant effect does not necessarily mean workers are safe in high temperatures, as population health studies[286, 509] have found negative health effects from extreme heat in Brisbane and Perth using morbidity data.

The exposure-response curves observed in the four cities are generally consistent with recent heat and WRI studies,[132, 183, 185, 187, 189, 190] and also with population health studies[10, 510] where the magnitude of heat-health effects increases at high temperatures. Although earlier WRI studies by Morabito et al.[122], Xiang et al.[45], and Spector et al.[135], showed a reverse-U-shaped curve, these studies did not consider denominator information (number of workers). The observed decrease in WRI at high and low temperatures is likely to reflect interruptions to work, rather than reduced risk. For example, outdoor work may cease at a specific heat threshold, or can be cancelled due to inclement winter conditions. As discussed in Chapter 2, the use of CCO study designs in Studies 1 and 2 (Chapters 4 and 5) overcomes the lack of denominator information and resulted in the familiar non-linear (U-shaped) curves, similar to McInnes et al.[132], Sheng et al.[190], and Calkins et al.[189].

10.3.1.1 Factors that may explain the difference in findings between cities

The differences observed across the four cities warrants further investigation, because it suggests that there are location and population-specific factors that influence the impact of temperature on workers' health. This is in contrast to studies examining temperature and morbidity/mortality risk in Australia, which have reported a similar relationship for Adelaide, Brisbane, Melbourne and Perth.[9, 10, 347, 351, 509, 511-514] The relationships between T_{max} and WRI across the four cities may be influenced by climatic and/or non-climatic factors. The climatic factors include: the number of warm-hot days and warm-hot nights, extreme temperatures observed, levels of humidity, diurnal temperature ranges, and the influences of local geographical phenomena (e.g. sea breezes) in each city. For example, Brisbane has less variation in daily temperatures (Figure K1, Appendix K), many fewer hot and very hot days (Figure 3.4), and higher humidity levels, compared to the other cities. Melbourne is known for having very changeable daily weather (Figure K1, Appendix K). Adelaide has a higher number of very hot days (Figure 3.3 and Figure K2, Appendix K) and generally low humidity. A distinct phenomenon unique to Perth is the 'Fremantle Doctor', a cooling afternoon sea breeze which provides relief by dropping temperatures dramatically.[286] These factors may moderate how temperatures affect workers and contribute to the distinct temperature and WRI relationships observed in each city.

There are several factors unrelated to climate which may also contribute to the observed differences in the WRI-temperature relationship between the study sites.

These may include, for example, differences in: the proportion of outdoor vs indoor workers, legislation, heat policies, acclimatisation,[6, 8] behavioural patterns, use of air-conditioning, and infrastructure (e.g. workplaces with white roofs and green infrastructures) and the demographic characteristics of the workforce. For example, at a broad level, the proportion of workers in outdoor industries based on classifications used by Xiang et al.[45] and used in this thesis, is higher in Perth (19%) and lower in Melbourne (11%).The proportion of 'labourers' is highest in Perth (73%) and lowest in Brisbane (45%), while that of 'machinery operators and drivers' is highest in Melbourne (75%) and lowest in Brisbane (46%).[255]

Additionally, the model of WHS legislations have been adopted in only two out of the four jurisdictions (South Australia and Queensland) examined in this thesis. However, consistency exists in most key areas of the existing OHS laws in Western Australia and Victoria, suggesting that different legislation is unlikely to be the major influential factor for the observed differences. Heat stress policies and recommendations by union bodies exist in some at-risk outdoor industries, but again there are variations between states. For example, as per the Construction, Forestry, Mining and Energy Union (CFMEU) policy, trade workers in unionised work sites can stop work when the temperature reaches 35 °C in Victoria and South Australia, while in Western Australia it is 37.5 °C.[515, 516] However, recently the Queensland branch of CFMEU established a stop-work rule at 35 °C, whereas previously extra breaks were recommended.[517] These differences may influence the impact of heat in relation to WRI.

10.3.2 Relationship between heatwaves and WRI claims

The fourth key finding is the consistent impact of heatwaves on WRI across the four cities. Two studies[421, 423] (Chapters 6 and 7) were conducted to investigate the effects of heatwaves of varying severity on the occurrence of WRI in Adelaide, Brisbane, Melbourne and Perth. Heatwaves were defined using a unique location-specific definition, the EHF, a metric that was recently introduced and is part of the National Heatwave Warning Service.[182] This definition accounting for both short-term adaptation over a period of one month and taking into account a long-term climate reference value, can be readily applied to any location. During moderate/high-severity heatwave days, the risk of WRI increased compared to non-heatwave days in each city, with the highest effect apparent in Brisbane.

10.3.3 Differences between heatwaves and temperature findings

There were some differences between the findings from analysis using T_{max} and that using EHF. This was particularly the case in Brisbane and Perth where a strong effect was only found during heatwaves and not during high temperatures. The exception was traumatic injuries in Perth for which there was a positive association with high temperatures. Firstly, it may be argued that the impacts on health during single days of heat and those during heatwaves (extended periods of high temperatures) can vary due to the intensity and duration of the heat.[518] Further, heatwaves are generally periods of not only higher daytime T_{max} but also higher overnight T_{min}. Hence, the effects can be cumulative and likely to induce fatigue on days with high temperatures if individuals have poor sleep on the previous night.[132, 188] Population health studies have also estimated higher health effects during heatwaves than during single days of heat.[8, 435] These studies have shown that factors such as impaired thermoregulation and dehydration contribute to the increased morbidity and mortality in the general population. The same factors can also apply for workers during episodes of several consecutive days of extreme heat. Varying results using T_{max} and EHF reflect how the heat exposure metric used for analysis can influence findings. Studies have also noted that the associations between heat extremes and health outcomes can vary depending on how extreme heat conditions are defined.[519, 520]

In summary, the relationships between heat and WRI claims appear to be sensitive to the exposure metric used in the analysis and location. It is evident that worker injury experience can be influenced by extreme heat distinct to a climatic region.

10.3.4 Stakeholder perceptions about heat-related injuries

This section below discusses key findings (5)–(9) arising from the surveys of stakeholders (HSPs and HSRs) on the perceived determinants of heat-related injuries. It should be noted that there is scant literature on surveys of HSPs and HSRs as mentioned in Chapter 2, except for a survey of industrial hygienists and mining supervisors.[199, 200]

The <u>fifth key finding</u> is that exposure to hot working conditions is regarded by both HSPs and HSRs as a clear health and safety hazard for workers. Seventy-four percent of the HSPs (who visit many workplaces) reported heat-related injuries/incidents occur in workplaces they visit or manage, compared to 43% of the HSRs (who are generally responsible for one workplace). If heat-related injuries are misclassified in respect to mechanism and nature of injury, WC data may provide an underestimate of the true number of these injuries, as described in Chapter 1. It is possible that the importance placed by stakeholders of the impacts of hot weather on WRI more reliably reflects the extent of the problem than WC data.

The sixth key finding is that there was a perception that fatigue and dehydration represent contributing factors that may act as precursors for WRI in hot weather. Both HSPs and HSRs reported that manual handling (musculoskeletal injuries) or joint/ligament injuries, hand injuries and wounds or lacerations were the most common type of injuries seen, while incidents seen included fatigue, muscle/heat cramps and severe dehydration. This finding from the surveys strengthens and validates the types of heat-related WRI found using WC data (Chapter 4–7). Nonetheless, symptoms of worker fatigue, heat cramps and dehydration are far less likely to be compensable and captured in the WC data. As mentioned in Chapter 1, official statistics from Safe Work Australia reveal that 2% of all compensated claims are for 'heat-related' claims, which captures several different types of illnesses and injuries.[99] HSPs also indicated that heat-related injuries included slips, trips or falls, consistent with the WC data analysis (Chapters 4–7). Also mentioned were injuries arising from not wearing PPE, impaired vision due to fogged safety glasses, and loss of control of tools. These findings correlate with the plausible model of why injuries occur in hot weather presented in Chapter 2 (Figure 2.3).[50]

The seventh key finding is that the reported use/non-use of PPE is a contributory factor to heat-related injuries. The provision of PPE against exposure to hazardous materials presents interesting scenarios in hot weather. For one, it was observed that 'not wearing PPE' was a contributing factor to injury; on the other hand, wearing of PPE was also an issue. Workers may feel thermal discomfort in the heat and may choose not to wear PPE and therefore be at risk of injuries from exposure to hazardous materials and chemicals.[521] If the PPE is not well designed to suit the work and work conditions, the risk of heat stress increases, due to the insulated microclimate formed above the skin, impeding evaporation.[474, 482]

The eighth key finding is that there is a perceived under-appreciation of heat risks by workers and supervisors, and a lack of effective safety leadership in some workplaces. When asked about the barriers to prevention, both HSPs and HSRs thought lack of awareness of workers that heat can be associated with ill health and injury is a top barrier. HSPs also thought that management concerns about productivity loss/and or deadlines was another barrier; and HSRs thought management often lacked commitment to protect health and safety. These findings are consistent with those of Xiang et al.[199]

The ninth key finding is that many workplaces are reliant on administrative controls and that some of these measures have the potential to reduce WRI in hot weather. Both groups of respondents indicated that 'access to cool drinking water' and PPE was the most frequently adopted prevention measure for outdoor workers, while for indoor workers, it was access to cool drinking water, adequate ventilation, and PPE. From these findings, it is clear that workplaces are routinely adopting administrative controls and personal protection measures, and some of these measures, including frequent breaks and self-pacing, have the potential to reduce the risk of heat-related injuries as evidenced by the findings in Chapters 8 and 9. Whereas higher-order controls such as rescheduling work are generally most efficient and preferable in reducing the hazard, it may not be practical or possible to implement such measures in every workplace.[167] In order to operationalise higher-order controls, the circumstances of each workplace needs to be understood. Workplaces need to at least provide appropriate access to water, breaks, and shade.

In summary, the perceptions of key stakeholders have identified specific issues associated with heat exposure in the workplace which complements and explains the epidemiological findings from the WC data. These findings are in general similar to those of Xiang et al.[199] who investigated industrial hygienists' perceptions on workplace heat exposure.

10.3.5 Vulnerable groups

Based on dual lines of evidence, the final key finding is that workers at higher risk of heat-related injuries include males, young workers, non-English speaking workers, labour-hire workers, new workers, and those in outdoor and some indoor industrial sectors, or in medium and heavy strength occupations. Evidence from the analysis of WC data indicates vulnerability in most of these groups, while evidence from surveys points to young workers, new workers and non-English speaking workers as being at-risk of heat-related injuries. This addresses objective (3), i.e. to identify worker subpopulations at greatest risk in hot weather. According to Safe Work Australia,[522] vulnerable workers are those who have a higher risk of general injuries or incidents in the workplace and they include: young workers, apprentice/trainee workers, migrant workers, workers in insecure jobs, labour hire workers, and culturally and linguistically diverse workers. Findings from Chapters 4 through 9 largely concur with this but showed that subgroups vulnerable to heat-related injuries vary according to worker subgroup, nature of work and work environment characteristics as discussed further in Sections 10.3.5.1 and 10.3.5.2.

10.3.5.1 Vulnerability by worker characteristics

Workers' demographic and work characteristics were examined as possible determinants for injuries in hot working conditions. These characteristics included gender, age, native language and experience.

Worker-specific analyses in Chapters 4, 6 and 7, revealed that male workers were at higher risk of heat-related injuries both at moderate and extreme hot temperatures and during heatwaves. This is consistent with findings from previous studies.[45, 127, 145] Male workers are known to be highly represented in temperature-sensitive industries, such as 'outdoor industries' where their risk profile comes from the combined effect of the heat exposure and the strenuous nature of the work undertaken. To a lesser extent, female workers were also found to be at risk in the heat (Chapters 4, 5, and 7), in contrast to most previous studies which have only identified male workers to be at risk.[45, 127, 145, 190] This result is possibly due to the high proportion of female workers in 'indoor industries' which was also consistently identified as an at-risk group (discussed in 10.3.4.2).

Consistent with the literature,[127, 132, 185, 189] young workers (<25 years) were found to be at higher-risk of WRI during moderate and extreme hot temperatures and heatwaves, and were also mentioned as a vulnerable group in the HSP survey. The reasons for increased risk in young workers have been discussed previously in Chapters 4 and 7, including limited or lack of training, competency in the assigned tasks, awareness of WHS risks, and heat exposure risks.[523] Additionally, inadequate supervision can be an issue for young workers as raised by HSPs (Chapter 8). Middle-aged (35-54 years) and older workers (>55 years) were also found to be at risk in the heat as noted in Chapter 4. Except for the studies by McInnes et al.[188]

and Calkins et al.[189] this finding is not common in the literature. However, other studies have reported greater heat intolerance and heat strain influenced by reduced fitness levels in those over 45 years of age.[524-526] Further, it is likely that a higher prevalence of pre-existing health conditions and underlying chronic morbidities may also explain higher risks among middle-aged and older workers.

Non-English speaking workers were suggested to be at higher risk of heat-related injuries by HSPs (as shown in Chapter 8). This finding needs to be interpreted with caution as it was raised in only one of the two self-reported surveys. Nevertheless, some of the likely risk factors for these workers include language barriers, cultural differences including reluctance to speak up, limited understanding of safe work practices, inexperience in the assigned task and/or individual workplace, and possibly limited acclimatisation.[527, 528] The same can also be said about labour-hire workers who were found to be at higher risks during heatwaves in Brisbane, Melbourne, and Perth (as shown in Chapter 7). This finding of higher WRI risks for labour-hire workers during hot weather has not previously been reported. An inquiry into labour hire workers in Victoria has revealed that OHS standards are lower in the labour hire sector as these workers often work in dangerous working environments, without being provided with adequate PPE, supervision, inductions or job-specific training.[460] Some of these factors have indeed been identified in the HSPs and HSRs surveys as part of this thesis (Chapters 8 and 9) and other studies (Hansen et al., unpublished).

New workers or apprentice/trainees were found to be at-risk of WRI during hot weather in the studies using WC data (Chapters 6 and 7) and identified in the HSP and HSR surveys (Chapters 8 and 9). Inexperience is a known risk factor for WRI[504] and lack of acclimatisation to heat in the work environment and job exertion requirements may place these workers at higher risk of WRI.[189] However, experienced workers or workers who were not an apprentice or trainee were also found to be at risk in the heat in Chapters 4 and 5. The information on workers' level of experience was reliant upon variables available in the different WC datasets. In the Tabulator dataset used in Chapters 4 and 6 the variable 'new workers' was used to indicate experience, while in the NDS3 dataset (Chapters 5 and 7) it was the 'apprentice/trainee' variable. As mentioned in Chapter 4, 'new workers' were those operationally defined as having less than a year of experience at the time of injury and those not meeting this definition were considered as 'experienced workers'. While these operationally used definitions do not describe the actual experience of the worker that influences their skills, responsibilities or tasks acquired over a longer period of time, it does reflect to a certain extent the familiarity of the worker with the tasks performed, work procedures, and to the work environment. While the variables used to indicate experience differed, a common characteristic is that experienced workers were generally not in the 15–24 age group. The category of 'new workers' in the 'Tabulator dataset' mostly applied to those from the 'manufacturing industry' while 'apprentice/trainees' were more often in the 'construction industry'. Both of these industries were indeed identified to be at-risk industries. The vulnerabilities associated with certain work conditions therefore seems to be an important factor, along with factors that deem a worker to be vulnerable (i.e. being a young worker or new worker).

10.3.5.2 Vulnerability by work and work environment characteristics

Factors that relate to work characteristics examined included: occupation, industry, physical demands of the work, potential workplace temperature exposures, and work factors and hazards. Factors that relate to work environment examined included: organisational size, worksite location, and organisational issues.

Increased risks of WRI were found in both outdoor and some indoor industrial sectors, with the pattern being more consistent for certain outdoor industrial sectors. This is in line with previous evidence but contrasts with that of Xiang et al.[45] who only found effects in outdoor industries. While the research in this thesis deals with outdoor ambient heat, in some indoor industrial sectors workers are exposed to process-generated heat (e.g. smelters, textile mills, and kitchens) and it is likely that outdoor heat adds to the heat stress problems in these workplaces.[461]

As discussed in Chapter 2, there are drawbacks in categorising of workers' heat exposure as outdoors or indoors using industry, as it does not consider the heterogeneity of exposures within industries. However, when using classifications by occupation, the findings reveal that workers working in 'regulated indoor climates' and 'in a vehicle or cab' are particularly at-risk during high temperatures and heatwaves. This is an unexpected finding and warrants closer investigation to determine which activities may be placing these workers at risk. Some examination of the conditions in regulated indoor climates is also justified because they may be highly variable. Further, according to the model code of practice for managing the work environment and facilities, the recommended zone of thermal comfort for sedentary work in indoor environments is usually between 20 °C and 26 °C with heightened risk to workers' health as thermal conditions move outside this range.[462] Fatigue, loss of concentration and reduced productivity are the known impacts of thermal discomfort which can lead to WRI and incidents.[167] Thus, increasing outdoor temperatures may indeed augment the health risks that workers in hot indoor environments already face in the absence of cooling systems or insufficient ventilation.

Another determinant of the heat risk for workers is the nature of work undertaken. The findings for different physical workloads (demands of the work) show that workers carrying out medium (somewhat physically demanding) and heavy strength (very physically demanding) work are at higher risk. This is an important finding as it indicates that doing outdoor work alone is not the main risk factor for WRI on hot days.[132, 529] This is because not all occupations categorised as medium or heavy demanding work are predominantly outdoors. Examples include heavy vehicle drivers, warehouse workers, health and personal workers, carpenters, cleaners, and machine operators. That workers in medium-demanding occupations are at risk is consistent with Adam–Poupart et al.[127] and Martinez-Solanas et al.[185] who reported heat effects for non-manual workers; but contrasts with McInnes et al.[132] who reported effects only for heavy demanding occupations. Further, work and work environment factors identified from the HSPs and HSRs surveys such as rushed activity, use of heavy impermeable PPE, insufficient access to water and rest breaks, may also play a role as to why WRI occur in these occupations and industries. In essence, these findings indicate that both work location (outdoors or indoors), and the level of physical strength required to carry a specific work need to be considered as risk factors for heat-related injuries.

10.4 SIGNIFICANCE OF THE RESEARCH

The rationale for the research relates to the unacceptable burden of injuries occurring in workplaces.[530] With respect to heat associated-WRI, the phenomenon is currently not well understand and is likely to be more important in the future with the likely increase in the number of days when working in the heat can be ‘dangerous’ for workers.[111] The specific contributions of this research to the field are as follows.

Firstly, a comprehensive review of the literature,[50] led to the development of a model of causation plausibly explaining how heat exposure could result in WRI. Secondly, using multiple lines of evidence the research has added to the growing body of knowledge about heat as an occupational hazard and has characterised the phenomenon on a national basis, thus providing a more complete picture of workers’ health and safety at high temperatures. The research has also contributed to new evidence that vulnerable workers are not just outdoor workers and those engaged in heavy physically demanding occupations, but also some indoor workers and those undertaking less physically demanding occupations. Thirdly, comparisons of different exposure metrics including daytime T_{max} and EHF_{sev}-defined heatwaves were made in order to potentially harmonise risk factors across different climate zones. The findings based on a normalised metric (i.e. EHF_{sev}) may provide an additional or more useful basis for informing safe work guidance to employers, supervisors, and workers during heatwaves regardless of climate (see Chapter 11). Fourthly, this research has quantified the magnitude of the heat effect on WRI using attributable risk and fractions which can provide a useful perspective for policy makers. For example, this research has shown that 5% of all WRI claims can be attributed to non-optimum temperatures, with heat accounting for 2.5%. Although this proportion may not be large, the implementation of prevention measures as suggested by stakeholders may result in measurable economic benefits, including savings associated with averting injury and lost productivity.

10.5 METHODOLOGICAL ISSUES

The choice of analytical methods used, the nature of the data, and issues related to multiple comparisons may influence the study findings. Each of these issues are briefly discussed below.

10.5.1 Analytical issues

Modelling relationships between an environmental variable (such as temperature) and health outcomes requires decisions to be made in relation to:

- Study design (TS vs CCO)
- Choice of model (TS: DLNM vs GEE vs GAM; CCO: conditional logistic/ conditional Poisson)
- Model distribution approach (Poisson vs negative binomial vs quasi-Poisson)
- Manner in which seasonality is controlled for in TS design, with respect to choice of df for time
- Df for natural cubic spline for exposure and lag dimensions
- Number of maximum lag days
- Strata length (28 days or 30 days: applies to CCO design) and
- Choice of temperature percentiles defining moderate and extreme heat.

The choices made in relation to these factors will undoubtedly influence the results of statistical analyses. The CCO study design was adopted because, unlike TS where the choice of df to control for long-term and seasonal trends is important and varies from study to study, the CCO study design used in this study meant that these trends were controlled for by design using short-interval strata, namely, one calendar week.[338, 355, 356] The choice of DLNM to model the association between daily temperature and the daily number of WRI was largely influenced by the temperature-morbidity/mortality studies which have utilised this model.[9, 10, 234, 346, 347, 349-351, 375] Therefore, the modelling choices were based on existing literature and confirmed using sensitivity analyses by varying the df, strata length and maximum lag days.

There are similarities in the findings from Chapter 4 and the study of Martinez-Solanas et al. in Spain,[185] which both use DLNM and similar modelling choices despite differences in study design (CCO vs TS). This provides validation to the choices of study design and analyses and gives confidence in the findings.

10.5.2 Data quality issues

The WC claims data used in four of the epidemiological studies in this thesis (Chapters 4–7) represent one of the major sources of data on WRI in Australia.[293, 309-313, 531-534] However, it is important to acknowledge that WC claims data are from an administrative database that is fundamentally intended for ‘managing claims, tracking payments and setting insurance premiums’.[304] As a result, the WC data are not designed for research purposes, and thereby present some quality concerns.

At its core, each state and territory administers their own compulsory WC system and regulate the health and safety of workers within their jurisdiction. While the fundamental structure of all the compensation schemes are similar, differences exist across schemes in administration, insurance arrangements, payable benefits, threshold limits, premium setting policies, dispute resolution, rehabilitation and return to work obligations.[293] These well-documented and acknowledged system differences by SWA are likely to have some effect in the way the data are collected.

Attempts have been made to enable the use of WC data nationally by standardised data recording protocols. Although claims are coded with standard agreed upon classifications, it is possible that certain fields are missing because either the worker or the employer did not provide the relevant information while completing the ‘workers’ injury form’ or the ‘employer injury claim’ form provided to the insurer. For example, the size of the business was an important variable considered in the studies conducted in Chapters 4 and 6; however, this was missing from the data provided for Victoria and Queensland, thereby excluding that variable in studies conducted in Chapters 5 and 7.

10.5.3 Multiple comparisons testing

One of the issues of concern for the research findings, especially studies in Chapters 4–7, is that spurious results may be obtained when many comparisons are made between several WRI outcomes (types, mechanism, agency and body location) and exposure variables (temperature and heatwave severity categories).[535] Methods such as the Bonferroni’s correction[536] or the ‘false discovery rate’[537] can be used to reduce the possibility of identifying significant findings by chance or spurious associations. However, there are debates on their suitability in exploratory studies. The main rationale behind not adopting these methods was that some important or plausible differences or results could be missed resulting in an increase in false-negative results when using Bonferroni correction.[536, 538] The false discovery rate approach has been found to be more suitable for laboratory experiments where a considerable number of comparisons and tests are normally done.[537, 539] Also, it has been argued that ‘no adjustments are needed for multiple comparisons’ as they tend to cause more problems than intended.[540]

In this research a progressive data analysis approach was undertaken, whereby the overall relationship between heat and WRI was first examined, then subgroup analyses were conducted. The subgroup analyses were based on the variables chosen a priori as per the data analysis plan (Appendix J) and were influenced by previous research[45, 145] and findings from the literature.[122, 127, 132, 135] The statistically significant findings thus obtained were not just presented as such but rather were examined for their plausibility and compared to existing literature.[45, 127, 132, 135, 145, 185, 188, 190] Where findings were influenced by small counts this was acknowledged and confidence intervals provided to aid readers in using 'their own judgement' in interpreting the results.[541] This approach is similar to that used in other studies.[272, 542-545]

10.6 OVERALL STRENGTHS OF THE RESEARCH

The major strength of this research is that it has evaluated the risk and susceptibility of workers and quantified the associated attributable burden of heat and WRI across four Australian cities with diverse climates and worker profiles. This is the first time such an extensive multi-city study has been conducted in Australia on heat-related WRI and their determinants. A multiple data source approach was used to address the research questions, combining both complex statistical models incorporating administrative data, and surveys of key stakeholders. The multiple data source approach yielded a triangulation of findings with the outcomes of surveys supporting and supplementing the major findings of the analysis of the WC data. Additional strengths specific to the two parts of the research (i.e. the analysis of WC data and stakeholder surveys) are discussed below.

10.6.1 Strengths of the analysis of workers' compensation data

There are several strengths for the four studies conducted in Part 1 of the research, as presented below.

First, the TS nature of the WC data over 10–12 years has provided a large sample size (~1 million compensated WRI claims) for the analyses carried out in Chapters 4–7.

Second, the WC data covering the vast majority of workers in the four jurisdictions of interest capture a wide range of severity of injuries and contain comprehensive information about the worker demographics, employment characteristics and injury details.[309, 312, 313] The comprehensive nature of the data has allowed the identification of at-risk worker subgroups by their occupation and industry.[312] Further, the use of WC data enabled the exploration of injury attributes such as the nature, agency, mechanism, and body location of injury, highlighting the types of injuries that are most likely to occur in hot weather. Such information represents a valuable tool for raising awareness of safety among industry, employers, and workers.

There were several strengths in the modelling approach used in the analysis of the WC data. First, two of the studies conducted in this research (Chapters 4 and 5) are the first studies in Australia and among the first two studies[183, 185] in the world, to make use of complex but flexible statistical modelling techniques such as the DLNM model which considers the lagged and non-linear effects of temperatures on WRI. Second, as discussed in Chapters 2 and 3, using daily injury claims on a given day without considering the total number of workers working on that same day can bias the results.[401] However, by utilising the CCO design, separately for each city the need for such information is precluded as each 'case' is compared to themselves as controls. The studies in Chapters 4 and 5 are indeed the first occupational health studies to apply DLNM models in the time-stratified CCO study design, thereby representing a novel methodological approach.

Third, the calculation of attributable fractions and numbers (see Chapters 4 and 5) complements the usual RR estimates gained from regression models. The calculation of attributable fractions and numbers has policy implications for prevention and future interventions as it quantifies the preventable injury burden due to a specific risk factor, which in this case is temperature.[10, 235, 236, 386, 390, 546] A similar attempt to estimate AF has been taken by only two other studies in the world[183, 185] and this thesis represents the first such attempt in Australia.

Fourth, the epidemiological studies conducted in this thesis examined the risks at moderately hot and extremely hot temperatures using temperature percentiles at the 90th and 99th, respectively, enabling comparisons between cities with respect to temperature gradient. Similarly, the use of a national heatwave metric that is location-specific accounted for the possibility of acclimatisation to warmer weather and also readily facilitated comparisons across cities.[430]

Fifth, a number of sensitivity analyses were conducted in line with existing literature. These included varying df for temperature and lag dimensions, replacing the meteorological data from a main BOM monitoring station with that of an alternative station, and use of average exposures across many available stations (Table K1, Appendix K). The main conclusions remained robust to these changes.

Sixth, the use of thermal composite indices such as AT, WBGT, UTCI, HX, and HI, in addition to daily T_{max} (the main exposure metric used) presented an advantage in that they accounted for humidity, wind speed and solar radiation. The consideration of these metrics to indicate heat stress in Chapters 4 and 5 is a strength, as previous Australian studies[45, 132, 188] have been limited to only temperature metrics.

Seventh, considering all claims (both injuries and illnesses), was a strength of the study as it mimics a negative control design.[547] For example, no significant associations for WRI not related to heat exposure (e.g. ‘injuries to nerves and spinal cord’ or ‘nervous system and sense organ diseases’) were found.

Finally, an additional strength of the four studies in this thesis (Chapters 4–7) is the use of occupational based classifications of indoor and outdoor environments and the consideration of potential physical demands. This approach is a refinement over that based on industrial groupings as in previous studies,[45, 127, 145] where exposure misclassification may have occurred due to possible inclusion of several indoor occupations being grouped under ‘outdoor industries’, or vice-versa.

10.6.2 Strengths of the stakeholder surveys

The major strength of surveying health and safety managers, professionals and workplace representatives is that it extends the understanding on the heat-injury phenomenon beyond the population level obtained using WC data. This approach provides a more detailed and nuanced understanding of the circumstances and the context in which injuries occur in workplaces during hot weather. Additionally, the surveys also highlight areas of concern that were not captured through WC data alone. As previously mentioned in Chapters 8 and 9, the surveys are likely to capture information about minor injuries or other injuries that may be excluded from WC claims data. Having such information from two groups of key stakeholders (HSRs and HSPs) is useful for understanding the heat and WRI phenomenon and has implications for development of policies and preventive practices.

10.7 OVERALL LIMITATIONS OF THE STUDY

The limitations of the six studies conducted as part of this research have largely been mentioned in the individual chapters. The following section briefly discusses the overall study limitations of Part 1 in Section 10.7.1, and of Part 2 in Section 10.7.2.

10.7.1 Limitations of the analysis of workers' compensation data

The main limitation of the four studies conducted in Part 1 (Chapters 4–7) relates in particular, to data sources used to ascertain exposures and outcomes, and the methodological challenges, and these are briefly addressed in turn.

First, administrative data sources such as the WC claims data have clear advantages as discussed in Section 10.7.1; however, there are some limitations. WC datasets are a subset of WRIs as they essentially capture injuries that were reported and accepted as compensation claims, the criteria for which varies across jurisdictions, and therefore WC data do not capture all WRI.[293] The under-reporting of injuries in WC datasets is a widely acknowledged limitation which may underestimate the actual risk for workers in industries such as 'agriculture, forestry and fishing', and 'construction' and those in smaller companies that are likely to under-report WRI.[548] Further, some workers are not included in WC datasets; for example, self-employed workers who represent about 10% of the Australian workforce.[72] Thus, WC datasets underestimate the true burden of WRI.

Second, due to the ecological nature of the study, assessments of heat exposure were not at the individual worker or localised worksite level, but instead used meteorological measurements of outdoor temperature from single weather stations at each study site. There are limitations to this approach as this introduces exposure misclassification, a common limitation of epidemiological studies examining heat-health relationships.[413] Such studies assume that workers in the defined study area, regardless of being outdoors or indoors, roughly experience the same exposure as that measured at the weather monitoring station. However, indoor temperatures can vary from that measured outdoors depending on worksite characteristics such as building type, building materials, surrounding environment, and use of adaptation measures such as air-conditioning and individual behavioural factors. Furthermore, a constant exposure is assumed across the whole geographical area for the working population at every unit of time. However, this is not the case in reality, as temperatures vary spatially and temporally depending on locations, time of day, other factors such as urban heat island effects, differences in elevation or wind circulation, amount of impermeable surface and distance from water.[549-551]

The exposure misclassification bias introduced can be classical or Berkson-type errors, the former leading the bias downwards, i.e. towards the null, and the latter resulting in the increased variance of the regression coefficient but unbiased estimate.[552, 553] However, the bias introduced with the use of ecological measures of weather station exposure in lieu of individual worker level measurement is likely to be non-differential due to the correlation between data from several weather stations and indoor and outdoor temperatures, resulting in an attenuation of the estimates.[554] Sensitivity analyses performed in Chapters 4 and 5 using data from alternative stations and averages from several stations did not substantially alter the estimates. Ideally, geocoding the location of the site of the WRI and matching this with high resolution meteorological data could address this issue, as in a study conducted by researchers in Washington, US.[135, 189]

Third, misclassification may occur with the geographical location where workers were exposed and injured. The 'postcode of the workplace where the injury occurred' variable was the only geographic information in the WC datasets used to define the study area. However, it cannot be ruled out that some workers may have been injured at locations other than their normal workplace. For example, a construction worker may have been injured at a suburban construction site but the postcode recorded could be of the employers' establishment. However, it was not possible to identify such records, thus classification errors are likely to be present.

Fourth, the role of workplace and personal risk factors on the heat-WRI relationship was not examined. This was due to the lack of information on relevant workplace risk factors such as heat adaptations (e.g. air-conditioning use) and personal risk factors such as fitness level, acclimatisation status, medical history, drug/alcohol use, or use of medications.

Fifth, while the epidemiological investigation includes workers from different cities, the findings cannot be seen as representative for other geographical areas in Australia or other regions in the world. While broad similarities may be gathered based on climate, the underlying characteristics of the workforce may limit the generalisability of the studies for workers in other cities.

Sixth, air pollutants were not adjusted for in the main models on the heat-WRI relationship. While this could be considered as a limitation, there is an ongoing debate among environmental health researchers on whether such adjustments are needed for in temperature-health models.[555] This is because pollution levels are influenced by daily temperature which is not influenced by pollution, thus making air pollutants a mediator rather than a confounder.[556] Furthermore, previous studies[8, 16, 331-333, 557] suggest that adjustments for air pollutants is likely to have a minimal effect on the temperature-health association.

Finally, cautious interpretation of the findings is warranted given the relatively small samples sizes in some stratified analyses. Additionally, the small number of WRI by workers in specific occupations or industrial groups prohibited the exploration of certain groups. This is likely to mask some sub-group variations in the exposure-response relationship. For example, workers in the waste collection services have been identified to be at risk of heat-related injuries in Spain[185] but in the current study these workers are collectively categorised as workers in ‘electricity, gas, water and waste services’.

10.7.2 Limitations of the stakeholder perception surveys

The major limitation of the two stakeholder perceptions survey studies (Chapters 8 and 9) is that they are cross-sectional in nature and therefore only provide a snapshot of the issue. As such, the associations observed between the frequency of injury experience and the risk factors assessed are not diagnostic on their own compared to longitudinal studies. Other limitations include the susceptibility to biases such as recall, selection, and responder bias. The relatively small sample sizes (307 HSPs and 222 HSRs) and non-representativeness of the samples are also limitations which can affect the external validity of the findings. Another limitation relates to the definition of indoor/outdoor workers (see Section 3.8). The questionnaire survey included a question relating to prevention practices for indoor/outdoor workers at face-value without a formal definition.

10.8 CHALLENGES FACED IN THE RESEARCH

Some of the main challenges faced in this research relate to the data and the methods, and these are briefly discussed below in Sections 10.9.1 and 10.9.2, respectively.

10.8.1 Challenges related to the data

The WC data provided by SWSA and SWA were at the state level and there was a need to restrict the claims to the metropolitan areas of each of the four cities only, due to the need to have localised temperature data and a large sample size. There are several ways of defining the 'metropolitan area' using the ABS provided Australian Statistical Geography Standard (ASGS) including greater capital city statistical areas (GCCSA), statistical area level classification (SA4, SA4, SA2 and SA1), significant urban areas (SUA), local government areas (LGAs) and postal areas (POA). The latter was chosen due to the availability of a postcode variable in the dataset for which the POA seemed the appropriate match. As mentioned in Chapter 4, the area encompassing postcodes 5000–5199, 5942, and 5950 were chosen to represent metropolitan Adelaide as used in previous studies.[45, 274] Similarly, for the other cities definitions of metropolitan areas were also based on previous studies.[132, 276]

Decisions were also made regarding data from the most appropriate weather monitoring stations best represented weather conditions across the defined study areas. A combination of approaches, i.e. using measurements from a single monitoring site,[45, 145] averages from all available sites,[132, 188] and satellite data[189] have been used in the literature. While there are limitations with using a single site or averaged exposures across several sites as discussed in Section 10.8.1, Guo et al.[558] have shown that the differences between the three approaches are not pronounced. Similar conclusions were also obtained in a recent study by Weinberger et al.[559]. Hence, as outlined in Chapter 3, a single weather station was used in each of the four cities and data from all available stations were used in sensitivity analyses. This approach is also similar to other studies.[45, 132]

Another challenge relating to data was the choice of temperature metrics (e.g. mean, minimum and maximum or composite thermal indices) and heatwave definition as mentioned in Chapters 2 and 3. While no consensus exists in the literature on the best temperature metric to use, Barnett et al.[288] have shown that no one metric is superior. They suggest that researchers should use the metric with most coverage and which can be easily understood by the general public.[288] Hence, daily T_{max} was used as the main exposure metric in Chapters 4 and 5, while others were used in the sensitivity analysis. Although many definitions of a heatwave exist, EHF was chosen for consistency between study sites as outlined in detail in Chapters 6 and 7.

10.8.2 Challenges relating to the methods

As discussed in Chapter 3, most of the environmental epidemiological studies assessing the effects of ambient temperatures and air-pollution on population health have primarily either used an ecological TS or CCO study design. The challenge faced in this research was to choose a study design appropriate for the research questions. The TS-design ideally requires denominator data (in this case number of workers) to enable calculation of incidence rates. However, only monthly level labour force data were available from the ABS. Based on a study by Adam-Poupart et al.[127], it was initially decided to use TS-design with labour force data as an offset. However, logistical issues including reduced workforce numbers during holiday periods, prevented the use of monthly labour force data. Testing of the length of the strata period using 28-day, 14-day and seven-day strata showed the optimal was the latter (i.e. one case day compared to six other control days). Thus, a CCO design with a narrow window (seven days) to account for these dips in worker numbers was decided upon as the study design in Chapters 4–7. As outlined in Chapters 2 and 3, the CCO design obviates the need for denominator data, and addresses the concerns around seasonal reductions in worker numbers.

10.9 PRACTICAL IMPLICATIONS FROM THIS RESEARCH

Findings from the analysis of the WC claims data indicated that WRI increase at high temperatures (Chapters 4 and 5) and during heatwaves (Chapters 6 and 7). Further, the finding that moderately hot temperatures have the greatest burden of injuries, adds to the understanding of the complexity of the problem. The implication of this finding is that workplace heat-health and injury prevention plans should be widened to include moderate heat and not just extreme heat. This is important considering that workers are more frequently exposed to moderately hot days (that are more common), than extremely hot days (which are relatively rare). Similar calls to include moderate heat in public health policies and plans have been made by researchers linking temperature and mortality/morbidity at a global scale.[9, 10]

From the survey data, there is general consensus about the need for more training about safety in hot conditions for both workers and supervisors. The training should cover not only risks of HRIs and perceived contributing factors such as ‘dehydration’ and ‘fatigue’ that can be the initial symptoms of heat stress, but also risks of injuries that can increase in heat-affected workers, with the mechanisms being multifactorial. However, the potential for misclassification of heat-related injuries exists and the importance of accurate reporting could also be included in training sessions.

In this research EHF-defined heatwaves consistently predicted impacts across different locations. The BOM’s national heatwave service provides forecast maps of heatwave conditions and severity in a three-day period, as classified by EHF_{sev} (see Figure 3.9). These maps, accessible on the BOM website, could serve as a starting point for workplaces to implement adequate preventive measures when moderate-severity heatwaves are forecast and well before heatwaves reach the highest severity. These may complement predicted T_{max} as an indicator of heat exposure. Given that none of the jurisdictional regulators in Australia currently have any guidelines or regulations for specific temperature thresholds at which precautions need to be taken, or when work should cease, the BOM heatwave maps may be useful as a guide to when preventive measures are required.[171]

In summary, the findings from this research have practical public health implications in the context of a warming climate. Besides the increased frequency and intensity of hot days, warm nights, and heatwaves are also increasing.[404] This translates into more heat exposure for workers. In the wake of future projections for the increasing number of hot days in Australian cities (as outlined in Figure 1.5),[109] it is vital that OHS of workers during hot weather be acknowledged and addressed to reduce the burden.

10.10 FURTHER RESEARCH

While the effects of ambient temperatures and heatwaves on OHS have been examined at the population level using administrative data sources, further research is needed to understand other aspects of the relationship between hot weather and WRI. Suggestions for further research at the population, workplace and individual levels, are outlined below:

10.10.1 National research to provide more local level relevance of heat as an occupational hazard

It is of interest to further explore how the relationships between temperature and the risk of WRI vary depending on differing demographic, socio-economic, infrastructural and climatic profiles across Australia. This should not be limited to estimating RRs, but measures such as attributable fractions and attributable numbers which quantify the whole WRI burden due to non-optimum moderate and extreme temperatures need to be estimated in other cities — e.g. Sydney, Darwin, Hobart and Canberra. Such a study would provide a comprehensive national picture and local evidence that could serve as important evidence for key stakeholders to plan suitable risk communication messages to workers, tailor prevention programs and evaluate the overall WRI burden due to non-optimum temperatures.

For consistency and comparability the study would need to employ a uniform modelling approach with a) city-specific analysis; b) meta-regression at the state-level (using climatic zones) and c) at a national level using a multi-variate meta-regression approach that is widely used in several multi-city and multi-country studies.[9, 10, 16, 346, 347, 350, 351, 512] Such research could also address the impacts of temperatures on OHS in non-metropolitan areas and rural and remote regions which have not been included in current and previous research. As the smaller number of daily claims in regional areas can be problematic, ‘cluster-analysis’ approach recently used in US studies[378, 554] where places that share common weather characteristics are grouped, may serve as an alternative approach in TS-analysis and address the sample size issue.

Although ‘journey claims’ (claims related to travel to and from work) were not included in the analyses in Chapters 4 to 7, it is possible that they represent an appreciable proportion of all accepted WRI with a concomitant effect and therefore warrants further investigation. This might identify potential interventions e.g. in the transport industry.

10.10.2 Research into the effectiveness of heatwave alerts and warnings

The severe impacts of heatwaves during the 2009 heatwaves in Adelaide and Melbourne prompted state emergency services and health departments to develop heat alerts and heatwave warning systems (HWS) aimed to protect the general public from the health impacts of heat. The evaluation of HWS and specific interventions in Adelaide showed significant reductions in morbidity in the general population.[21] However, it is unknown whether and to what extent the HWS has had an effect on reducing WRI. A CCO design could be used to compare WRI on days without HWS versus those with, adjusting for temporal factors and T_{max}.[560] Additionally, it would be useful to know how well public heat warnings affect work practices, and how these warnings and work advisories complement each other.

10.10.3 Research on projections of temperature and heatwave-related excess WRI under climate change scenarios

Researchers from the worldwide 'Multi-City Multi-Country Research Network'[290, 512] using two adaptation and three population change scenarios in 35 countries across the world, have shown that with future climate change, both temperature and heatwave-related excess mortality will increase in most regions. It is therefore of interest to quantify the expected burden of WRI associated with variation in outdoor temperatures and heatwaves under different climate change scenarios. Evidence thus generated could inform policy makers in planning better adaptation and mitigation strategies so as to reduce the health impacts.

10.10.4 Research on surveillance and vulnerability mapping

As mentioned in Chapter 2, the majority of heat-WRI risks have been established using WC data. However, the limitations of WC in regard to coverage and under-reporting have been identified. It would be useful for future research to explore the feasibility of data-linkage between WC and other surveillance data sources such as ambulance call-outs, hospital admissions, and emergency department presentations. This would provide a more comprehensive estimation of WRI related to heat. Indeed, a study in Melbourne investigated the differences and similarities between different sources of WRI (WC data, emergency department data, and hospital admissions data) and found that different population groups and types of injuries were captured in these datasets.[241] For example, WRI to young workers, and open wound and burn injuries were captured in emergency department data, while WC data were more likely to capture injuries in older age groups and musculoskeletal injures. Furthermore, it would be beneficial to develop a heat vulnerability index for occupational settings, similar to heat vulnerability index done at the population level,[561, 562] using occupational, socio-economic, health, demographic, environmental and climate measures. High resolution gridded meteorological data matched to the geographical location of the WRI could be used which may help to minimise the inherent exposure misclassification when using data from single monitoring stations. Such research could potentially provide policymakers and regulators a powerful tool for tracking vulnerable workplaces.

10.10.5 Research on the economic burden of heat-related work-related injury

No research has been conducted in Australia to examine the extent to which hot weather conditions increase the associated economic burden of WRI. This would build upon a previous study where significant increases in medical costs and work-days lost due to heat-induced illness were identified in Adelaide.[563]

10.10.6 Research at the individual and workplace level

The conceptual framework of how injuries arise in hot weather presented in Chapter 2, captures a range of important risk factors categorised at the work, worker, and work environment dimension. The role of physiological and psycho-behavioural factors has also been discussed conceptually and raised in stakeholder surveys. However, there is a need to clearly elucidate the complex mechanisms involved in the aetiology of heat-related workplace injuries. This could be done by conducting field studies where some of the factors such as psychomotor vigilance or balance performance could be tested in heat exposed workers. This would build upon previous investigations undertaken by Spector et al[564] of pear and cherry harvesters and Larsen et al[565] (who used simulated environments for firefighters). In the case of Spector et al[564], it was a relatively small group of workers in moderately hot conditions, while the Larsen et al study[565] was conducted in an artificial environment with volunteers. Hydration status and level of sweating could be evaluated as effect modifiers of the heat and WRI risk relationship.

Knowing workers' physiological, physical and cognitive responses to heat could aid in clarifying the underlying mechanisms of the heat-WRI phenomenon.

Further research is also needed to examine PPE and suitable fabrics that allow heat dissipation while affording protection to the workers from chemicals and other hazards.

Finally, there is a need to understand how workers, supervisors, and employers perceive the risks, what information they need to minimise these in hot weather, and what forms of training are needed and how these should be delivered. This information could be gathered using qualitative research and case-study approaches.

10.11 CHAPTER SYNOPSIS

This chapter has provided a discussion and synthesis of key findings from the research presented in Chapters 4–9. Multiple lines of evidence about the risk, susceptibility, and the attributable burden of WRI in hot weather from WC data and stakeholder surveys were considered. This chapter has also outlined the key strengths and limitations of the research, along with issues concerning findings, and the challenges faced during the research. Further, the significance and implications of the research have been considered, along with recommendations for future research. The next chapter concludes the thesis and identifies specific recommendations for specific stakeholders based on the key research findings.

11

Chapter 11: Conclusion and Recommendations

11.1 CONCLUSION

The work presented in this thesis provides evidence that working in hot conditions is a clear and significant health and safety hazard for workers. Occupational injuries have been shown to occur at an increased rate in working conditions for both indoor and outdoor workers. High temperature days increase heat exposure for workers yet it is not just during extreme heatwaves that injuries increase. These results suggest that working in hot conditions needs to be treated as seriously as any other health and safety hazard, due to the range of health and safety problems that exposure can cause. In addition, the research emphasises that the impacts on workers should not be neglected in the debate about climate change and public health consequences, as the impacts of ambient temperatures are not limited to the general population alone. The broader impacts of temperatures presents a challenge that is multi-faceted, with potential consequences for workers, supervisors, employers, regulators, and policy makers.

While the risks associated with heat exposure are not homogenous as they can vary depending on worker, work or work environment characteristics, it needs to be highlighted that the adverse effects of heat on workers' health and safety can be widespread and not limited to vulnerable groups identified in this thesis. Stakeholder perception findings indicate that there is an under-appreciation of the risks by workers and supervisors and lack of safety leadership in workplaces.

With modifiable work and organisational factors, there is a need for workplaces to address prevention strategies and have a supportive safety culture for workers. Efforts need to be taken to reduce heat exposure and its health effects directed towards the work environment, the task being undertaken, and individual workers themselves, by adopting a combination of higher and lower-order controls. Examples include: having adequate ventilation for indoor workers, and shaded work areas for outdoor workers, shaded rest areas, allowing regular breaks, rescheduling work times (where practicable) and providing suitable PPE. Attempts to reduce dehydration and fatigue in workers should also be addressed. Together, these measures may facilitate a reduction in the risk of heat as a health and injury hazard, and protect workers from the impacts of increasing temperatures and heatwaves that are predicted to increase in frequency, intensity, and duration in the context of Australia's warming climate.

11.2 SPECIFIC RECOMMENDATIONS FROM THIS RESEARCH

Finding (a): HSPs and HSRs identified specific deficiencies in relation to: lack of heat stress training, lack of specific heat-related guidelines and regulations, lack of awareness among workers and supervisors, poor supervision, and policies not being adhered to.

Recommendation: Based on the above finding, it is recommended that jurisdictional safety regulators and policy makers target areas such as heat stress training, induction, supervision, and associated policy and procedures related to working in hot weather. There is need to increase awareness of the currently available heat and work guidance materials and to foster compliance. It is also recommended that the OHS laws, regulations, codes of practices, and guidelines provided by each state regulator be updated to include heat-associated risks including injury risks.

In the case of employers, it is recommended that they create/refine/update their hot weather health and safety policies and ensure that they are written and reviewed annually. Every heat-exposed worker should be made aware of, and understand, the policy. Also, to maximise the acquisition and retention of information pertaining to heat-work hazards, there is a need for employers to consider ways of improving how they conduct orientation and training for workers. Possible options include training in the form of daily toolbox meetings prior to the start of work on hot days, with an emphasis on staying hydrated, taking breaks, and the need to look out for each other. Finally, heat stress training should be mandatory for supervisors who should monitor the safety of their workers in the heat.

Finding (b): The WC data analysis and the surveys identified certain at-risk groups to include males, young workers, labour hire workers, new workers, and non-English speaking workers.

Recommendation: Based on the above finding, it is recommended that jurisdictional regulators consider running promotional campaigns targeted to these groups, to increase awareness of heat-associated injury risks. This could be undertaken using mass media, social media, and other communication e-tools, ensuring that messages are aimed at the right groups and delivered in appropriate ways that suit them.

It is also recommended that regulators engage with employers and workers to promote a shared responsibility for collective and individual safety.

It is recommended that employers promote strong safety culture and good leadership so that workers feel empowered and are confident to raise issues without concerns of job security.

Finding (c): The WC data analysis showed that WRI increase as temperatures increase with both indoor and outdoor workers affected, with some particularly at-risk. Although there were variations between cities, overall, WRI were more common at higher temperatures compared to lower temperatures, and during moderate/high severity heatwaves. The consistency in the impacts during EHF-defined heatwaves provides an opportunity for regulators to issue messages and warnings for workplaces.

Recommendation: Based on the above finding, it may be appropriate for jurisdictional regulators to issue alerts and warning messages following the tiered approach shown in Table 11.1, based on heatwave type.

Table 11.1 Summary of heatwave arrangements by regulators linked to heatwave levels.

Heatwave type	Colour code	Temperature	Community impact	WRI risk	Regulator action
No heatwave	White	Normal	---------	---------	
Low-intensity heatwave	Yellow	Top 10%	Most people have capacity to cope	No effect	Alert and advice for basic health and safety planning via websites, social media
Severe heatwave	Orange	Top 2%	Increased deaths and illness in vulnerable groups	Increased risk	Issue alerts to workplaces, heighten awareness targeted messages
Extreme heatwave	Red	Top 1%	Health risk for anyone who does not take precautions to keep cool, even the healthy		Issue warnings for work to be modified and extra care to be taken and if heatwave is widespread and prolonged then consider advising to cease work.

It is recommended that employers and workers keep track of the BOM's heatwave forecasting and assessment service available at the BOM website (http://www.bom.gov.au/australia/heatwave/).

Employers could alert and warn their employees on days of moderate/high-severity heatwaves (i.e. orange/red shade in the forecast map) to modify their work, e.g. heavy work to be undertaken in the cooler hours of the day, and workers to have more rest periods and drink more. Table 11.2 provides a sample tiered system that employers could use to protect the health and safety of their workers.

Table 11.2 Summary of heatwave arrangements for employers linked to heatwave levels.

	No heatwave	**Low-intensity heatwave**	**Severe heatwave**	**Extreme heatwave**
Temperatures	Normal	Highest 10%	Highest 2%	Highest 1%
Action	Basic heat safety and planning	Implement precautions	Heighten awareness, provide adequate supervision and monitor if workers follow safety procedures and use equipment correctly. Encourage hydration and breaks in the shade as often as possible. Additional protective measures, close monitoring of workers, and reconsider if strenuous work needs to be done outdoors.	

Finding (d): PPE leading to higher body temperature was identified as a key issue by both HSPs and HSRs.

Recommendation: Based on the above finding, it is recommended that the manufacturers of PPE consider improving its comfort and suitability for hot weather conditions as some can impair heat loss.

11.3 PRACTICAL CHALLENGES FOR IMPLEMENTING RECOMMENDATIONS

While the above recommendations stem primarily from the research findings, there are some interesting (and important) aspects about the work sector that may present as barriers to these recommendations being implemented. For example, is there a broader problem with culture and attitudes that needs to be addressed? Or are there problems with the workforce or management not engaging with OHS issues (especially in some sectors)? The answer may be yes in some cases. A survey undertaken by SWA on perceptions of WHS identified that there was a greater acceptance of risk taking and rule breaking in order to complete work on time in some workplaces, particularly among sole traders, employers in the ‘Transport, postal and warehousing industry’, ‘construction’ and ‘mining’ labourers and factory process workers.[566] This highlights that the need to slow down and self-pace in the heat may be ignored, especially as hot weather is seen to be a ‘normal’ part of the Australian summer. Another issue is the changing nature of the work sector, i.e. more insecure employment, the gig economy, more labour hire, and more ‘imported’ labour’. All these issues together could pose risks to workers’ health and safety in the heat and therefore careful consideration needs to be given about how the specific recommendations would be implemented to reduce WRI and make workplaces safer. Therefore, greater awareness of the heat hazard at all levels of management and more broadly amongst workers at risk should be a clear priority.

Summary of Section E

This final section has summarised the findings from the research presented in this thesis which was conducted in several stages encompassing the analysis of WC claims data and surveys of stakeholders. The significance and implications of the work were outlined and suggestions made for future research. Finally evidence-based recommendations for ways to reduce the burden of WRI in hot weather were presented.

Appendices

Appendix A: Tabulator and NDS3 Dataset

Table A1 List of variables used for analysis from the Tabulator dataset.

Claimant details	Occurrence details
Industry of employer	Date of injury
Size of employer	Postcode of workplace
Sex	Nature of injury
Occupation	Body location of injury
Experienced / New worker	Mechanism of injury
	Agency of injury
	Time of injury

Table A2 List of variables used for analysis from the National Data Set for Compensation-Based Statistics (NDS3) dataset.

Claimant details	Occurrence details	Outcome of occurrence
Industry of employer	Date of injury	Time lost from work
Size of employer	Postcode of workplace	
Sex	Nature of injury	
Occupation	Body location of injury	
Labour hire indicator	Mechanism of injury	
Apprentice/trainee indicator	Agency of injury	
Number of hours usually worked each week	Time of injury	

Appendix B: Supplementary Material

B1 Supplementary Material for Chapter 2

Table B1 Search strategy: terms, databases, limitations and number of articles for review.

Databases	Strategy	Number of hits	Number imported into Endnote
PubMed Filters: English, humans	#1 Heat stress[tw] OR Heat stress disorders[mh] OR Hot temperature[mh] OR heat[tw] OR hot weather[tw] OR hot temperature*[tw] OR high temperature*[tw] OR ambient temperature*[tw] OR heatwave*[tw] OR heat wave*[tw] OR climate change[mh] OR climate change*[mh] OR global warming[mh] OR outdoor[tw] OR thermal exposure[tw] OR solar radiation [tw] OR sun exposure [tw] OR UV-index [tw]	324976	
	#2 (Industry[mh:noexp] OR Industry[tw] OR Industries[tw] OR Industrial[tw] Environmental Exposure[mh:noexp] OR Occupational Exposure[mh:noexp] OR Occupation health [mh] OR Work[tw] OR workplace[tw] OR work-related[tw] OR workplace[mh] OR employment[tw] OR employment[mh] OR occupation*[tw] OR employee*[tw]) OR company*[tw] OR AGRICULTURE INDUSTRY[mh:noexp] OR FORESTRY[mh] OR Forestry[tw] OR building site*[tw] OR WORKER*[TW] OR Occupational Health and safety[tw])	2583579	
	#3**(**Workers' compensation [mh] OR Wounds and injuries[mh] OR Accidental falls[mh] OR FALLS[TW] OR Accidents, occupational[mh] OR injur*[tw] OR accident*[tw]) OR ((accident[tiab] OR accidents[tiab] OR injury[tiab] OR injuries[tiab] OR 'Wounds and Injuries'[Mesh] OR 'injuries' [Subheading])))	1422576	
	#4 Epidemiol*[tw] OR Morbidit*[tw] OR INCIDENC*[TW] OR PREVALENC*[TW]**]**		
	#5 #1 AND #2 AND #3 AND #4	2416824	582
Embase Filters: English, humans	#1 'high temperature':ab,ti OR 'high temperatures':ab,ti AND 'hot temperature':ab,ti OR 'hot temperatures':ab,ti OR 'high ambient temperature':ab,ti OR 'high ambient temperatures':ab,ti OR 'ambient temperature':ab,ti OR 'ambient temperatures':ab,ti OR 'outdoor temperature':ab,ti OR 'outdoor temperatures':ab,ti OR heatwaves:ab,ti OR 'heat stress'/exp OR 'heat stress' OR 'heat stress disorders':ab,ti OR 'global warming':ab,ti OR 'climate change'/exp OR 'climate change' OR 'thermal exposure'/exp OR 'thermal exposure' OR heatwave:ab,ti OR 'extreme heat'/exp OR 'extreme heat'	128716	
	#2 work:ti OR worker*:ab,ti OR employment:ti OR 'occupational health':ti OR workplace:ab,ti OR 'work place':ab,ti OR 'work environment'/exp OR 'workman compensation'/exp OR 'industry'/exp	556688	

Databases	Strategy	Number of hits	Number imported into Endnote
	#3 ('injury'/exp OR accident:ab,ti OR accidents:ab,ti OR injury:ab,ti OR injuries:ab,ti) OR ('heat injury':ab,ti OR Injur* OR 'accident'/exp OR injur*:ab,ti OR accident*:ab,ti OR harm* OR wound* OR 'fall'/exp OR falling* OR (work* NEAR/1 injur*):ti OR (work* NEAR/1 injur*):ti,ab)	2572431	
	#4 epidemiologic* NEXT/1 (stud* OR survey*) OR 'case control study'/syn OR (population OR hospital) NEXT/5 'based case control' OR 'case control' NEXT/3 (analys* OR design* OR evaluation* OR research OR stud* OR survey* OR trial*) OR 'case comparison' NEXT/5 (analys* OR stud*) OR 'cohort analysis'/syn OR ('case base' OR 'case matched' OR 'case referent' OR cohort OR concurrent OR incidence OR longitudinal OR followup OR 'follow up' OR prospective OR retrospective OR 'cross-sectional' OR prevalence) NEXT/1 (analys* OR design* OR evaluation* OR research OR stud* OR survey* OR trial*) OR 'prospective method' OR 'crossover procedure'/syn OR 'retrospective study'/syn OR morbidit*	2369019	
	#5 #1 AND #2 AND #3 AND #4		105
Scopus	#1 TITLE-ABS-KEY("heat" OR "Heatwave" OR "Hot temperature" OR "Hot weather" OR "Thermal exposure" OR "Ambient temperature" OR "High temperature" OR "High ambient temperature" OR "Heat stress" OR "Climate change" OR "Outdoor temperature" OR "Heat exposure" OR "environmental temperature")	2067185	
	#2 TITLE-ABS-KEY ("Work-related" OR "Occupation" OR "Work" "Workplace" OR "Outdoor industry" OR "workplace" OR "Indoor industry" OR "Worker's compensation")	45900	
	#3 (TITLE-ABS-KEY ("Occupational injury" OR "Work injury" OR "Accident" OR "Wound" OR "Damage" OR "Work-related injury" OR "incident" OR "Fall risk" OR "falling" OR "occupational accident")) OR (TITLE-ABS KEY (accident OR accidents OR injury OR injuries))	3068939	
	#4 TITLEABSKEY ("Epidemiology" OR "Morbidity" OR "Prevalence" OR "Incidence")	2334640	

Databases	Strategy		Number of hits	Number imported into Endnote
	#5	#1 AND #2 AND #3 AND #4		24
CINAHL Filters: English, Humans, Narrow by Subject Major: - wounds and injuries - occupational safety - stress, occupational - occupational diseases - environmental health - occupational exposure - work environment - occupational health - occupational-related injuries - public health - environmental exposure	#1 MH heat OR Ti heat* OR AB heat* OR TX heat* OR TX heatwave* OR TX hot temperature* OR TX hot weather OR TX High temperature* OR TX thermal exposure* TX ambient temperature* OR TX high ambient temperature* OR TX HEAT STRESS OR TX CLIMATE CHANGE* OR TX outdoor temperature* OR TX heat exposure*		106501	
	#2 TX work-related OR TX work* TX workplace OR TX employment OR TX employee* OR TX occupation OR TX company OR TX industry		405191	
	#3 TX occupational injur* OR TX work injur* OR TX "work injur*" OR MH accident OR TX accident* OR TX work-related injur* OR TX incident* TX worker's compensation OR TX wounds and injuries OR TX accidental falls OR TX falls		304385	
	#4 TI epidemiology OR AB epidemiology OR TX epidemiology OR MH epidemiology OR TX morbidit*		352267	
	#5	#1 AND #2 AND #3 AND #4		547

Databases	Strategy	Number of hits	Number imported into Endnote
Science Direct	#1 "heat" OR "Heatwave" OR "Hot temperature" OR "Hot weather" OR "Thermal exposure" OR "Ambient temperature" OR "High temperature" OR "High ambient temperature" OR "Heat stress" OR "Climate change" OR "Outdoor temperature" OR "Heat exposure" OR "environmental temperature"	2,988,712	
Filter: Journals only, English	#2 "Occupational injury" OR "Work injury" OR "Accident" OR "Wound" OR "Damage" OR "Work-related injury" OR "incident" OR "Fall risk" OR "falling" OR "occupational accident"	30537	
	#3 "Work-related" OR "Occupation" OR "Work" "Workplace" OR "Outdoor industry" OR "workplace" OR "Indoor industry" OR "Worker's compensation"	9572	
	#4 "Epidemiology" OR "Morbidity" OR "Prevalence" OR "Incidence"	2,441,583	
	#5 #1 AND #2 AND #3 AND #4		191
Web of Science	#1 TITLE: (("extreme weather" OR "ambient temperature" OR "extreme heat" OR Heat OR "high temperature" OR "high temperatures" OR "Heat wave" OR "Heat waves" OR temperature OR temperatures OR "temperature extremes"))	904285	
	#2 TITLE: ((injur* OR trauma OR wound* OR accident*))	425877	
	#3 TITLE: ((work* OR workplace* OR occupation* OR worker*))	560650	
	#4 #1 AND #2 AND #3		19
TOTAL RESULTS			**1468**

B2 Supplementary Material for Chapter 4

Calculation of Meteorological Variables

1. Apparent Temperature

The calculation of apparent temperature (AT) combines relative humidity, wind speed, solar radiation and maximum temperature into a single value;[1]

$AT_{air}=T_{air}+0.348e-0.70ws+0.70\frac{Q}{(ws+10)}-4.25$

Where:

T_{air}=Dry bulb temperature (°C)

e=Water vapour pressure (hPa) [humidity]

ws=Wind speed (m/s) at an elevation of 10 meters

Q=Net radiation absorbed per unit area of body surface (w/m^2)

The vapour pressure can be calculated from the temperature and relative humidity using the equation: $e=\frac{Rh}{100*6.105*\exp(17.27*\frac{Tair}{237.7+Tair})}$ where: Rh=relative humidity

2. Heat Index

HI combining temperature and relative humidity,[2] was calculated as;

HI=

$-42.379+2.04901523*T+10.14333127*Rh-.22475541*T*Rh-.00683783*T*T-.05481717*Rh*Rh+.00122874*T*T*Rh+.00085282*T*Rh*Rh-.00000199*T*T*Rh*Rh$

Where:

T: Temperature (in Fahrenheit)

Rh: relative humidity (in percent)

Note: Certain adjustments are made to the HI depending on the relative humidity and temperature ranges.

- If Rh is less than 13% and temperature range is 80–112, then the following value is subtracted from HI:

Adjustment=HI−[(13-Rh)/4]*SQRT {[17-ABS (T-95)]/17}

Where:

ABS: absolute value and SQRT: square root

- If Rh is greater than 85% and temperature range is 80–87, then the following value is added to HI:

Adjustment=HI + [(Rh-85)/10] * [(87-T)/5]

- If the temperature range is below 80, then HI is derived as;

HI=0.5 * {T + 61.0 + [(T-68.0)*1.2] + (Rh*0.094)}

3. Humidex

Humidex is similar to HI as it also combines relative humidity and temperature and is used by Canadian meteorologists,[3] derived as;

Humidex (HX)=T_{max} + (0.5555*(e-10)

Where:

e: Vapor pressure (in millibars)

4. Universal Thermal Comfort Index and Wet Bulb Globe Temperature

These two indices was calculated from the Excel Heat Stress Calculator downloaded from http://www.climatechip.org/excel-wbgt-calculator

The calculations of UTCI follows the methods described on www.utci.org while WBGT calculations followed the recommended Liljegren method where, temperature, humidity, solar radiation and wind speed are combined to generate a single value.[4]

$$WBGT\ (outdoor) = 0.7 \times Tnwb + 0.2 \times Tg + 0.1 \times Ta$$

Where:

Tnwb=natural wet bulb temperature

Tg=globe temperature

Ta=ambient temperature

Claim Characteristics

Table B2 Claim characteristics by worker details, Adelaide (2003–2013).

Factor	Categories	n	%
Age (years)	15–24	37540	17
	25–34	46823	21
	35–54	109342	49
	>55	30814	14
Experience	Experienced	192900	86
	New	31731	14
Gender	Female	75455	34
	Male	149176	66
Industry	Agriculture, Forestry, Fishing and Hunting	1608	1
	Communication	137	0.8
	Community Services	69455	31
	Construction	17199	8
	Electricity, Gas and Water	1797	1
	Finance, Property and Business Services	10156	5
	Manufacturing	54124	24
	Mining	1414	1
	Public Administration and Defence	6543	3
	Recreation, Personal and Other Services	12276	5
	Transport and Storage	12387	6
	Wholesale and Retail Trade	37507	17

Table B3 Claim characteristics by work activity, Adelaide (2003–2013).

Factor	Categories	n	%
Occupational groups	Animal and Horticultural	6653	3
	Automobile Drivers	1640	1
	Carpenters	5730	3
	Cleaners	6870	3
	Construction	3933	2
	Electrical	5954	3
	Emergency Workers	6069	3
	Engineers	1457	1
	Farmers	224	0.1
	Food Factory	5536	2
	Food Service	7545	3
	Handypersons	3977	2
	Health and Personal Support	17781	8
	Heavy Vehicle Drivers	12172	5
	Hospitality	3387	2
	Machine Operators	24380	11
	Metal Workers	23764	11
	Miners	701	0.3
	Nurses	9719	4
	Office	32530	14
	Other Health Professionals	1028	0.5
	Outdoor Work Not Elsewhere Classified	1224	1
	Painters	597	0.3
	Passenger Transport	1748	1
	Plumbers	6429	3
	Printers	1339	1
	Scientists	1422	1
	Teachers	8328	4
	Vehicle Workers	8075	4
	Warehousing	14406	6
Physical demands of work	Limited (≤5 kg)	49646	22
	Light (5–10 kg)	39407	18
	Medium (10–20 kg)	86644	39
	Heavy (>20 kg)	48929	22

Table B4 Claim characteristics by workplace, Adelaide (2003–2013).

Factor	Categories	n	%
Potential workplace temperature exposure	Regulated indoors	153218	68
	Unregulated indoors	559	0.2
	Outside	1486	1
	In a vehicle or cab	11001	5
	Multiple locations	58362	26
Size of business	Small (1–19 employees)	33240	15
	Medium (20–199 employees)	73253	33
	Large (≥200 employees)	118138	53
Season	Warm (October–March)	111254	50
	Cold (April–September)	113377	50
Day of week	Monday	42720	19
	Tuesday	42919	19
	Wednesday	42170	19
	Thursday	40041	18
	Friday	35091	16
	Saturday	12565	6
	Sunday	9125	4
Public holidays	Yes	2645	1
	No	221986	99

Workers' Compensation Claims Data

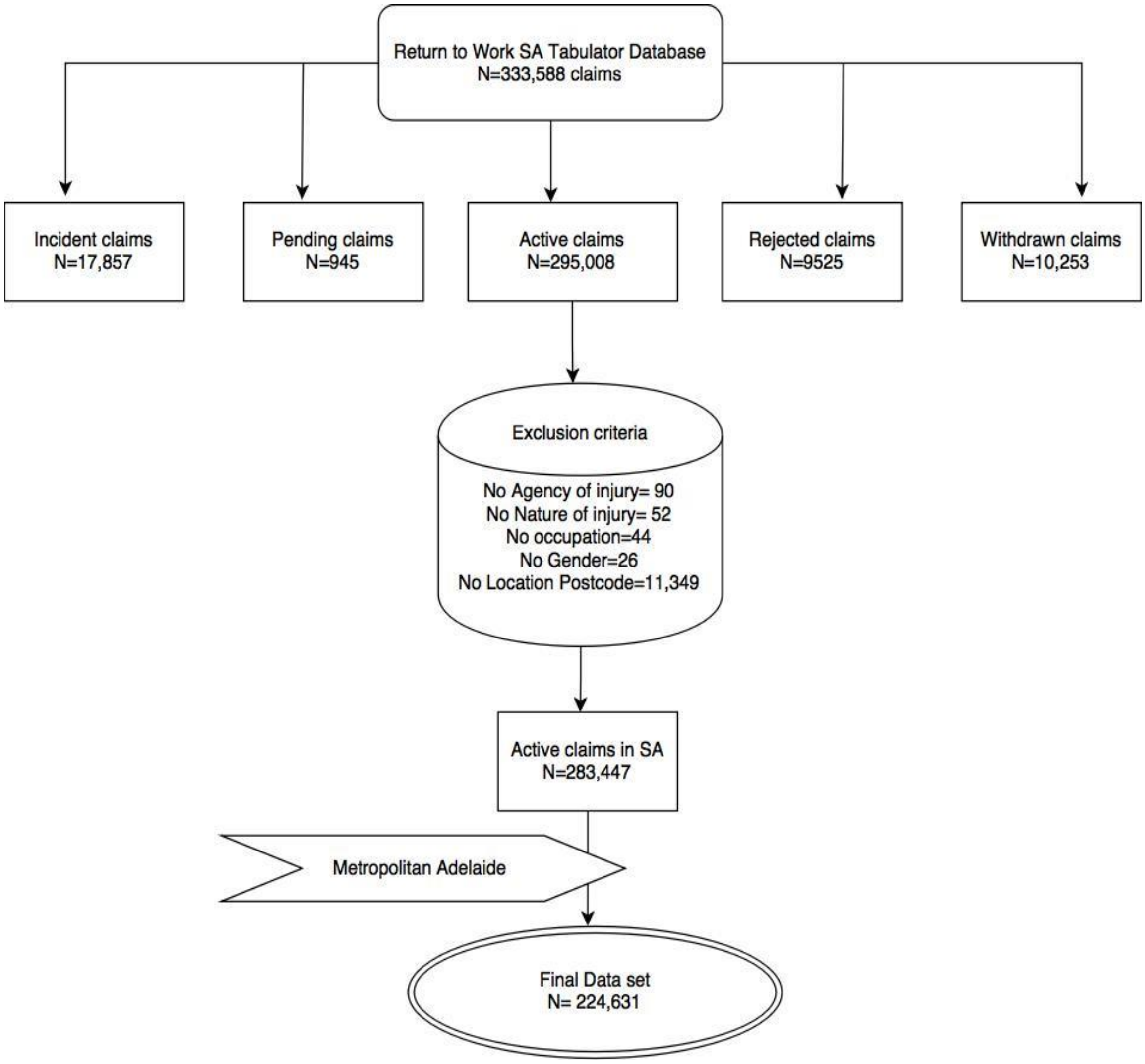
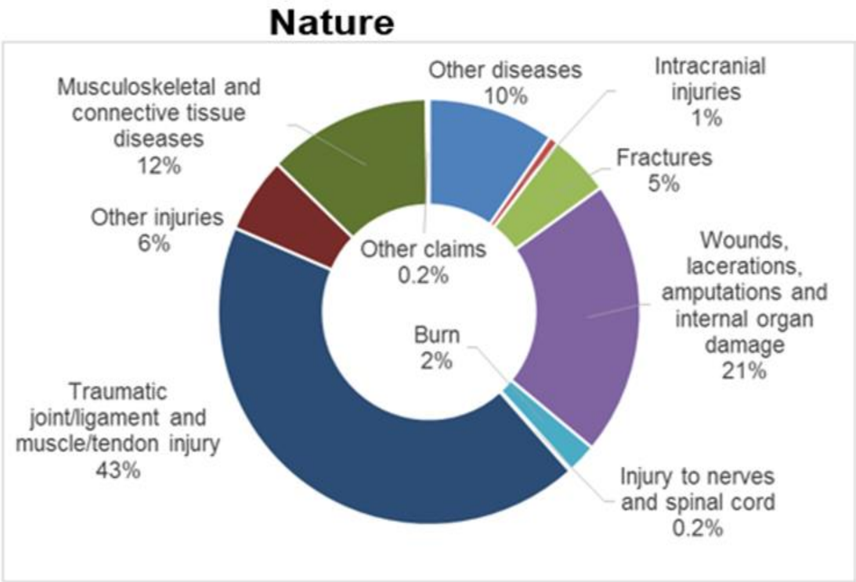


Figure B1 Flow diagram of inclusion and exclusion criteria for data selection.

Injury Characteristics



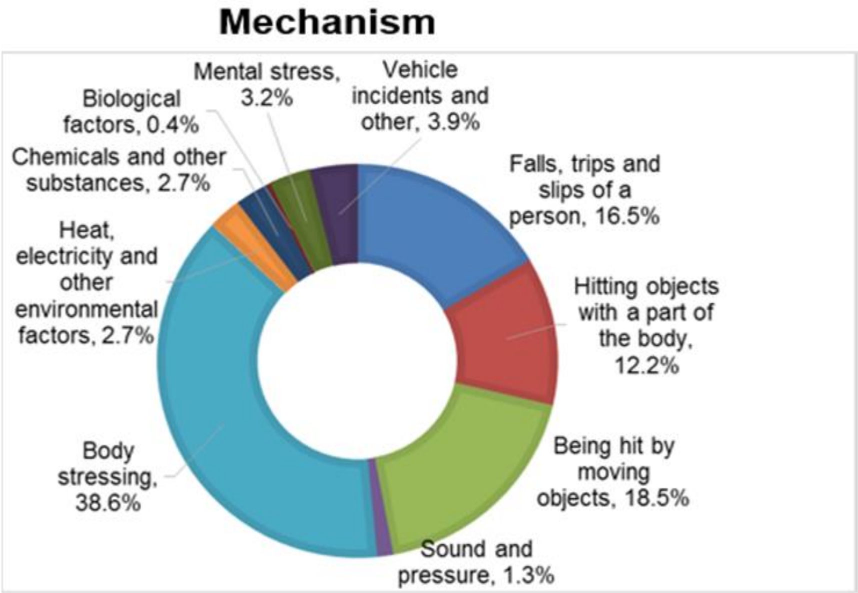


Figure B2 Injury characteristics by nature, agency, mechanism and body location (Adelaide, South Australia, 2003–2013).

Time Trends Over Time

From Figure B3, it can been seen that the number of claims have declined between 2003–04 and 2012–13. The two clusters in the scatterplot represent the number of claims during weekdays (upper cluster) and those during weekends and public holidays (lower cluster).

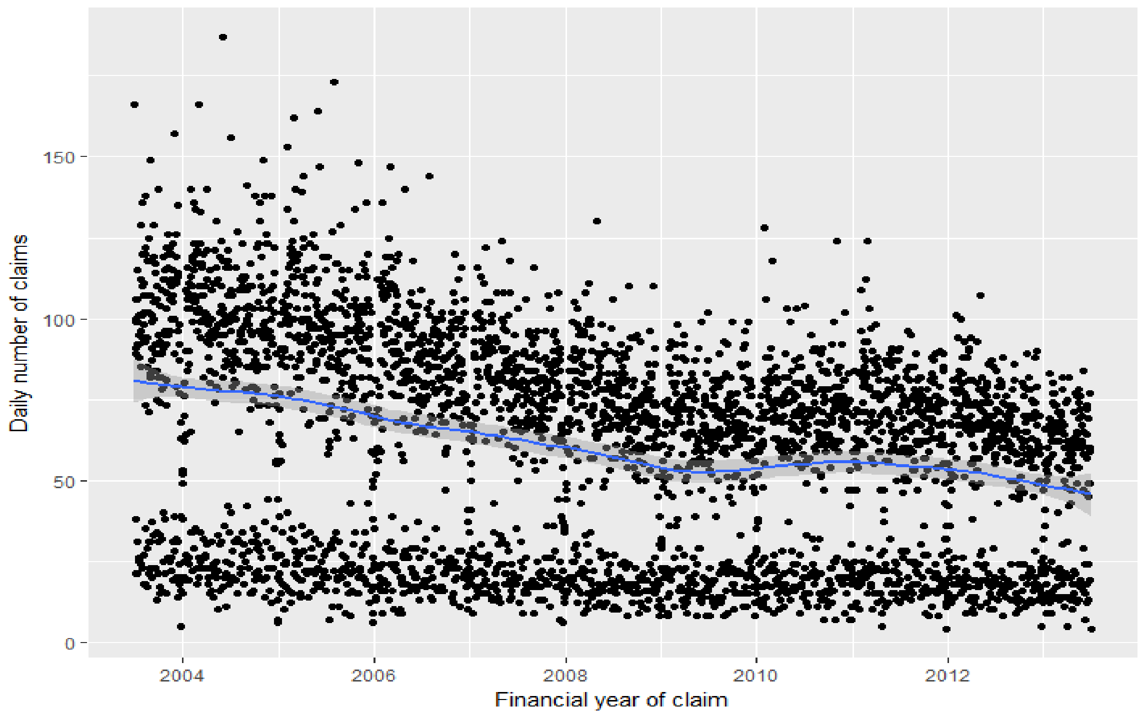


Figure B3 Characteristics of the workers' compensation claims (Adelaide, South Australia, 2003–2013).

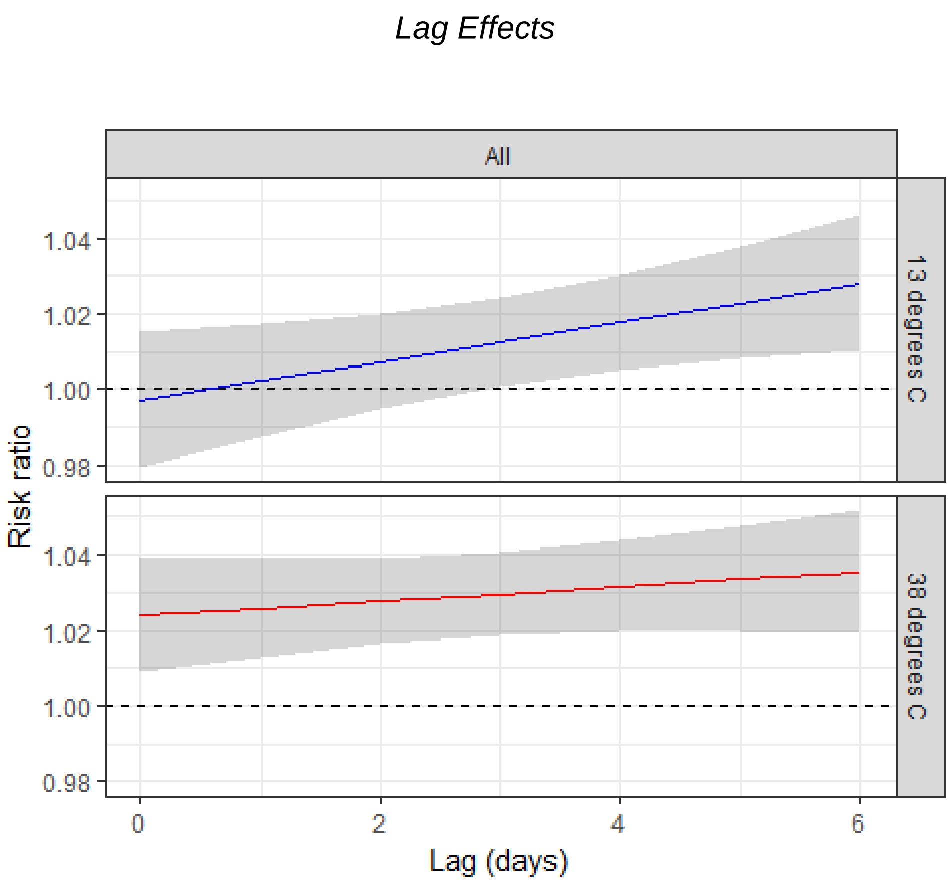


Figure B4 The effects of hot and cold temperatures on workers' compensation claims (Adelaide, South Australia, 2003–2013) along the lag days at selected temperatures: 1st percentile (13 °C) and 97.5th percentile (38 °C).

Sensitivity Analyses

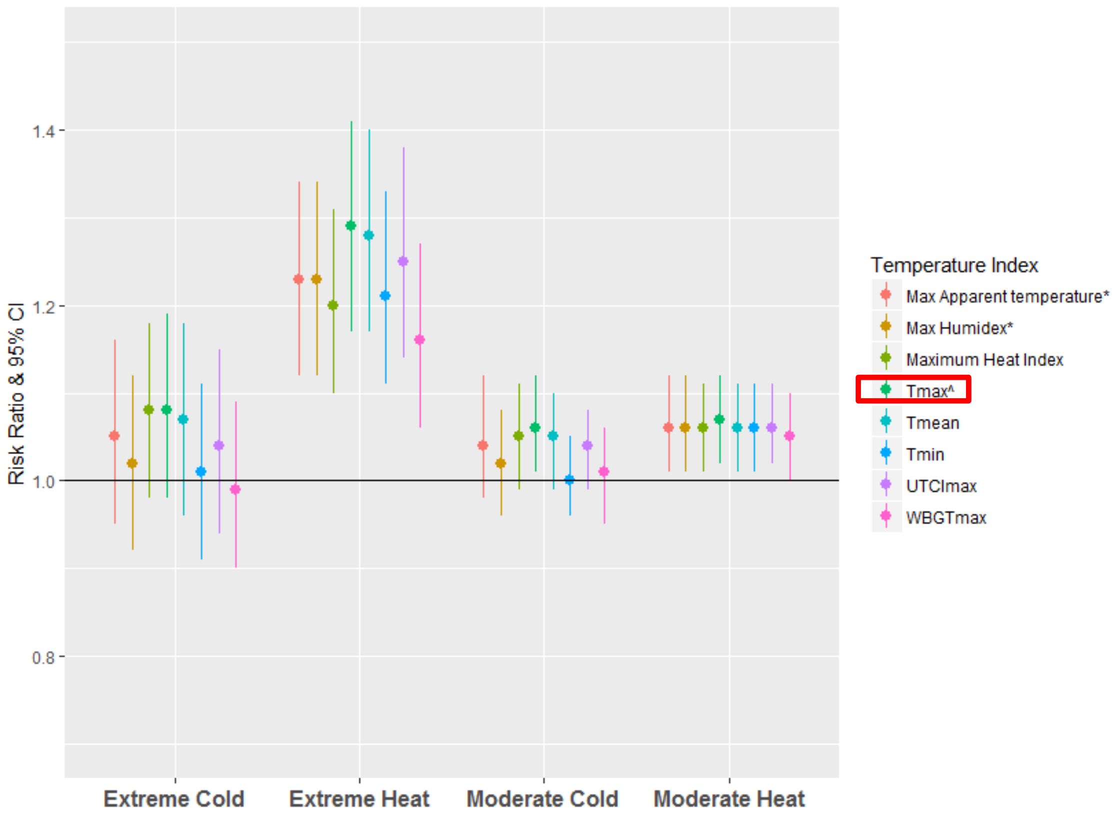


Figure B5 Sensitivity analysis of relative risk (RR) estimates by different meteorological metrics.

References

1. Australian Bureau of Meterology. About the Formula for Apparent Temperature. BOM; 2017 [updated 5 Feb 2010; cited 2017 22 Oct]. Available from: http://www.bom.gov.au/info/thermal_stress/?cid=003bl08#atapproximation

2. National Oceanographic and Atmospheric Administration National Weather Service. The Heat Index Equation. Maryland2014 [cited 2017 10 August]. Available from: http://www.wpc.ncep.noaa.gov/html/heatindex.shtml

3. Environment and Climate Change Canada. Glossary—Humidex. Government of Canada; 2017 [updated 10 Oct 2017; cited 2017 22 Oct]. Available from: http://climate.weather.gc.ca/glossary_e.html#h

4. Lemke B, Kjellstrom T. Calculating Workplace Wbgt from Meteorological Data: A Tool for Climate Change Assessment. Ind Health. 2012;50(4):267–78.

B3 Supplementary Material for Chapter 5

Claim characteristics

Table B5 Description of the workers' compensation claims dataset, 2005–2016.

Classification	Combined n (%)	Brisbane n (%)	Melbourne n (%)	Perth n (%)
All claims	798,831	260,730 (32.6)	258,379 (32.3)	279,722 (35.0)
Gender				
Female	274,580 (34.4)	95,037 (36.5)	937,37 (36.3)	85,806 (30.7)
Male	524,251 (65.6)	165,693 (63.6)	164,642 (63.7)	193,916 (69.3)
Age group (years)				
15–24	128,975 (16.2)	43,751 (16.8)	30,033 (11.6)	55,191 (19.7)
25–34	170,243 (21.3)	55,092 (21.1)	52,864 (20.5)	62,287 (22.3)
35–54	376,073 (47.1)	123,957 (47.5)	130,796 (50.6)	121,320 (43.4)
>55	123,540 (15.5)	37,930 (14.6)	44,686 (17.3)	40,924 (14.6)
Worker Experience				
Apprentice/trainee	18,094 (2.3)	8311 (3.2)	4915 (1.9)	4868 (1.7)
Other	698,155 (87.4)	251,901 (96.6)	253,023 (97.9)	193,231 (69.1)
Industry				
Agriculture, Forestry & Fishing	6597 (0.8)	2670 (1)	1463 (0.6)	2464 (0.9)
Mining	12,282 (1.5)	4103 (1.6)	787 (0.3)	7392 (2.6)
Manufacturing	144,065 (18)	45,428 (17.4)	41,619 (16.1)	57,018 (20.4)
Electricity, gas, water and waste services	8898 (1.1)	2895 (1.1)	2433 (0.9)	3570 (1.3)
Construction	82,741 (10.4)	23,867 (9.2)	23,868 (9.2)	35,006 (12.5)
Wholesale Trade	43,399 (5.4)	9752 (3.7)	18,913 (7.3)	14,734 (5.3)
Retail trade	79,132 (9.9)	20,408 (7.8)	29,100 (11.3)	29,624 (10.6)
Accommodation & Food Services	32,163 (4)	10,448 (4)	10,755 (4.2)	10,960 (3.9)
Transport, Postal & Warehousing	68,133 (8.5)	21,839 (8.4)	27,896 (10.8)	18,398 (6.6)
Information Media & Telecommunications	5612 (0.7)	1143 (0.4)	2910 (1.1)	1559 (0.6)
Financial & Insurance Services	5349 (0.7)	1272 (0.5)	2696 (1)	1381 (0.5)
Rental, Hiring & Real Estate Services	8751 (1.1)	2524 (1)	2827 (1.1)	3400 (1.2)
Professional, Scientific & Technical Services	15,455 (1.9)	3010 (1.2)	5799 (2.2)	6646 (2.4)
Administrative & Support Services	33,565 (4.2)	14,296 (5.5)	11,592 (4.5)	7677 (2.7)
Public Administration & Safety	51,829 (6.5)	23,291 (8.9)	15,589 (6)	12,949 (4.6)
Education & Training	57,344 (7.2)	25,769 (9.9)	12,825 (5)	18,750 (6.7)
Health Care & Social Assistance	101,627 (12.7)	38,318 (14.7)	31,857 (12.3)	31,452 (11.2)
Arts & Recreation Services	16,980 (2.1)	2453 (0.9)	7915 (3.1)	6612 (2.4)
Other Services	249,09 (3.1)	7244 (2.8)	7535 (2.9)	10,130 (3.6)
Claim severity				
Minor claims	346,512 (43.4)	95,215 (36.5)	66,800 (25.8)	184,497 (65.9)
Major claims	452,319 (56.6)	165,515 (63.5)	191,579 (74.1)	95,225 (34.0)

Table B6 Relative risks for workers' compensation claims in hot and cold temperatures stratified by worker, work and work environment characteristics in Brisbane and Perth, 2005–2016 (RR with 95% CI).

	Brisbane[a]				Perth[b]			
Exposure	**Extreme cold**	**Moderate cold**	**Moderate heat**	**Extreme heat**	**Extreme cold**	**Moderate cold**	**Moderate heat**	**Extreme heat**
Claim severity								
Minor claims	0.94 (0.80,1.10)	1.06 (0.97,1.17)	0.94 (0.88,1.01)	1.03 (0.86,1.22)	0.94 (0.84,1.05)	0.97 (0.91,1.03)	1.03 (0.97,1.10)	1.07 (0.96,1.20)
Major claims	0.87 (0.78,0.98)	0.96 (0.90,1.03)	0.97 (0.93,1.02)	0.96 (0.85,1.08)	1.01 (0.87,1.17)	1.04 (0.96,1.12)	0.90 (0.83,0.98)	0.92 (0.79,1.06)
Gender								
Male	0.89 (0.79–0.99)	0.99 (0.93,1.07)	0.97 (0.92,1.02)	1.01 (0.89,1.14)	0.95 (0.86,1.06)	0.98 (0.93,1.04)	1.01 (0.96,1.08)	1.07 (0.96,1.19)
Female	0.89 (0.77,1.05)	0.98 (0.90,1.08)	0.96 (0.90,1.02)	0.94 (0.80,1.11)	0.99 (0.85,1.16)	1.01 (0.93,1.10)	0.93 (0.85,1.02)	0.92 (0.79,1.07)
Age group (years)								
15–24	0.73 (0.58,0.92)	0.96 (0.84,1.10)	0.99 (0.90,1.09)	1.16 (0.90,1.48)	0.98 (0.81,1.19)	1.01 (0.91,1.12)	1.03 (0.92,1.15)	1.15 (0.95,1.40)
25–34	0.84 (0.68,1.03)	1.01 (0.90,1.14)	0.95 (0.88,1.04)	1.05 (0.84,1.29)	0.91 (0.75,1.09)	0.97 (0.88,1.07)	0.92 (0.83,1.02)	0.91 (0.76,1.10)
35–54	0.95 (0.83,1.09)	1.01 (0.93,1.09)	0.97 (0.92,1.03)	0.99 (0.86,1.14)	0.93 (0.82,1.07)	0.98 (0.92,1.05)	0.97 (0.90,1.05)	1.03 (0.90,1.17)
>55	1.00 (0.78,1.28)	0.96 (0.83,1.10)	0.93 (0.85,1.03)	0.74 (0.57,0.95)	1.15 (0.91,1.44)	1.03 (0.91,1.16)	1.09 (0.96,1.24)	0.98 (0.78,1.24)
Worker experience								
Apprentice/Trainee	0.76 (0.44,1.31)	1.05 (0.76,1.45)	0.88 (0.70,1.12)	0.96 (0.51,1.81)	0.64 (0.29,1.38)	0.85 (0.57,1.27)	0.79 (0.55,1.15)	0.85 (0.46,1.57)
Other	0.90 (0.82,0.99)	0.99 (0.94,1.05)	0.97 (0.93,1.01)	0.98 (0.89,1.09)	0.97 (0.87,1.08)	0.98 (0.93,1.04)	1.03 (0.97,1.09)	1.06 (0.96,1.18)
Potential workplace temperature exposure								
Regulated indoors	0.89 (0.79,0.99)	1.00 (0.93,1.07)	0.95 (0.91,1.01)	0.96 (0.85,1.09)	0.95 (0.85,1.05)	0.98 (0.93,1.04)	0.98 (0.92,1.04)	1.00 (0.90,1.11)
Unregulated indoors and outside	0.82 (0.38,1.76)	0.85 (0.54,1.33)	1.01 (0.73,1.38)	0.83 (0.36,1.93)	1.97 (0.87,4.47)	1.27 (0.82,1.98)	0.91 (0.58,1.43)	0.47 (0.22,1.03)
In a vehicle or cab	1.10 (0.76,1.58)	1.14 (0.92,1.41)	0.98 (0.85,1.14)	1.20 (0.81,1.75)	0.99 (0.68,1.43)	1.04 (0.85,1.27)	0.90 (0.73,1.11)	0.99 (0.68,1.43)
Multiple locations	0.85 (0.71,1.03)	0.95 (0.86,1.06)	0.98 (0.91,1.06)	1.00 (0.82,1.21)	0.96 (0.81,1.15)	0.99 (0.90,1.08)	1.04 (0.94,1.15)	1.13 (0.95,1.35)
Physical demands								
Limited (≤5kg)	0.78 (0.64,0.95)	0.91 (0.81,1.02)	0.97 (0.90,1.05)	0.91 (0.74,1.14)	0.96 (0.79,1.16)	1.00 (0.90,1.10)	1.00 (0.89,1.11)	1.07 (0.88,1.30)
Light (5–10kg)	1.05 (0.83,1.31)	1.16 (1.02,1.32)	0.88 (0.81,0.97)	0.94 (0.75,1.19)	0.96 (0.79,1.16)	0.99 (0.89,1.09)	1.01 (0.90,1.12)	1.06 (0.88,1.28)
Medium (10–20kg)	0.95 (0.81,1.12)	0.97 (0.89,1.07)	1.02 (0.95,1.08)	1.04 (0.87,1.22)	0.94 (0.82,1.09)	0.99 (0.92,1.07)	0.98 (0.90,1.06)	1.03 (0.90,1.19)

	Brisbane[a]				Perth[b]			
Exposure	**Extreme cold**	**Moderate cold**	**Moderate heat**	**Extreme heat**	**Extreme cold**	**Moderate cold**	**Moderate heat**	**Extreme heat**
Heavy (>20 kg)	0.81 (0.67,0.97)	0.98 (0.88,1.10)	0.95 (0.89,1.03)	1.01 (0.83,1.23)	1.00 (0.83,1.20)	0.99 (0.89,1.09)	0.98 (0.89,1.09)	0.91 (0.76,1.10)
Industry								
Indoor	0.92 (0.71–1.20)	0.99 (0.94–1.06)	0.96 (0.92–0.99)	0.97 (0.73–1.28)	0.90 (0.82–1.00)	0.96 (0.91–1.01)	0.99 (0.93–1.05)	1.03 (0.93–1.14)
Outdoor	0.89 (0.81–0.98)	0.93 (0.80–1.09)	1.02 (0.91–1.13)	0.98 (0.88–1.09)	1.18 (0.98–1.41)	1.10 (0.99–1.21)	0.97 (0.87–1.07)	0.97 (0.81–1.16)

Abbreviations: CI: confidence interval; RR: relative risk. *p <0.05

a. All temperatures were compared with the median maximum temperature of 27 °C.
b. All temperatures were compared with the median maximum temperature of 24 °C.

Table B7 Relative risks for workers' compensation claims in hot and cold temperatures using alternative temperature metrics in Brisbane, Melbourne and Perth, 2005–2016 (RR with 95% CI).

City	**Brisbane**		**Melbourne**		**Perth**	
Temperature metric	**Cold effect**	**Heat effect**	**Cold effect**	**Heat effect**	**Cold effect**	**Heat effect**
T_{max}*	0.89 (0.81–0.98)	0.98 (0.89–1.09)	0.99 (0.90–1.09)	1.14 (1.03–1.25)	0.96 (0.88–1.05)	1.02 (0.93–1.11)
T_{mean}	1.09 (0.97–1.21)	0.99 (0.90–1.09)	1.06 (0.96–1.16)	1.09 (0.99–1.19)	1.02 (0.93–1.12)	1.04 (0.94–1.14)
T_{min}	1.19 (1.08–1.30)	0.97 (0.88–1.07)	1.10 (1.01–1.20)	1.01 (0.92–1.10)	1.04 (0.95–1.14)	1.10 (0.99–1.21)
HX_{max}~	0.92 (0.84–1.01)	1.01 (0.91–1.10)	1.02 (0.93–1.12)	1.12 (1.02–1.24)	0.96 (0.89–1.05)	1.03 (0.94–1.14)
HI_{max}~	0.90 (0.82–0.99)	0.99 (0.90–1.09)	1.02 (0.93–1.12)	1.12 (1.02–1.24)	0.97 (0.89–1.06)	1.03 (0.93–1.14)
$WBGT_{max}$^	0.92 (0.85–1.02)	1.01 (0.92–1.11)	1.03 (0.94–1.13)	1.12 (1.02–1.24)	0.97 (0.89–1.06)	1.04 (0.94–1.14)
$UTCI_{max}$^	0.90 (0.83–0.99)	0.99 (0.90–1.11)	0.91 (0.84–1.01)	1.14 (1.03–1.26)	0.95 (0.88–1.04)	1.03 (0.93–1.13)
AT_{max}^	0.92 (0.84–1.02)	1.01 (0.91–1.11)	0.94 (0.86–1.03)	1.13 (1.03–1.24)	0.96 (0.88–1.05)	1.01 (0.92–1.11)

Abbreviations: Maximum humidex (HX_{max}); maximum heat index (HI_{max}); maximum Wet Bulb Globe Temperature ($WBGT_{max}$); Universal Thermal Comfort Index ($UTCI_{max}$) and maximum apparent temperature (AT_{max}). Symbols used:

- Main metric used in this study*
- Composite temperature indices combining temperature and relative humidity ~
- Composite temperature indices combining temperature, relative humidity, wind speed and solar radiation ^

B4 Supplementary Material for Chapter 6

Table B8 Effect estimates (risk ratios) for the associations between workers' compensation claims and heatwave severity in Adelaide, October to March 2003 to 2013.

Exposure	Risk ratio (95% CI)		
		HWD1	HWD2
Claim characteristics	Low-intensity	Moderate/high-severity	
All claims	1.01 (0.98,1.04)	1.31 (1.28,1.34)	1.02 (0.98,1.06)
Injury claims	1.02 (0.96,1.03)	1.32 (1.29,1.36)	1.02 (0.98,1.07)
Illness claims	1.13 (1.03,1.25)	1.21 (1.14,1.30)	0.94 (0.82,1.07)
Gender			
Female	0.98 (0.92,1.03)	1.23 (1.19,1.28)	1.01 (0.94,1.08)
Male	1.03 (0.99,1.07)	1.35 (1.32,1.39)	1.02 (0.97,1.07)
Age group			
15–24	1.00 (0.92,1.08)	1.27 (1.21,1.34)	1.08 (0.98,1.18)
25–34	0.99 (0.92,1.06)	1.41 (1.35,1.48)	1.00 (0.91,1.09)
35–54	1.01 (0.96,1.06)	1.29 (1.26,1.34)	1.01 (0.95,1.06)
>55 years	1.07 (0.98,1.16)	1.28 (1.21,1.36)	1.02 (0.91,1.13)
Worker experience			
Experienced worker	1.02 (0.98,1.05)	1.31 (1.28, 1.34)	1.01 (0.97,1.06)
New worker	0.99 (0.91,1.07)	1.34 (1.26, 1.41)	1.03 (0.94,1.14)
Industry location			
Outdoor	1.04 (0.94,1.16)	1.42 (1.33, 1.51)	1.11 (0.98,1.27)
Agriculture, Forestry, Fishing & Hunting	0.95 (0.66,1.37)	1.79 (1.41, 2.26)	0.98 (0.62,1.54)
Construction	1.06 (0.94,1.19)	1.38 (1.28, 1.48)	1.06 (0.92,1.23)
Electricity, Gas & Water	0.88 (0.6,1.29)	1.74 (1.35, 2.23)	1.46 (0.92,2.30)
Mining	1.21 (0.81,1.82)	1.17 (0.89, 1.54)	1.77 (1.03,3.02)
Indoor	1.01 (0.98,1.04)	1.30 (1.27, 1.33)	1.01 (0.97,1.05)
Communication	0.61 (0.16,2.37)	1.97 (0.9, 4.32)	0.34 (0.06,1.91)
Community Services	0.97 (0.92,1.03)	1.27 (1.22, 1.32)	1.05 (0.98,1.13)
Finance, Property & Business Services	1.08 (0.93,1.25)	1.15 (1.05, 1.27)	1.04 (0.87,1.25)
Manufacturing	1.08 (1.01,1.16)	1.47 (1.41, 1.53)	1.01 (0.93,1.10)
Public Administration & Defence	1.10 (0.91,1.34)	1.49 (1.32, 1.68)	0.93 (0.73,1.19)
Recreation, Personal & Other Services	0.93 (0.82,1.07)	1.06 (0.97, 1.16)	0.85 (0.72,1.01)
Transport & Storage	1.05 (0.92,1.19)	1.39 (1.28, 1.52)	0.95 (0.80,1.12)
Wholesale & Retail Trade	0.99 (0.92,1.07)	1.22 (1.16, 1.28)	1.06 (0.96,1.17)
Occupations			
Managers	0.95 (0.79,1.14)	1.21 (1.08,1.36)	0.83 (0.65,1.06)
Professionals	0.91 (0.82,1.02)	1.20 (1.11,1.29)	1.08 (0.95,1.24)
Technicians & trade workers	1.04 (0.97,1.11)	1.32 (1.27,1.38)	1.03 (0.94,1.12)
Community & personal	0.97 (0.89,1.05)	1.15 (1.08,1.22)	0.92 (0.83,1.03)
Clerical & administrative	1.06 (0.92,1.22)	1.29 (1.18,1.41)	0.96 (0.80,1.15)
Sales workers	0.84 (0.74,0.96)	1.17 (1.07,1.27)	1.04 (0.88,1.21)
Machinery operators & drivers	1.07 (0.99,1.15)	1.42 (1.35,1.49)	1.08 (0.98,1.19)

Labourers	1.08 (1.02,1.16)	1.42 (1.36,1.48)	1.06 (0.97,1.15)

Shaded cells denote statistically significant differences based on the 95% CI; HWD1 based on EHF intensity and HWD2 based on Tmax of 35 °C for ≥3 consecutive days.

Table B9 Risk ratios of workers' compensation claims by work environment characteristics by heatwave severity in Adelaide metropolitan area, October to March 2003 to 2013.

Exposure	**Risk ratio (95% CI)**		
		HWD1	**HWD2**
Work environment	**Low-intensity**	**Moderate/high-severity**	
Size of business			
Small	1.01 (0.93,1.10)	1.30 (1.23,1.37)	0.98 (0.88,1.10)
Medium	1.05 (0.99,1.11)	1.34 (1.29,1.39)	1.04 (0.97,1.12)
Large	0.99 (0.95,1.03)	1.31 (1.26,1.34)	1.01 (0.96,1.07)
Worksite location			
Adelaide CBD	0.99 (0.91,1.06)	1.22 (1.16,1.28)	0.98 (0.89,1.08)
Adelaide Inner suburb	1.01 (0.97,1.05)	1.36 (1.32,1.39)	0.99 (0.94,1.05)
Adelaide Outer suburbs	1.05 (0.98,1.13)	1.28 (1.22,1.33)	1.11 (1.02,1.21)
Workplace hazards			
Dangerous chemical substances	1.10 (0.96,1.26)	1.46 (1.34,1.60)	1.10 (0.92,1.31)
Equipment, machinery, tools	0.90 (0.72,1.12)	1.29 (1.21–1.38)	0.90 (0.69,1.17)
Electricity	0.98 (0.88,1.08)	1.42 (0.81–2.51)	1.05 (0.92,1.20)
Dangerous locations	0.68 (0.44,1.06)	1.29 (0.95–1.74)	1.13 (0.68,1.87)
Multiple hazards	1.05 (0.99,1.11)	1.38 (1.33–1.44)	1.04 (0.97,1.12)
Time of injury			
00.00–01.59	1.07 (1.01,1.15)	1.29 (1.24, 1.35)	0.85 (0.77,0.93)
02.00–03.59	1.15 (0.85,1.55)	1.41 (1.12, 1.78)	1.02 (0.71,1.47)
04.00–05.59	1.06 (0.77,1.45)	1.10 (0.90, 1.35)	0.85 (0.58,1.27)
06.00–07.59	0.97 (0.85,1.12)	1.51 (1.38, 1.64)	1.26 (1.06,1.49)
08.00–09.59	0.98 (0.90,1.06)	1.56 (1.48, 1.64)	1.07 (0.97,1.18)
10.00–11.59	0.99 (0.92,1.07)	1.37 (1.30, 1.43)	1.03 (0.94,1.14)
12.00–13.59	0.99 (0.90,1.08)	1.21 (1.14, 1.28)	1.16 (1.03,1.30)
14.00–15.59	1.06 (0.97,1.16)	1.17 (1.10,1.24)	1.02 (0.91,1.14)
16.00–17.59	0.94 (0.83,1.07)	1.24 (1.14, 1.34)	1.00 (0.85,1.18)
18.00–19.59	1.08 (0.90,1.29)	1.16 (1.03, 1.31)	1.20 (0.96,1.51)
20.00–21.59	1.15 (0.94,1.40)	1.04 (0.90, 1.21)	1.02 (0.79,1.32)
22.00–23.59	1.04 (0.81,1.35)	1.19 (0.99, 1.44)	1.19 (0.86,1.64)

Shaded cells denote statistically significant differences based on the 95% CI; HWD1 based on EHF intensity and HWD2 based on Tmax of 35 °C for ≥3 consecutive days.

B5 Supplementary Material for Chapter 7

Calculation of Excess Heat Factor

Heatwaves are normally defined as a periods of unusually or exceptionally hot weather. However, the challenge is, what defines an unusual or exceptionally hot event at different locations? Bearing in mind these complexities, the Australian BOM introduced, the EHF which is now part of the national heatwave warning service. Following trials in 2014 EHF has been a widely used metric in the literature both locally[1–11] and internationally[12–15] to define heatwaves and heatwave severity.

Put simply, this index is based on a three-day averaged daily mean temperature (DMT, represented as T in equations (a and b)) and is calculated as the product of two excess heat indices (EHIs): the significance index (EHI_{sig}) and the acclimatisation index (EHI_{accl}). These EHIs that indicate excess heat and heat stress, respectively are calculated as follows:

$$EHI_{sig}=(T_i+T_{i+1}+T_{i+2})/3-T_{95} \quad (a)$$

$$EHI_{accl}=(T_i+T_{i+1}+T_{i+2})/3-(T_{i-1}+\ldots+T_{i-30})/30 \quad (b)$$

$$EHF=EHIsig * \max(1, EHI_{accl})$$

Where T is the daily mean temperature, EHI_{sig} is the significance index, and EHI_{accl} is the acclimatisation index.

The comparison of the three-day DMT to the 95th percentile of DMT (long term climate reference value) produces EHI_{sig} which characterises how unusual the heat is in a specific location.[16] The EHI_{accl} which characterises the heat stress, is the comparison of the same three-day DMT to the DMT of the previous 30 days. In other words, this formula takes into account both the long-term climate reference value and the short term adaptation to increasing heat over a period of one month.[16] A heatwave event exists in a location if the EHF_{BOM} value is positive. Heatwave severity (EHF_{sev}) specific to each location as used in this study, is calculated as the ratio of EHF to the historical 85th percentiles of values of all positive EHF:

$$EHF_{sev} = EHF \div 85^{th} \text{ percentile of all positive values.}$$

The heatwave severity is categorised into four categories:

- No heatwave (daily $EHF_{sev} \leq 0$)
- Low-intensity ($0 < $ daily $EHF_{sev} < 1$)
- Severe ($1 \leq$ daily $EHF_{sev} < 3$)
- Extreme (daily $EHF_{sev} \geq 3$)

In this study heatwave exposure, defined by EHF_{sev} was analysed using the following categories:

- No heatwave: daily $EHF_{sev} \leq 0$;
- Low-intensity: daily $EHF_{sev} > 0$ and < 1;
- Moderate-severity: daily $EHF_{sev} \geq 1$ and < 2, and
- High-severity: daily $EHF_{sev} \geq 2$.

Further details on the development, calculation, and usage of EHF_{BOM} are provided by Nairn and Fawcett (2014).[16]

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B6 Supplementary Material for Chapter 8

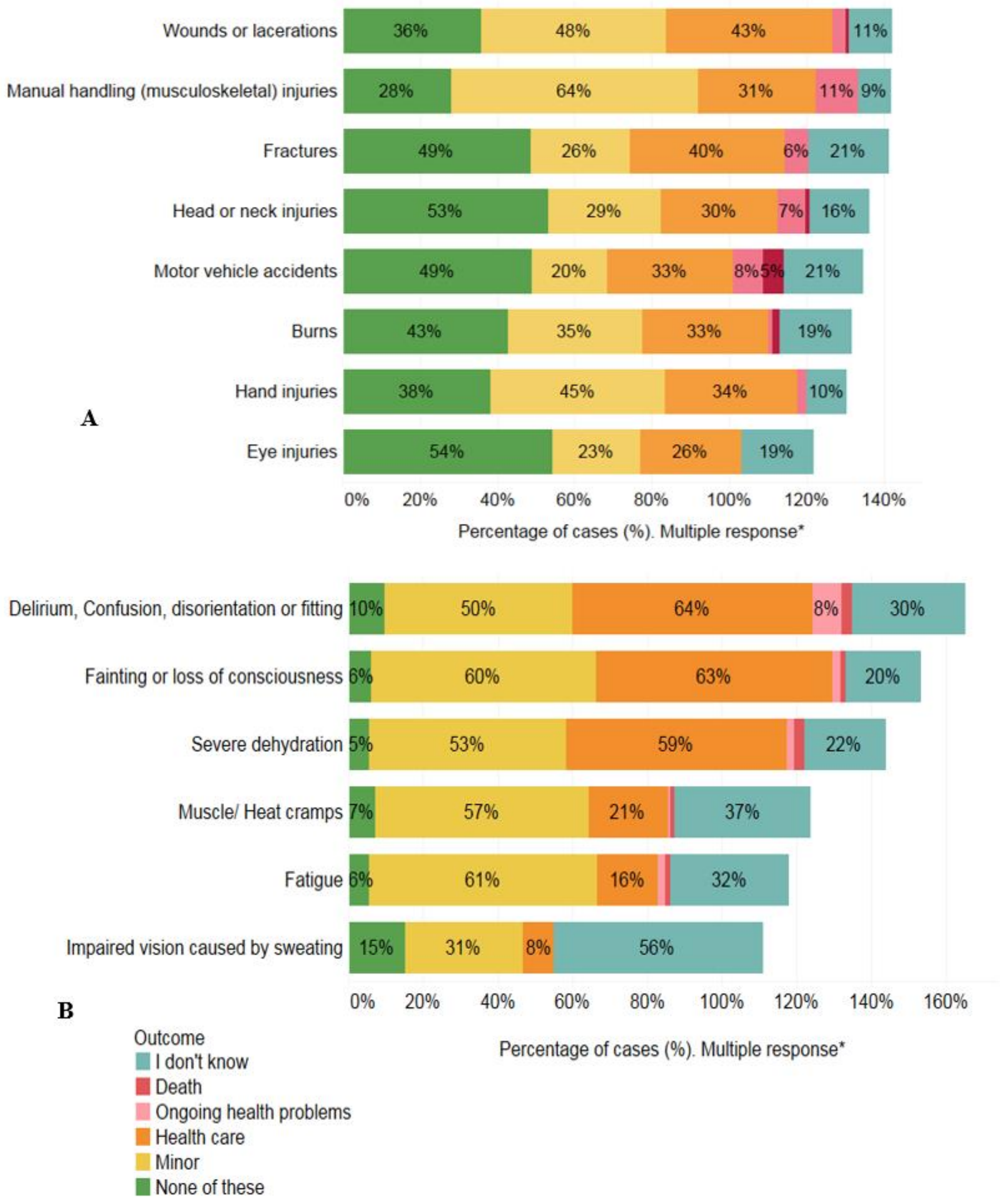

Figure B6 Outcome of Injuries/incidents cited by HSPs. A) Injuries; B) Incidents.

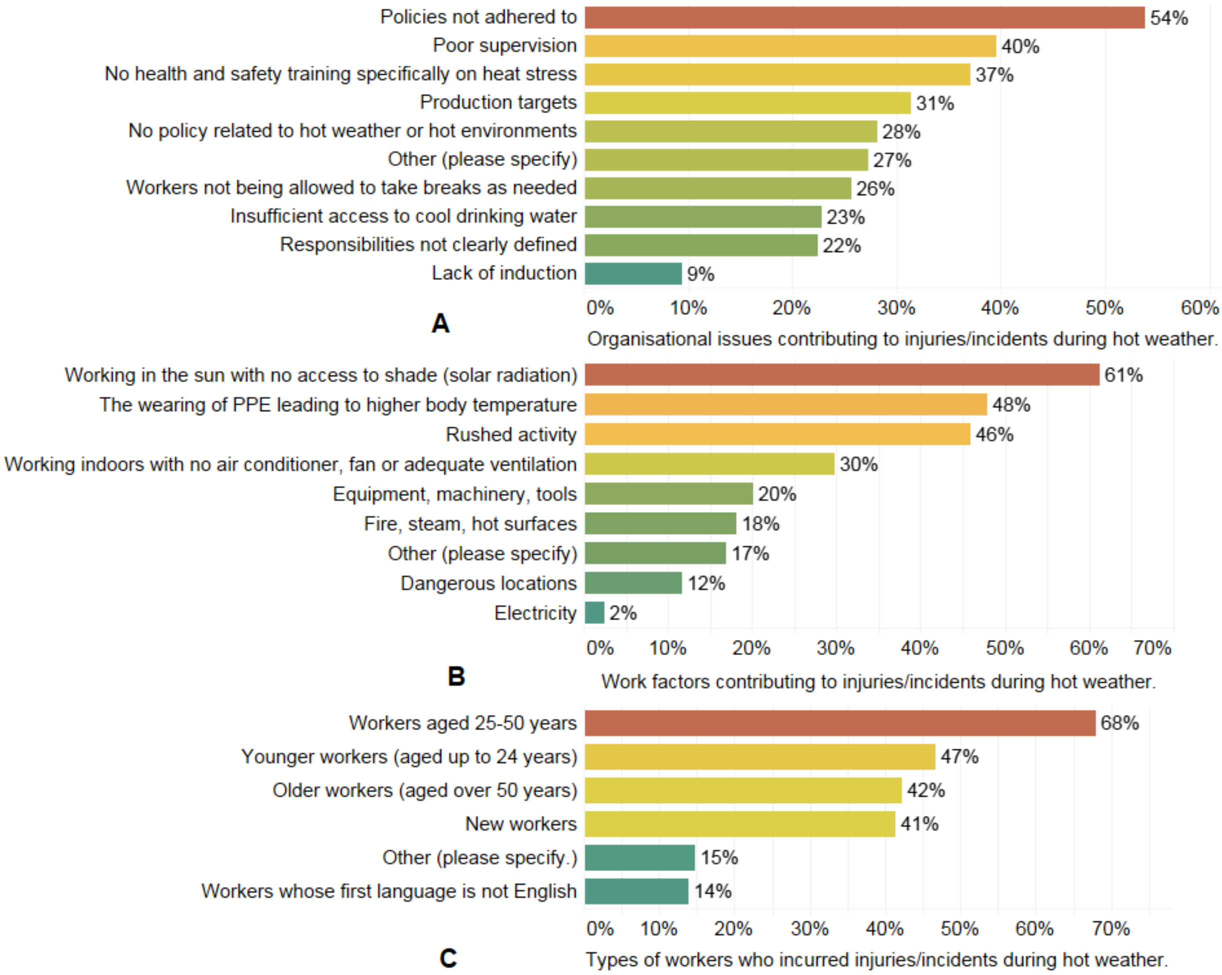

Figure B7 Contributing factors: (A) Organisational issues; (B) work factors and hazards; (C) types of workers who incurred heat-related injuries/incidents during hot weather as reported by HSPs.

Of these work practices, what do you think is the most important for preventing heat stress in outdoor workers? (choose only one) **A**	Heat stress training	22%
	Access to cool drinking water	19%
	Work gets re-scheduled to cooler times	13%
	Outdoor work ceases if temperature is extreme	12%
	Work/rest regimes	10%
	Workers allowed to self-pace	10%
	Job rotation	4%
	Shade erected over work area	3%
	Rest/lunch area with air conditioning	3%
	Increased supervision	3%
	PPE supplied	1%
	WH&S information signage on display	1%
	Urine specific gravity testing	1%
	Shaded rest area	0%

Of these practices, what do you think is the most important for preventing heat stress in indoor workers? (choose only one) **B**	Heat stress training	25%
	Air conditioning	24%
	Access to cool drinking water	21%
	Workers allowed to self-pace	11%
	Adequate ventilation	9%
	Job rotation	6%
	Shielding of heat sources	3%
	Packaged cooling systems to ventilate confined spaces	2%
	Urine specific gravity testing	0%
	Colour urine charts (to indicate dehydration)	0%
	H&S information signage on display	0%

Figure B8 Work practices most important for preventing heat stress in outdoor workers (A) and indoor workers (B).

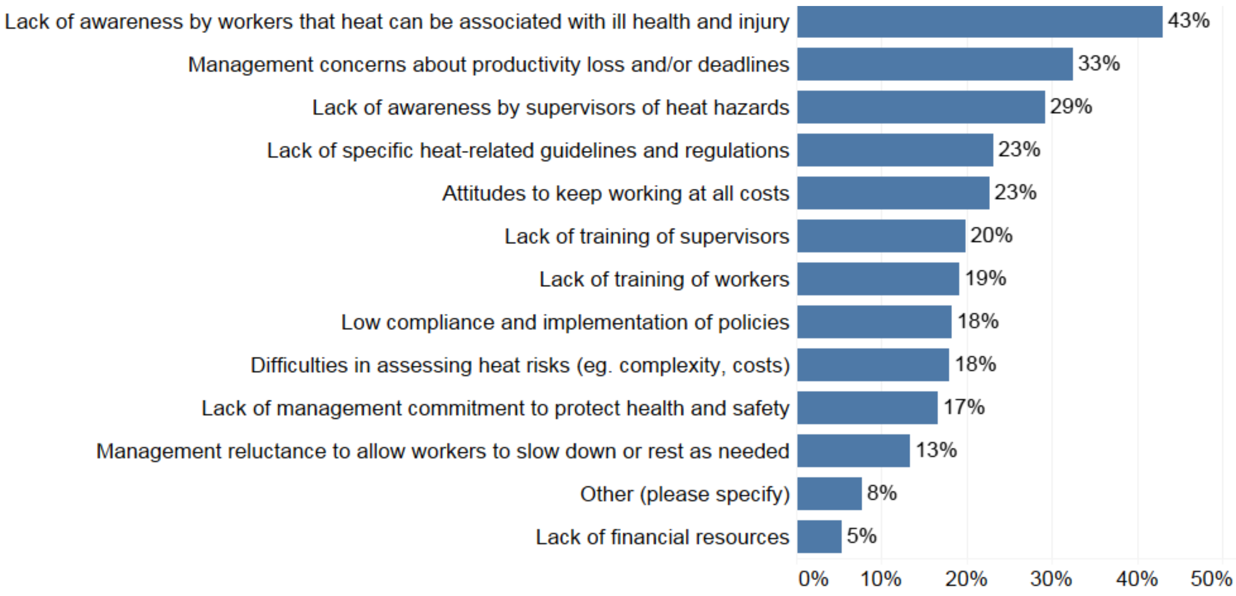

Figure B9 Perceived barriers for prevention of heat-related injuries, HSP perceptions.

Percentages shown do not add to 100% as multiple responses were allowed per respondent.

Table B10 Questions on prevention measures, HSPs perceptions.

Prevention questions	n (%)
Provision for outdoor work to cease if temperature is extreme	**n=254**
Yes	139 (55)
No	115 (45)
At what temperature does outdoor work cease	**n=132***
35 °C or below	7 (5)
36 °C	8 (6)
37 °C	10 (8)
38 °C	19 (14)
Varies between workplaces	88 (67)
Access to air-conditioning or fans for indoor workers	**n=248**
Never	1 (0.4)
Rarely	10 (4)
Sometimes	52 (21)
Often	184 (74)
Don't know	1 (0.4)
Types of cooling systems	**n=249**
Evaporative	46 (19)
Refrigerated	126 (51)
Industrial fans	55 (22)
Others	22 (9)

Note: * refers to questions with skip-logic.

Table B11 Questions on heat-stress training, HSPs perceptions.

Questions	n (%)
Training available for preventing heat-related injuries/incidents	**251**
Yes	105 (42)
No	44 (18)
Some workplaces	98 (39)
Don't know	4 (2)
Training for supervisors	**203***
Yes	105 (52)
No	10 (5)
Some workplaces	84 (41)
Don't know	4 (2)
Supervisors and workers trained separately	**191***
Yes	19 (10)
No	85 (45)
Varies by workplace	68 (36)
Don't know	19 (10)
How often is heat-stress training conducted?	**205~**
Annually regardless of job	73 (35.6)
Once only at induction when starting a new job where heat could be a hazard	63 (30.7)
Others	39 (19)
Don't know	30 (14.6)
Every two years	17 (8.3)
Once when changing roles or when using new equipment /processes where heat could be a hazard	17 (8.3)
How is heat stress training conducted?	**204~**
On site by health and safety professionals	136 (67)
On site by supervisors	94 (46)
On-line	74 (36)
On-site by consultants	28 (14)
Off site by professionals	24 (12)
Don't know	5 (2.5)
Quality of the heat stress training	**202**
Adequate	74 (37)
Limited	62 (31)
Varies	42 (21)
Comprehensive	17 (8)
Don't know	7 (4)
Is this training assessed?	**202**
No	94 (47)

Questions	n (%)
Sometimes	43 (21)
Yes	29 (14)
Varies by type of workplace	21 (10)
Unsure/ Don't know	15 (7)
Source of information and resources for heat stress training	**205~**
The employer	144 (70)
The safety regulator	50 (24)
Consultants	42 (21)
Other providers	23 (11)
The industry association	21 (10)
Unsure	17 (8)
Australian Institute of Occupational Hygienists (AIOH)	14 (7)

Note: ~ refers to questions with multiple responses and * refers to questions with skip-logic

Table B12 Questions on policies, guidelines, and risk assessments, HSPs perceptions.

Questions	n (%)
Heat stress or hot weather policy	**n=245**
Yes	153 (63)
No	50 (20)
Some industries[4]	33 (14)
Not sure	9 (4)
Heat stress management is implemented	**n=246**
Partially	155 (63)
Fully	69 (28)
Not at all	17 (7)
Unsure/Don't know	5 (2)
Indicators of heat risk	**n=247**
Air temperature at weather bureau	125 (51)
Air temperature on site	111 (45)
Apparent temperature (feels like temperature)	61 (25)
WBGT on site	44 (18)
None of the above	28 (11)
Thermal work limit calculation	21 (9)
Predicted heat strain calculation	19 (8)
Unsure/Don't know	14 (6)
Other (please specify)	18 (4)
Ingestible thermometers	5 (2)
Universal Thermal Comfort Index	4 (2)
Use of mobile device apps in heat stress management	**n=247**
No	164 (66)
Don't know	53 (22)
Yes	30 (12)

[4] Construction, Mining and Manufacturing

Table B13 Questions on productivity loss and potential solutions, HSPs perceptions.

Productivity loss	**n (%)**
Hot weather contributes to productivity loss	**n=245**
Yes	128 (52)
Sometimes	107 (44)
No	8 (3)
Unsure /Don't know	2 (1)
How much of a problem?	**n=235**
Minor problem	137 (58)
Major problem	65 (28)
Unsure/ Don't know	18 (8)
No problem	15 (6)
Have potential solutions been discussed?	**n=233**
Yes	119 (51)
No	79 (34)
Unsure /Don't know	35 (15)

Survey Questionnaire-Chapter 8

UNDERSTANDING AND PREVENTING INJURIES IN HOT WORKING CONDITIONS

THANK YOU FOR PARTICIPATING IN THIS SURVEY

This survey, which is being conducted by researchers at The University of Adelaide, is investigating workplace injuries in association with heat exposure.

This survey will take you approximately 10-20 minutes to complete and is anonymous to maintain confidentiality.

Your contribution to this survey is very greatly appreciated.

There are 7 sections in the survey. Please complete each section before moving to the next.

You may skip any questions you do not wish to answer.

SECTION 1: DEMOGRAPHICS

The following questions are about yourself:

1. In which state/territory do you mainly work?

- ◯ ACT
- ◯ NSW
- ◯ NT
- ◯ QLD-North
- ◯ QLD-South
- ◯ SA
- ◯ TAS
- ◯ VIC
- ◯ WA-North
- ◯ WA-South

2. What is your gender?

◯ Male ◯ Female ◯ Unspecified

3. What is your age group?

◯ 18-24 years ◯ 25-34 years ◯ 35-54 years ◯ 55 years and over

4. Approximate number of years of experience in health and safety:

◯ less than 5 years ◯ 5-10 years ◯ 11-20 years ◯ more than 20 years

5. For the purposes of this survey, your answers mainly reflect your experience in which industry (tick only one box below, and base your answers to the survey on your experience in that specific industry)

- ◯ Transport & Storage
- ◯ Manufacturing
- ◯ Mining
- ◯ Agriculture, Forestry & Fishing
- ◯ Construction
- ◯ Wholesale Trade & Retail Trade
- ◯ Electricity, Gas & Water
- ◯ I work with many business & industries
- ◯ Other (please specify: eg. hospitality, emergency services, etc)

6. Your current role in Health & Safety:

- ◯ Consultant
- ◯ Health and Safety Manager
- ◯ Health and Safety professional
- ◯ Inspector
- ◯ Other (please specify)

SECTION 2: HEAT-RELATED INJURIES/INCIDENTS

The following questions relate to the type of the injuries or incidents that you may have come across and the possible contributing factors.

7. In your experience of workplaces, would you say that injuries or incidents caused by (partly at least) hot/very humid weather occur:

- ◯ Never
- ◯ Often
- ◯ Rarely
- ◯ I don't know
- ◯ Sometimes

8. What type of **injuries** have occurred in workplaces that you visited where heat exposure could have been a (direct or in-direct) contributing factor? (tick all that apply)

- ☐ Head or neck injuries
- ☐ Fractures
- ☐ Hand injuries (eg. tools slipped)
- ☐ Burns (eg. burnt hand)
- ☐ Eye injuries
- ☐ Manual handling (musculoskeletal) injuries OR Joint/ligament injuries (e.g. sprains or strains)
- ☐ Wounds or lacerations
- ☐ Motor vehicle accidents
- ☐ Other (please specify)

9. Did any of the above injuries lead to: (tick all that apply)

	Sent home	Days off work	Ambulance called	Visit to Emergency department	Stay in hospital	Ongoing health problems	Death	None of these	I don't know
Head or neck injuries	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hand injuries (eg. tools slipped)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Eye injuries	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wounds or lacerations	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fractures	☐	☐	☐	☐	☐	☐	☐	☐	☐
Burns (eg. burnt hand)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Manual handling (musculoskeletal) injuries OR Joint/ligament injuries (e.g. sprains or strains)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Motor vehicle accidents	☐	☐	☐	☐	☐	☐	☐	☐	☐

10. In hot weather, have you encountered injuries in the following categories? (tick all that apply)

- ☐ Injuries caused by falling off a ladder
- ☐ Injuries occurring due to hot machinery or surfaces
- ☐ Impaired vision due to fogged safety glasses
- ☐ Loss of grip leading to injury
- ☐ Injuries with power tools
- ☐ Injuries resulting from not wearing PPE
- ☐ Loss of control of tools leading to injury
- ☐ Injuries arising from slips, trips or falls
- ☐ Other (please specify)

11. In your experience, what other types of **<u>incidents or illnesses</u>** have occurred in workplaces where heat exposure could be a contributing factor? (tick all that apply)

- ☐ Fainting or loss of consciousness
- ☐ Fatigue
- ☐ Muscle / Heat cramps
- ☐ Severe dehydration
- ☐ Impaired vision caused by sweating
- ☐ Delirium, confusion,disorientation or fitting
- ☐ Other (please specify)

12. Did any of the above incidents lead to: (tick all that apply)

	Sent home	Days off work	Ambulance called	Visit to Emergency department	Stay in Hospital	Ongoing health problems	Death	None of these	I don't know
Fainting or loss of consciousness	☐	☐	☐	☐	☐	☐	☐	☐	☐
Severe dehydration	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fatigue	☐	☐	☐	☐	☐	☐	☐	☐	☐
Impaired vision caused by sweating	☐	☐	☐	☐	☐	☐	☐	☐	☐
Muscle/ Heat cramps	☐	☐	☐	☐	☐	☐	☐	☐	☐
Delirium, confusion, disorientation or fitting	☐	☐	☐	☐	☐	☐	☐	☐	☐

The following questions relate to possible contribution of the workplace environment, work factors and the workers, to heat-related injuries/incidents.

13. What **work factors and hazards** do you think may have contributed to these heat-related injuries/incidents? (tick all that apply)

- ☐ Rushed activity
- ☐ The wearing of personal protective equipment (PPE) leading to higher body temperature
- ☐ Working in the sun with no access to shade (solar radiation)
- ☐ Working indoors with no air conditioner, fan or adequate ventilation
- ☐ Equipment, machinery, tools
- ☐ Electricity
- ☐ Fire, steam, hot surfaces
- ☐ Dangerous locations
- ☐ Other (please specify: e.g.new process/untested procedures)

14. Which of the following **organisational issues** do you think may have contributed to these heat-related injuries/incidents? (tick all that apply)

- ☐ No policy related to hot weather or hot environments
- ☐ Policies not adhered to
- ☐ Responsibilities not clearly defined
- ☐ Lack of induction
- ☐ No health and safety training specifically on heat stress
- ☐ Production targets
- ☐ Poor supervision
- ☐ Workers not being allowed to take breaks as needed
- ☐ Insufficient access to cool drinking water
- ☐ Other (please specify)

15. What **types of workers** have incurred these heat-related injuries/incidents? (tick all that apply)

- ☐ New workers
- ☐ Younger workers (aged up to 24 years)
- ☐ Workers aged 25-50 years
- ☐ Older workers (aged over 50 years)
- ☐ Workers whose first language is not English
- ☐ Other (please specify: e.g. noncompliance, personal risk factors and/or lifestyle)

SECTION 3: PREVENTIVE MEASURES

The following questions are about preventing heat-related injuries or incidents in outdoor and indoor workers.

16. For **outdoor workers,** how often are the following work practices adopted during hot weather? (tick all that apply)

	Never	Rarely	Sometimes	Often	Always	Unsure / Don't Know / N/A
Access to cool drinking water						
Broad brimmed hats supplied						
PPE supplied (eg. gloves, helmets)						
Use of cool vests						
Sunscreen supplied						
WH&S information signage on display						
Heat stress training						
Shaded rest area						
Shade erected over work area						
Rest/lunch area with air conditioning						
Rest/lunch area with an electric fan						
Packaged cooling systems to ventilate confined spaces						
Workers allowed to self-pace						
Job rotation						
Increased supervision						
Work gets re-scheduled to cooler times						
Work/rest regimes						
Colour urine charts (to indicate dehydration)						
Urine specific gravity testing						

Other (please specify)

17. Of these work practices, what do you think is the **most important** for preventing heat stress in outdoor workers? (choose only one)

- ◯ Access to cool drinking water
- ◯ Broad brimmed hats supplied
- ◯ PPE supplied
- ◯ Use of cool vests
- ◯ WH&S information signage on display
- ◯ Outdoor work ceases if temperature is extreme
- ◯ Heat stress training
- ◯ Shade erected over work area
- ◯ Shaded rest area
- ◯ Rest/lunch area with air conditioning
- ◯ Job rotation
- ◯ Increased supervision
- ◯ Workers allowed to self-pace
- ◯ Work gets re-scheduled to cooler times
- ◯ Work/rest regimes
- ◯ Colour urine charts (to indicate dehydration)
- ◯ Urine specific gravity testing

18. In workplaces you visit/manage, is there a provision for outdoor work to cease if temperature is extreme?

◯ Yes ◯ No

19. At what temperature does outdoor work cease in extreme heat?

- ◯ 35 degrees or below
- ◯ 36 degrees
- ◯ 37 degrees
- ◯ 38 degrees
- ◯ Other (please specify, eg. varies between workplaces)

20. For **indoor workers,** how often are the following work practices adopted during hot weather? (tick all that apply)

	Never	Rarely	Sometimes	Often	Always	Unsure / Don't Know / N/A
Access to cool drinking water	◯	◯	◯	◯	◯	◯
Shielding of heat sources	◯	◯	◯	◯	◯	◯
PPE supplied (eg. safety goggles, gloves)	◯	◯	◯	◯	◯	◯
Adequate ventilation	◯	◯	◯	◯	◯	◯
Fan only cooling	◯	◯	◯	◯	◯	◯
Packaged cooling systems to ventilate confined spaces	◯	◯	◯	◯	◯	◯
Heat stress training	◯	◯	◯	◯	◯	◯
H&S information signage on display	◯	◯	◯	◯	◯	◯
Job rotation	◯	◯	◯	◯	◯	◯
Workers allowed to self-pace	◯	◯	◯	◯	◯	◯
Colour urine charts (to indicate dehydration)	◯	◯	◯	◯	◯	◯
Urine specific gravity testing	◯	◯	◯	◯	◯	◯

Other (please specify)

21. Of these practices, what do you think is the **most important** for preventing heat stress in indoor workers? (choose only one)

- ◯ Access to cool drinking water
- ◯ PPE supplied
- ◯ Shielding of heat sources
- ◯ Adequate ventilation
- ◯ Air conditioning
- ◯ Packaged cooling systems to ventilate confined spaces
- ◯ Heat stress training
- ◯ H&S information signage on display
- ◯ Job rotation
- ◯ Workers allowed to self-pace
- ◯ Colour urine charts (to indicate dehydration)
- ◯ Urine specific gravity testing

22. In workplaces you visit, is access to air conditioning or fans available for indoor workers?

◯ Never ◯ Rarely ◯ Sometimes ◯ Often ◯ Don't know

23. Generally, what type of cooling systems do these workplaces have?

- ◯ Evaporative
- ◯ Refrigerated
- ◯ Industrial fans
- ◯ Other (please specify)

SECTION 4: TRAINING

The following questions are about heat training in workplaces.

24. Is there training available on preventing heat-related injuries/incidents in workplaces that you currently visit?

◯ Yes ◯ Some workplaces ◯ No ◯ I don't know

25. Is training on preventing heat-related injuries/incidents available for **supervisors** in workplaces that you currently visit?

◯ Yes ◯ Some workplaces ◯ No ◯ I don't know

26. Are supervisors and workers trained separately?

◯ Yes ◯ Varies by workplace ◯ No ◯ Unsure / I don't know

27. Generally speaking, how often is heat-stress training conducted in workplaces you currently visit? (tick all that apply)

- ☐ Once only at induction when starting a new job where heat could be a hazard
- ☐ Once when changing roles or when using new equipment/ techniques/processes where heat could be a hazard
- ☐ Annually regardless of job
- ☐ Every two years
- ☐ I don't know
- ☐ Other (please specify)

28. Generally speaking, how is health and safety training conducted in workplaces you currently visit? (tick all that apply)

- ☐ On site by supervisors
- ☐ On site by consultants
- ☐ On-line
- ☐ On site by health and safety professionals
- ☐ Off site by professionals
- ☐ I don't know

29. In your opinion what is generally the quality of the heat stress training?

○ Comprehensive ○ Adequate ○ Limited ○ Varies ○ Don't know

30. Is this training assessed?

○ Yes ○ Sometimes ○ Varies by type of worker ○ No ○ Unsure / Don't know

31. Generally speaking, who provides the information and resources for the heat stress training? (tick all that apply)

- ☐ Consultants
- ☐ The employer
- ☐ The Safety Regulator
- ☐ Other providers (please specify)
- ☐ Australian Institute of Occupational Hygienists (AIOH)
- ☐ The Industry Association
- ☐ Unsure

SECTION 5: POLICIES & GUIDELINES

The following questions are about management policies and risk assessment tools.

32. Generally speaking, is there a hot weather or heat stress policy in workplaces that you visit?

- ◯ Yes
- ◯ No
- ◯ Not sure
- ◯ Some → which industrial sectors? (please specify)

33. Generally speaking, would you say that heat stress management is implemented:

◯ Fully ◯ Partially ◯ Not at all ◯ Unsure / I don't know

34. As an indicator of heat risk, which scientific measures are used to indicate heat thresholds in workplaces you currently visit? (tick all that apply)

- ☐ Air temperature on site
- ☐ Air temperature at weather bureau
- ☐ Wet Bulb Globe Temperature (WBGT) on site
- ☐ Apparent temperature (feels like temperature)
- ☐ Thermal work limit calculation
- ☐ Predicted heat strain calculation
- ☐ Universal Thermal Comfort Index
- ☐ Ingestible thermometers
- ☐ None of the above
- ☐ Unsure / Don't know
- ☐ Other (please specify)

35. Do any workplaces you currently visit use mobile device apps to assist in heat stress management?

◯ No ◯ Don't know

◯ Yes (which app(s)? please specify, eg. SunSmart app, Predicted Heat Strain app, OSHA app)

SECTION 6: BARRIERS

You have nearly finished the survey.
The following questions are about barriers faced when establishing preventive measures for best practice.

* 36. What do you see as the most important barriers for the prevention of occupational injuries/incidents during very hot weather? (tick up to three)

- ☐ Lack of awareness by workers that heat can be associated with ill health and injury
- ☐ Lack of awareness by supervisors of heat hazards
- ☐ Lack of training of workers
- ☐ Lack of training of supervisors
- ☐ Lack of management commitment to protect health and safety
- ☐ Lack of financial resources
- ☐ Lack of specific heat-related guidelines and regulations
- ☐ Low compliance and implementation of policies
- ☐ Management concerns about productivity loss and/or deadlines
- ☐ Management reluctance to allow workers to slow down or rest as needed
- ☐ Attitudes to keep working at all costs
- ☐ Difficulties in assessing heat risks (eg. complexity, costs)
- ☐ Other (please specify)

SECTION 7: PRODUCTIVITY & POTENTIAL SOLUTIONS

This last section is about your views on solving the problems associated with productivity loss and compromised health and safety in the heat.

37. Do you think that hot weather contributes to productivity loss?

○ Yes ○ Sometimes ○ No ○ Don't Know / Unsure

38. How much of a problem do you think productivity loss due to the effect of heat is on workers?

○ No problem ○ Minor problem ○ Major problem ○ Unsure / Don't know

39. Have potential solutions to the issue of productivity loss during hot weather been discussed in workplaces you visit/manage?

- ◯ Yes
- ◯ No
- ◯ Unsure / don't know

40. What potential solutions to the issue of productivity loss during hot weather have been discussed?

41. Do you have any suggestions for the prevention of heat-related injuries and health issues in Australian workplaces?

END OF SURVEY

Thank you very much for taking the time to complete our questionnaire. Your contribution to this research is much appreciated.

If you have any queries or further interest in this research, please contact:
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B7 Supplementary Material for Chapter 9

Table B14 Types of heat-related injuries (n=287*), HSR perceptions.

Type of injuries*	n	% of cases
Manual handling (musculoskeletal) injuries or joint/ligament injuries	84	55
Others	48	31
Hand injuries	40	26
Burns	32	21
Wounds or lacerations	29	19
Head or neck injuries	21	14
Motor vehicle accidents	18	12
Eye injuries	10	7
Fractures	5	3

***** multiple responses

Table B15 Types of HRI symptoms and other incidents (n=445*), HSR perceptions.

Type of illness/incidents	n	% of cases
Fatigue	139	90
Muscle/Heat cramps	81	53
Severe dehydration	76	49
Fainting or loss of consciousness	60	39
Impaired vision caused by sweating	57	37
Delirium, confusion, disorientation or fitting	23	15
Others	9	6

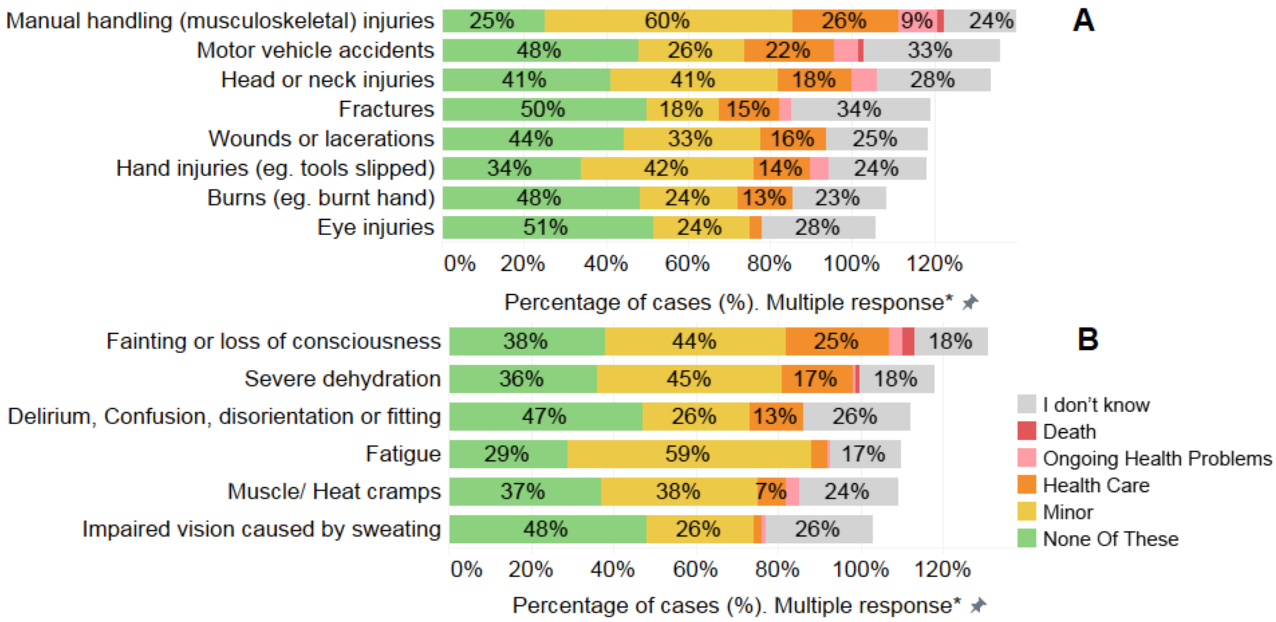

Figure B10 Types of HRIs (A) and illnesses (B) and their outcomes, HSR perceptions.

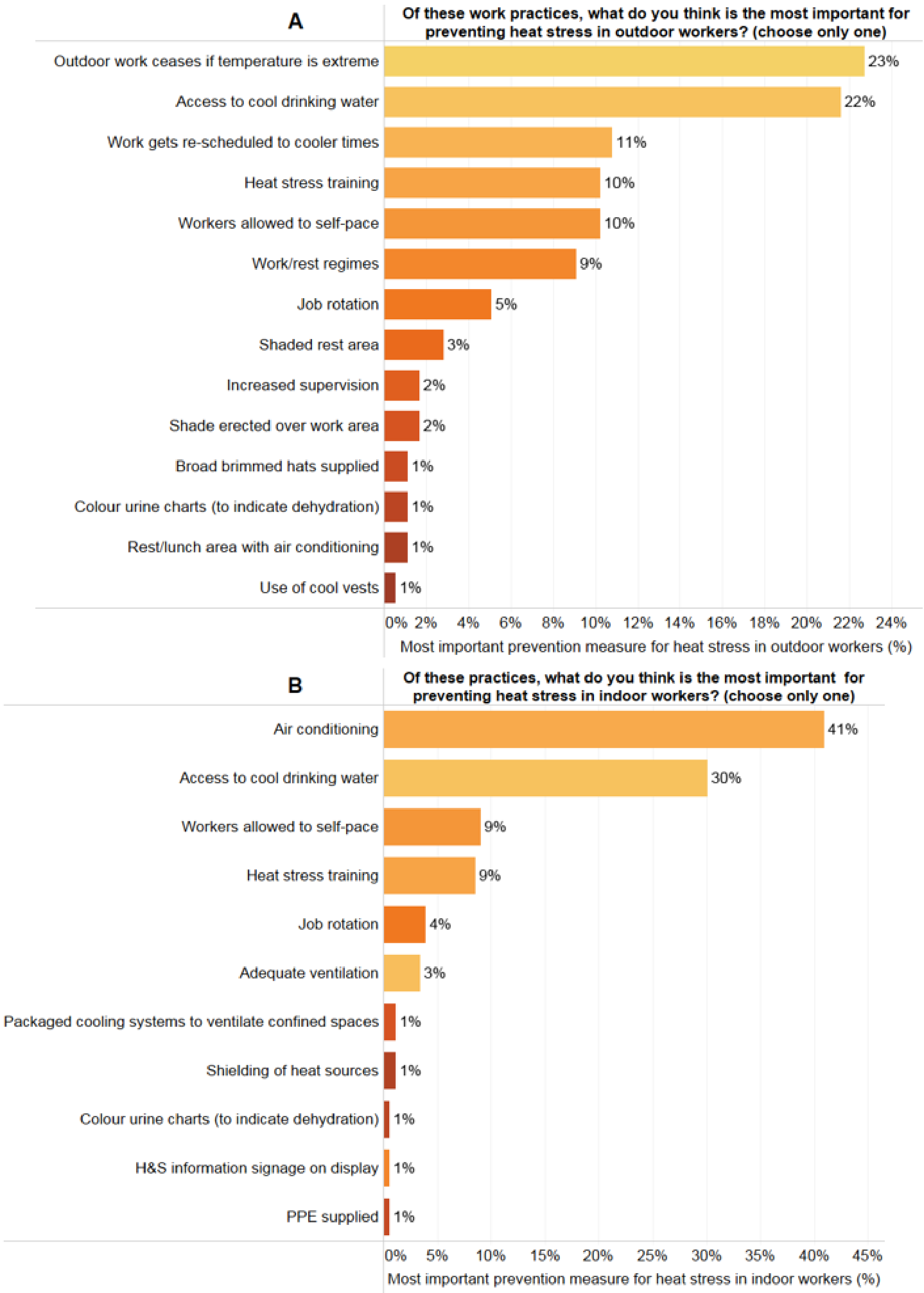

Figure B11 Most important work practices for outdoor workers (A) and indoor workers (B), HSR perceptions.

Table B16 Questions on prevention, HSR perceptions.

Prevention questions	n (%)
Provision for outdoor work to cease if temperature is extreme	**n=175**
Yes	87 (50)
No	88 (50)
At what temperature does outdoor work cease	**n=91***
35 °C or below	12 (13)
36 °C	9 (10)
37 °C	10 (11)
38 °C	23 (25)
Other	37 (41)
Access to air-conditioning or fans for indoor workers	**n=185**
Never	2 (1)
Rarely	6 (3)
Sometimes	31 (17)
Often	143 (77)
Don't know	3 (2)
Types of cooling systems	**n=179**
Evaporative	37 (21)
Refrigerated	107 (60)
Industrial fans	19 (11)
Others	16 (9)

* skip-logic

Table B17 Questions on heat-stress training, HSR perceptions.

Heat stress training	n (%)
Training available for preventing heat-related injuries/incidents	**n=183**
No	84 (46)
Yes	64 (35)
Don't know	35 (19)
Training available for supervisors	**n=70***
No	5 (7)
Yes	56 (80)
I don't know	9 (13)
Supervisors and workers trained together	**n=55***
No	25 (46)
Unsure / I don't know	5 (9)
Varies	12 (22)
Yes	13 (24)
How often is heat-stress training conducted?	**n=67***
Annually regardless of job	23 (34)
Once only at induction when starting a new job where heat could be a hazard	21 (31)
Others	14 (21)
Don't know	15 (22)
Every two years	2 (3)
Once when changing roles or when using new equipment where heat could be a hazard	6 (9)
How is heat stress training conducted?	**n=67***
On site by health and safety professionals	27 (40)
On site by supervisors	27 (40)
On-line	21 (31)
On-site by consultants	9 (13)
Off site by professionals	10 (15)
Don't know	4 (6)

* skip-logic

Table B18 Policies and risk assessment tools, HSR perceptions.

Policies and guidelines	n (%)
Heat stress or hot weather policy	**n=184**
Yes	106 (58)
No	39 (21)
Not sure	39 (21)
Indicators of heat risk	**n=177**
Air temperature at weather bureau	54 (31)
Air temperature on site	30 (17)
Apparent temperature (feels like temperature)	11 (6)
WBGT on site	6 (3)
None of the above	23 (13)
Unsure / Don't know	42 (24)
Other (please specify)	11 (6)
Use of mobile device apps in heat stress management	**n=185**
No	138 (75)
Don't know	36 (20)
Yes	11 (6)

Survey questionnaire-Chapter 9

UNDERSTANDING AND PREVENTING INJURIES IN HOT WORKING CONDITIONS

THANK YOU FOR PARTICIPATING IN THIS SURVEY

This survey, which is being conducted by researchers at The University of Adelaide, is investigating workplace injuries in association with heat exposure.

This survey will take you approximately 10-20 minutes to complete and is anonymous to maintain confidentiality.

Your contribution to this survey is very greatly appreciated.

There are 6 sections in the survey. Please complete each section before moving to the next.

You may skip any questions you do not wish to answer.

SECTION 1: DEMOGRAPHICS

The following questions are about you & your workplace.

1. In which state/territory do you mainly work?

- ◯ ACT
- ◯ NSW
- ◯ NT
- ◯ QLD-North
- ◯ QLD-South
- ◯ SA
- ◯ TAS
- ◯ VIC
- ◯ WA-North
- ◯ WA-South

2. What is your gender?

◯ Male ◯ Female ◯ Unspecified

3. What is your age group?

◯ 18-24 years ◯ 25-34 years ◯ 35-54 years ◯ 55 years and over

4. Approximate number of years of experience in health and safety:

◯ less than 5 years ◯ 5-10 years ◯ 11-20 years ◯ more than 20 years

5. For the purposes of this survey, your answers mainly reflect your experience in which industry (tick only one box below, and base your answers to the survey on your experience in that specific industry)

- ◯ Transport & Storage
- ◯ Manufacturing
- ◯ Mining
- ◯ Agriculture, Forestry & Fishing
- ◯ Construction
- ◯ Wholesale Trade & Retail Trade
- ◯ Electricity, Gas & Water
- ◯ I work with many business & industries
- ◯ Other (please specify: for eg. emergency services, hospitality, etc.)

6. Your current role in Health & Safety:

- ◯ Union official
- ◯ Site supervisor
- ◯ Health and Safety Representative
- ◯ Other (please specify)

7. How many employees in your workplace?

- ◯ Up to 20 employees
- ◯ More than 201 employees
- ◯ 21 to 201 employees
- ◯ N/A

8. Is your workplace part of a larger (e.g. national/multinational) organisation?

◯ Yes ◯ No ◯ Unsure ◯ N/A

9. Does your organisation have any employees on piece rates (i.e. a pay rate for the amount picked, packed or made etc.)?

◯ Yes ◯ No ◯ Unsure ◯ N/A

10. Does your organisation have workers who work under production targets that allow them to leave work once they meet their target?

◯ Yes ◯ No ◯ Unsure ◯ N/A

SECTION 2: HEAT-RELATED INJURIES/INCIDENTS

The following questions relate to the type of the injuries or incidents that you may have come across and the possible contributing factors.

11. In your workplace, would you say that injuries or incidents caused by (partly at least) hot/very humid weather occur:

- ◯ Never
- ◯ Often
- ◯ Rarely
- ◯ I don't know
- ◯ Sometimes

12. What type of **injuries** have occurred in your workplace where hot weather could have been a (direct or indirect) contributing factor? (tick all that apply)

- ☐ Head or neck injuries
- ☐ Hand injuries (eg. tools slipped)
- ☐ Eye injuries
- ☐ Wounds or lacerations
- ☐ Fractures
- ☐ Burns (eg. burnt hand)
- ☐ Manual Handling (musculoskeletal) injuries OR Joint/ligament injuries (e.g. sprains or strains)
- ☐ Motor vehicle accidents
- ☐ Other (please specify)

13. Did any of the above injuries lead to: (tick all that apply)

	Sent home	Days off work	Ambulance called	Visit to Emergency department	Stay in hospital	Ongoing health problems	Death	None of these	I don't know
Head or neck injuries	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hand injuries (eg. tools slipped)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Eye injuries	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wounds or lacerations	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fractures	☐	☐	☐	☐	☐	☐	☐	☐	☐
Burns (eg. burnt hand)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Manual handling (musculoskeletal) injuries OR Joint/ligament injuries (eg.sprains or strains)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Motor vehicle accidents	☐	☐	☐	☐	☐	☐	☐	☐	☐

14. Apart from injuries, what types of **incidents or illnesses** have occurred in your workplace where hot weather could be a contributing factor? (tick all that apply)

- ☐ Fainting or loss of consciousness
- ☐ Severe dehydration
- ☐ Fatigue
- ☐ Impaired vision caused by sweating
- ☐ Muscle/ Heat cramps
- ☐ Delirium, confusion, disorientation or fitting
- ☐ Other (please specify)

15. Did any of the above incidents lead to: (tick all that apply)

	Sent home	Days off work	Ambulance called	Visit to Emergency department	Stay in Hospital	Ongoing health problems	Death	None of these	I don't know
Fainting or loss of consciousness	☐	☐	☐	☐	☐	☐	☐	☐	☐
Severe dehydration	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fatigue	☐	☐	☐	☐	☐	☐	☐	☐	☐
Impaired vision caused by sweating	☐	☐	☐	☐	☐	☐	☐	☐	☐
Muscle/ Heat cramps	☐	☐	☐	☐	☐	☐	☐	☐	☐
Delirium, confusion, disorientation or fitting	☐	☐	☐	☐	☐	☐	☐	☐	☐

The following questions relate to possible contribution of the workplace environment, work factors and the workers, to heat-related injuries/incidents.

16. What **work factors and hazards** do you think may have contributed to these heat-related injuries/incidents? (tick all that apply)

- ☐ Rushed activity
- ☐ The wearing of personal protective equipment (PPE) leading to higher body temperature
- ☐ Working in the sun with no access to shade (Solar radiation)
- ☐ Working indoors with no air conditioner, fan or adequate ventilation
- ☐ Equipment, machinery, tools
- ☐ Electricity related
- ☐ Fire, steam, hot surfaces
- ☐ Dangerous locations
- ☐ Other (please specify; eg.new/untested process/procedures)

17. Which of the following **organisational issues** do you think may have contributed to these heat-related injuries/incidents? (tick all that apply)

- ☐ Lack of health and safety training specifically on heat stress
- ☐ Lack of supervision
- ☐ Inadequate resources and facilities
- ☐ Other (please specify)

18. What **types of workers** have incurred these heat-related injuries/incidents? (tick all that apply)

- ☐ New workers
- ☐ Young workers (aged up to 24 years)
- ☐ Workers aged 25-50 years
- ☐ Older workers (aged over 50 years)
- ☐ Workers whose first language is not English
- ☐ Other (please specify: e.g. noncompliance, personal risk factors and/or lifestyle)

SECTION 3: PREVENTIVE MEASURES

The following questions are about preventing heat-related injuries or incidents in outdoor and indoor workers

19. For **outdoor workers,** how often are the following work practices adopted during hot weather? (tick all that apply)

	Never	Rarely	Sometimes	Often	Always	Unsure/ Don't know / N/A
Access to cool drinking water	○	○	○	○	○	○
Broad brimmed hats supplied	○	○	○	○	○	○
PPE supplied (e.g. gloves, helmets)	○	○	○	○	○	○
Use of cool vests	○	○	○	○	○	○
Sunscreen supplied	○	○	○	○	○	○
WH&S information signage on display	○	○	○	○	○	○
Heat stress training	○	○	○	○	○	○
Shaded rest area	○	○	○	○	○	○
Shade erected over work area	○	○	○	○	○	○
Rest/lunch area with air conditioning	○	○	○	○	○	○
Rest/lunch area with an electric fan	○	○	○	○	○	○
Packaged cooling systems to ventilate confined spaces	○	○	○	○	○	○
Workers allowed to self-pace	○	○	○	○	○	○
Job rotation	○	○	○	○	○	○
Increased supervision	○	○	○	○	○	○
Work gets re-scheduled to cooler times	○	○	○	○	○	○
Work/rest regimes	○	○	○	○	○	○
Colour urine charts (to indicate dehydration)	○	○	○	○	○	○
Urine specific gravity testing	○	○	○	○	○	○

Other (please specify)

20. Of these work practices, what do you think is the **most important** for preventing heat stress in outdoor workers? (choose only one)

- ◯ Access to cool drinking water
- ◯ Broad brimmed hats supplied
- ◯ PPE supplied
- ◯ Use of cool vests
- ◯ WH&S information signage on display
- ◯ Outdoor work ceases if temperature is extreme
- ◯ Heat stress training
- ◯ Shaded rest area
- ◯ Shade erected over work area
- ◯ Rest/lunch area with air conditioning
- ◯ Job rotation
- ◯ Increased supervision
- ◯ Workers allowed to self-pace
- ◯ Work gets re-scheduled to cooler times
- ◯ Work/rest regimes
- ◯ Colour urine charts (to indicate dehydration)
- ◯ Urine specific gravity testing

21. In your workplace, is there a provision for outdoor work to cease if temperature is extreme?

◯ Yes ◯ No

22. At what temperature does outdoor work cease in extreme heat?

◯ 35 degrees or below ◯ 36 degrees ◯ 37 degrees ◯ 38 degrees

◯ Other (please specify)

23. For **indoor workers,** how often are the following work practices adopted in hot weather? (tick all that apply)

	Never	Rarely	Sometimes	Often	Always	Unsure/ Don't Know / N/A
Access to cool drinking water	◯	◯	◯	◯	◯	◯
Shielding of heat sources	◯	◯	◯	◯	◯	◯
PPE supplied (eg. safety goggles, gloves)	◯	◯	◯	◯	◯	◯
Adequate ventilation	◯	◯	◯	◯	◯	◯
Fan only cooling	◯	◯	◯	◯	◯	◯
Packaged cooling systems to ventilate confined spaces	◯	◯	◯	◯	◯	◯
Heat stress training	◯	◯	◯	◯	◯	◯
H&S information signage on display	◯	◯	◯	◯	◯	◯
Job rotation	◯	◯	◯	◯	◯	◯
Workers allowed to self-pace	◯	◯	◯	◯	◯	◯
Colour urine charts (to indicate dehydration)	◯	◯	◯	◯	◯	◯
Urine specific gravity testing	◯	◯	◯	◯	◯	◯

Other (please specify)

24. Of these practices, what do you think is the **most important** for preventing heat stress in indoor workers? (choose only one)

- ◯ Access to cool drinking water
- ◯ PPE supplied
- ◯ Shielding of heat sources
- ◯ Adequate ventilation
- ◯ Air conditioning
- ◯ Packaged cooling systems to ventilate confined spaces
- ◯ Heat stress training
- ◯ H&S information signage on display
- ◯ Job rotation
- ◯ Workers allowed to self-pace
- ◯ Colour urine charts (to indicate dehydration)
- ◯ Urine specific gravity testing

25. In your workplace, is access to air conditioning or fans available for indoor workers?

- Never
- Rarely
- Sometimes
- Often
- Don't know

26. What type of cooling systems do you have in your workplace?

- Mostly evaporative
- Mostly refrigerated
- Mostly industrial fans
- Other (please specify)

SECTION 4: TRAINING

The following questions are about heat training in your workplace.

27. Is there training available on preventing heat-related injuries/incidents in your workplace currently?

- Yes
- No
- I don't know

28. Is training on preventing heat-related injuries/incidents available for **supervisors** in your workplace currently?

- Yes
- No
- I don't know

29. Are supervisors and workers trained separately?

- Yes
- Varies
- No
- Unsure / I don't know

30. How often is heat-stress training currently conducted in your workplace? (tick all that apply)

- [ ] Once only at induction when starting a new job where heat could be a hazard
- [ ] Once when changing roles or when using new equipment/ techniques/processes where heat could be a hazard
- [ ] Annually regardless of job
- [ ] Every two years
- [ ] I don't know
- [ ] Other (please specify)

31. How is health and safety training currently conducted in your workplace? (tick all that apply)

- ☐ On site by supervisors
- ☐ On site by consultants
- ☐ On-line
- ☐ On site by health and safety professionals
- ☐ Off site by professionals
- ☐ I don't know

SECTION 5: POLICIES & GUIDELINES

You have nearly finished the survey.
The following questions are about management policies and risk assessment tools.

32. Is there a hot weather or heat stress policy in your workplace?

○ Yes ○ No ○ Not sure

33. If you use temperature as an indicator of heat risk in your workplace, which temperature measure is used? (tick all that apply)

- ○ Air temperature on site
- ○ Wet Bulb Globe Temperature (WBGT) on site
- ○ Air temperature at weather bureau
- ○ None of the above
- ○ Apparent temperature (feels like temperature)
- ○ Unsure / Don't know
- ○ Other (please specify)

34. Does your workplace currently use mobile device apps to assist in heat stress management?

- ○ No
- ○ Don't know
- ○ Yes (which app(s)? please specify, eg. SunSmart app, Predicted Heat Strain app, OSHA app)

SECTION 6: BARRIERS & RECOMMENDATIONS

This last section is about barriers faced when establishing preventive measures for best practice and your views on solving the problems associated with health and safety in the heat.

* 35. What do you see as the most important barriers for the prevention of occupational injuries/incidents during very hot weather? (tick up to three)

- [ ] Lack of awareness by workers that heat can be associated with ill health and injury
- [ ] Lack of awareness by supervisors of heat hazards
- [ ] Lack of training of workers
- [ ] Lack of training of supervisors
- [ ] Lack of management commitment to protect health and safety
- [ ] Lack of financial resources
- [ ] Lack of specific heat-related guidelines and regulations
- [ ] Low compliance and implementation of policies
- [ ] Management concerns about productivity loss and/or deadlines
- [ ] Management reluctance to allow workers to slow down or rest as needed
- [ ] Attitudes to keep working at all costs
- [ ] Difficulties in assessing heat risks (eg. complexity, costs)
- [ ] Other (please specify)

36. Do you have any suggestions for the prevention of heat-related injuries and health issues in Australian workplaces?

END OF SURVEY

Thank you very much for taking the time to complete our questionnaire. Your contribution to this research is much appreciated.

If you have any queries or further interest in this research, please contact:

Blesson Varghese,
School of Public Health, the University of Adelaide,
blesson.varghese@adelaide.edu.au

Appendix C: Data Access Approvals

As mentioned in Chapter 3, the Tabulator dataset used in Chapters 4 and 6 was obtained from SWSA following a confidentiality agreement. The national dataset used in Chapters 5 and 7 were obtained from SWA following approvals from concerned jurisdictions. Both the confidentiality agreement and data release approval letters are provided in the order below:

- Appendix C1: SWSA Research Dataset Confidentiality Agreement
- Appendix C2: Return to WorkSA Approval Letter
- Appendix C3: Office of Industrial relations, Queensland Treasury Approval Letter
- Appendix C4: WorkCover WA Data Release Agreement
- Appendix C5: WorkCover WA Approval
- Appendix C6: WorkSafe Victoria Approval

Appendix C1: SafeWork SA Research Dataset Confidentiality Agreement

SAFEWORK SA
WORK HEALTH AND SAFETY

REQUEST FOR VARIATION TO AGREEMENT

This form is to make a formal request to SafeWork SA for the variation to an existing agreement.

Requested Change	
Project title: *Extreme Heat Exposure and Workers' Health in South Australia*	
Project manager: Alana Hansen	**Reference Number:** *SAFE 11/0548 1*
Change Category (Check all that apply): *(changes to project deliverables)* X Project Personnel *(changes to staff and/or researchers)*	
Describe the Change Being Requested: Changes to project team members as attached.	

EXECUTION

DINO PISANIELLO	....	27/5/16
Name of Research Project Data Custodian *(print name)*	**Signature**	**Date**
Alana Hansen		27/5/16
Name of Authorised Researcher *(print name)*	**Signature**	**Date**
Blesson Mathew Varghese		27/5/16
Name of Authorised Researcher *(print name)*	**Signature**	**Date**
....	....	....../....../.........
Name of SafeWork SA Data Representative *(print name)*	**Signature**	**Date of Execution**

Alana Hansen	....	27/5/16
Name of Project Manager *(print name)*	**Signature**	**Date**

PART 4 SECURITY AUDIT SELF-ASSESSMENT TOOL

Mr Blesson Mathew Varghese

		Research Project Data Custodian ------------ Please provide answers in this section	SafeWork SA Data Custodian Use only
1	*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:*	*Eg Excel 2007*	✓
1a	*Agreed alternative Dataset format:*		
2	*The location and name of any server on which the Dataset is to be installed is provided below:*		✓
2a	*Server location:*	The University of Adelaide \\uofa\users$\users4\a1606446	✓
2b	*Server name:*	a1606446	
3	*The locations and asset numbers (or serial numbers) of all computers on which the Dataset will be installed or analysed are provided below:*		
3a	*Computer asset/serial number:*	*DPBYWXXF*	✓
3b	*Computer location:*	*Room 810, Level 8 Hughes Building, The University of Adelaide, North Tce, Adelaide*	✓
3c	*Computer asset/serial number:*		
3d	*Computer location:*		
4	*All storage locations where the Dataset will be installed or analysed are able to be password protected.*	*Yes / ~~No~~*	✓
5	*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.*	*Yes / ~~No~~*	✓
6	*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.*	*Yes / ~~No~~*	✓
7	*All computers on which the Dataset will be installed or analysed are firmly attached to their workstations or located in a Secure Room*	*Yes / ~~No~~*	– TBA.
8	*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. Alternatively, the Unit-Record paper output from the Dataset will be used only in a Secure Room.*	*Yes / ~~No~~*	✓
9	*A shredder is available for the destruction of Unit-Record paper output from the Dataset when it is no longer required. Alternatively, the SafeWork SA Data Custodian or delegate has agreed to securely destroy it through the services of SafeWork SA.*	*Yes /No*	✓
10	*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:* *These means are approved by the SafeWork SA Data Custodian or delegate.*	*Describe security arrangements here*	✓

data delivered Colin Horrocks ,
Blesson Varghe

Dino Pisaniello

		Research Project Data Custodian ------------ Please provide answers in this section	SafeWork SA Data Custodian Use only
1	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:	Eg Excel 2007	✓
1a	Agreed alternative Dataset format:		
2	The location and name of any server on which the Dataset is to be installed is provided below:		✓
2a	Server location:	The University of Adelaide \\uofa\users$\users2\a1065832	✓
2b	Server name:	a1065832	✓
3	The locations and asset numbers (or serial numbers) of all computers on which the Dataset will be installed or analysed are provided below:		
3a	Computer asset/serial number:	PB01ABK9	✓
3b	Computer location:	Room 814, Level 8 Hughes Building, The University of Adelaide, North Tce, Adelaide	✓
3c	Computer asset/serial number:		
3d	Computer location:		
4	All storage locations where the Dataset will be installed or analysed are able to be password protected.	Yes / ~~No~~	✓
5	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.	Yes / ~~No~~	✓
6	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.	Yes / ~~No~~	✓
7	All computers on which the Dataset will be installed or analysed are firmly attached to their workstations or located in a Secure Room	Yes / ~~No~~	✓
8	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. Alternatively, the Unit-Record paper output from the Dataset will be used only in a Secure Room.	Yes / ~~No~~	✓
9	A shredder is available for the destruction of Unit-Record paper output from the Dataset when it is no longer required. Alternatively, the SafeWork SA Data Custodian or delegate has agreed to securely destroy it through the services of SafeWork SA.	Yes /No	✓
10	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: These means are approved by the SafeWork SA Data Custodian or delegate.	Describe security arrangements here	✓

data delivered 27/5/16

PART 5 IDENTITIES OF SIGNATORIES

Name:	Mr Blesson Mathew Varghese
Position Title:	PhD student
Organisation:	School of Public Health, The University of Adelaide
Phone:	8313 9190
Mobile	0431 246 502
Email:	blesson.varghese@adelaide.edu.au
Role in the project:	Conducting data analysis as part of PhD studies

Name:	Dr Alana Hansen
Position Title:	Senior Research Officer
Organisation:	School of Public Health, The University of Adelaide
Phone:	8313 1043
Mobile	0413 840 154
Email:	alana.hansen@adelaide.edu.au
Role in the project:	Project officer

Name:	Dino Pisaniello
Position Title:	Professor in Occupational and Environmental Hygiene
Organisation:	School of Public Health, The University of Adelaide
Phone:	8313 3571
Mobile	0417 876 077
Email:	dino.pisaniello@adelaide.edu.au
Role in the project:	Research Leader

Appendix C2: Return to WorkSA Approval Letter

Mon 19/06/2017 8:13 AM

Oakley, Julia <Julia.Oakley@rtwsa.com>

RE: Request for jurisdictional approval (SA) for NDS3 data access from Safe Work Australia

To Blesson Mathew Varghese

Cc Swincer, Margaret; Rowett, Shelley (AGD); Dino Pisaniello; Alana Hansen; Peng Bi

You replied to this message on 19/06/2017 9:04 AM.

Hi Blesson

I am happy for you to obtain the South Australian data from Safe Work Australia. Please take this email as formal approval.

cheers

Julia Oakley
General Manager Regulation
ReturntoWorkSA
400 King William Street Adelaide SA 5000
Phone: 08 8233 2475
Mobile: 0407 662 196
www.rtwsa.com I julia.oakley@rtwsa.com

Appendix C3: Office of Industrial relations, Queensland Treasury Approval Letter

Thu 4/05/2017 9:24 AM

WCR statistics <statistics@qcomp.com.au>

RE: Request for jurisdictional approval (QLD) for NDS3 data access from Safe Work Australia

To Blesson Mathew Varghese

Cc Dino Pisaniello; Alana Hansen; Peng Bi

Hi Blesson,

Queensland has no issues with you obtaining this data from SafeWork Australia – please consider this email our approval. Should you require anything else, please let me know.

Regards,

Aleisha Dunn
Manager, Workers' Compensation Data & Reporting
Data and Evaluation Services
Office of Industrial Relations
Queensland Treasury

P: (07) 3020 6366
E: aleisha.dunn@justice.qld.gov.au

Appendix C4: WorkCover WA Data Release Agreement

WorkCoverWA
2 Bedbrook Place
Shenton Park
Western Australia 6008
www.workcover.wa.gov.au
wa.gov.au

telephone 08 9388 5555
facsimile 08 9388 5550
advisory services 1300 794 744
TTY 08 9388 5537

Data Release Agreement

Please return to WorkCover WA following notification of approval of data release

I, the undersigned, agree to the following:

Data confidentiality

All workers' compensation policy data at the individual record level obtained or acquired by __Jane Heyworth__________________________(UWA) from WorkCover WA shall be treated as strictly confidential.

This data shall not be disclosed or provided to any person who has not signed a Data Release Agreement with WorkCover WA.

In addition:

1. No attempt shall be made to identify any employer or employee contained in such records.
2. No aggregate data from such records shall be reported or published with a cell size less than five without written permission of the Chief Executive Officer, WorkCover WA.
3. All data at the individual record level on computer tape, cartridge, disk, CD-ROM, other computerised storage media, or in hard copy shall be stored in a secure location.
4. All data at the individual record level on a computer hard drive shall be password protected.
5. Any breach or suspected breach of data confidentiality shall be reported immediately to the Chief Executive Officer, WorkCover WA.
6. The obligation of confidentiality, non-disclosure and non-use shall remain permanent.

Due acknowledgement

1. WorkCover WA will be acknowledged in any written report arising from use of this data.
2. It is agreed that WorkCover WA and the individual who is in receipt of the data will meet at the conclusion of the project to discuss any matters relating to intellectual property and/or publication of research arising from the provision of data.

WorkCoverWA
2 Bedbrook Place
Shenton Park
Western Australia 6008
www.workcover.wa.gov.au
wa.gov.au

telephone 08 9388 5555
facsimile 08 9388 5550
advisory services 1300 794 744
TTY 08 9388 5537

Data usage limitations

1. Due to the dynamic nature of workers' compensation claims, the interpretation of data supplied must be undertaken with some caution. Data users are advised to carefully consider the provisional nature of the data before using it for decisions that concern personal or public safety or the conduct of business that involves substantial monetary or operational consequences.

2. The accuracy or reliability of the data is not guaranteed or warranted in any way. WorkCover WA has made a reasonable effort to ensure that the data is up-to-date, accurate, complete, and comprehensive at the time of provision. This data is reported to this agency by insurers for the specified period. Data users are responsible for ensuring by independent verification its accuracy, currency or completeness.

3. Neither WorkCover WA, or its agencies or representatives are responsible for data that is misinterpreted or altered in any way. Derived conclusions and analysis generated from this data are not to be considered attributable to WorkCover WA.

4. This data is provided 'as is' and in no event shall WorkCover WA, its agencies or representatives be liable for any damages, including, without limitation, damages resulting from lost data or lost profits or revenue, the costs of recovering such data, the costs of substitute data, claims by third parties or for other similar costs, or any special, incidental, punitive or consequential damages, arising out of the use of the data.

5. Information concerning the accuracy and appropriate uses of the data or concerning other workers' compensation data may be obtained by contacting WorkCover WA.

Any intentional violation of this agreement shall be dealt with at the discretion of the Chief Executive Officer, WorkCover WA.

(Signature)

16/5/2017
Date

______Professor Jane Heyworth ______________________________
(Print Name and Title)

Appendix C5: WorkCover WA Approval

From: Franky Ku [mailto:Franky.Ku@workcover.wa.gov.au]
Sent: Friday, 19 May 2017 10:20 AM
To: 'Richard.Webster@swa.gov.au' <Richard.Webster@swa.gov.au>
Cc: Jane Heyworth <jane.heyworth@uwa.edu.au>; Han Chan <Han.Chan@workcover.wa.gov.au>
Subject: FW: TRIM: RE: Request for NDS3 data from Safe Work Australia

Hi Richard

I refer to Dr Jane Heyworth's email dated 12 May 2017 regarding the release of WA NDS3 data from Safe Work Australia for the ARC project.

The WorkCover WA CEO, Chris White has approved the request and attached the Data Release Agreement and Data Request Form signed by Dr Heyworth.

Should you have any queries, please feel free to contact me.

Best regards

Franky Ku | A/Manager Business Intelligence Services
Legislation and Scheme Information

P (08) 9388 5573
E franky.ku@workcover.wa.gov.au

WorkCoverWA
2 Bedbrook Place
Shenton Park
Western Australia 6008
www.workcover.wa.gov.au

A workers' compensation and injury management scheme that works for all.

T @WorkCoverWA **| W** workcover.wa.gov.au

Appendix C6: WorkSafe Victoria Approval

From: peter_mckee@worksafe.vic.gov.au [mailto:peter_mckee@worksafe.vic.gov.au]
Sent: Friday, 21 July 2017 8:54 AM
To: Dino Pisaniello
Cc: Alana Hansen; anna_zisimopoulos@worksafe.vic.gov.au
Subject: Re: FW: Fw:Request for jurisdictional approval (VIC) for NDS3 data access from Safe Work Australia

Hi Dino,

Following to our conversation earlier this week I am pleased to advise that approval has been granted for you to access Victoria's NDS data subject to your approval of the following terms:

1. All data shall be treated as strictly confidential.

2. No attempt shall be made to identify any employer or employee contained in such records.

3. No aggregate data from such records shall be reported or published with a cell size of less than five.

4. All data at the individual record level shall at all times be stored in a secure location and password protected

5. Any breach or suspected breach of data confidentiality shall be reported the Chief Executive. WorkSafe Victoria

6. The obligation of confidentiality, non-disclosure shall remain permanent.

7. The data is not to be given to anyone else.

8. The data and it will not be used for any other purposes other than the one agreed.

Could you please confirm your agreement via return email.

Cheers, Peter

Peter McKee Scheme Performance Division	peter_mckee@worksafe.vic.gov.au Tel/ 9641 1456 Mob/ 0421 583 148	Head Office, 222 Exhibition Street Melbourne VIC 3000 www.worksafe.vic.gov.au	WorkSafe VICTORIA

Appendix D: Injury Categorisation and Corresponding TOOC3 Groupings

Table D1 Injury categorisation and corresponding TOOC3 major groupings.

Category	TOOCS3 Major Group
Fractures	B: Fractures
Musculoskeletal	F: Traumatic Joint/Ligament and Muscle/Tendon Injury
	H: Musculoskeletal and Connective Tissue Diseases
Neurological	A: Intracranial Injuries
	E: Injury to Nerves and Spinal Cord
	L: Nervous System and Sense Organ Diseases
Mental health conditions	I: Mental Diseases
Other traumatic	C: Wounds, Lacerations, Amputations and Internal Organ Damage
	D: Burn
	G: Other Injuries
Other diseases	J: Digestive System Diseases
	K: Skin and Sub-cutaneous Tissue Diseases
	M: Respiratory System Diseases
	N: Circulatory System Diseases
	O: Infectious and Parasitic Diseases
	Q: Other Diseases
Other claims	R: Other Claims

Source: Adapted from Lane T, Collie A, Hassani-Mahmooei B.[293]

Appendix E: Survey Advertisements

- **Safe Work SA**

- **Safe Work Australia**

- **SA State Emergency Service**

SA State Emergency Service
September 7, 2017 ·

Like Page

$50 gift vouchers available for people who have have sustained injury while working in hot conditions & are willing to participate in a 30-60 minute research interview.

http://www.adelaide.edu.au/oeh/heat/

Or if you have worked in hot conditions & would like to share your views on preventing injuries in the heat, please complete the flowing 5 minute survey.

https://www.surveymonkey.com/r/2XGRRFZ

Understanding and Preventing Injuries in Hot Working Conditions

While quite a bit is known about the dangers of heat stroke for people working in hot weather, we know less about injuries that occur in these conditions. A team led by researchers at the University of Adelaide is undertaking a project to better understand the circumstances underpinning injuries in hot workplaces. Injuries may arise for reasons including loss of concentration, sweaty hands, solar glare, hot surfaces or accumulated fatigue.

The project is funded by the Australian Research Council and is being conducted in cooperation with the Queensland University of Technology, Monash University, the University of Western Australia, SafeWork SA, SA Health and Safe Work Australia. The research is examining the relationship between hot weather and workplace injury, and exploring stakeholders' and workers' perceptions. The aim is to better understand heat-related occupational injuries and ultimately aid in prevention.

Blesson Varghese is a PhD student working on the project and is keen to recruit participants in the study. Blesson said health and safety representatives and professionals, as well as people affected by heat in the course of their work, can participate by completing an online survey to comment on their personal experiences and views on prevention. The researchers are also keen to hear directly from people who have experienced occupational heat incidents. People participating in an interview will be thanked with a $50 gift voucher.

Emergency management personnel and SES volunteers often work in harsh conditions and exceptionally hot weather that can have a detrimental effect on health and safety. Anyone interested in participating in the study can find the surveys on the project website http://www.adelaide.edu.au/oeh/heat or get more details from alana.hansen@adelaide.edu.au, telephone 08 8313 1043.

ADELAIDE.EDU.AU

Occupational and Environmental Health Laboratory

The University of Adelaide Occupational and Environmental Health Laboratory (OEHL) was established in 1987 and was set up at its...

- **Safety Institute of Australia (now the Australian Institute of Health & Safety)**

https://www.sia.org.au/news-and-publications/news/understanding-and-preventing-h

UNDERSTANDING AND PREVENTING HEAT-RELATED INJURIES

Home / News / Understanding and preventing heat-related injuries

Print Share

The following article is a general news item provided for the benefit of members. Its contents do not necessarily reflect the views of the Safety Institute of Australia.

Date: Tuesday, 19 December, 2017 - 14:30 Category: Industry news Location: National News

Researchers at University of Adelaide are undertaking a national project to better understand the circumstances underpinning workplace injuries that occur in hot working conditions. The project is funded by the Australian Research Council and is examining the relationship between hot weather and workplace injury, and exploring stakeholders' and workers' perceptions. The ultimate aim is to facilitate resources to aid in the prevention of heat-related occupational injuries.

The project website http://www.adelaide.edu.au/oeh/heat provides several opportunities for people to participate in this research.

- Online questionnaire surveys are available for health and safety professionals and health and safety representatives. The surveys are anonymous and take 10-20 minutes to complete. Questions relate to heat-associated risks, experiences of injuries, and implications for productivity loss.
- Interested people can also make general comments about their experiences and views on the prevention of heat-related injuries via a short (5 minute) online survey.
- People who have had an injury while working in hot conditions can participate in a confidential telephone (or face-to-face) interview lasting 30-60 minutes. Interview participants will receive a $50 gift voucher.

For more information about the research, please visit http://www.adelaide.edu.au/oeh/heat or contact alana.hansen@adelaide.edu.au, telephone (08) 8313 1043.

- **OHSreps**

Wed 6/09/2017 2:38 PM

OHS Reps Info <ohsinfo=vthc.org.au@cmail19.com> on behalf of OHS Reps Info <ohsinfo@v

SafetyNet 418

To Blesson Mathew Varghese

You forwarded this message on 6/09/2017 3:02 PM.
Click here to download pictures. To help protect your privacy, Outlook prevented automatic download of some pictures in this message.

Research: Working in hot conditions - participants wanted
A research project funded by the Australian Research Council is being conducted by the University of Adelaide, in cooperation with Queensland University of Technology, Monash University, the University of Western Australia, SafeWork SA, SA Health and Safe Work Australia. The researchers say that while a lot is known about heat-induced illness in workers, less is known about injuries that occur in hot weather. These may arise for a number of reasons including loss of concentration, sweaty hands, solar glare, hot surfaces or accumulated fatigue.

The aims of this research project are to:

1. Examine the relationship between hot weather and workplace injury, and the influencing factors;
2. Explore stakeholder perceptions; and
3. Improve policies and facilitate resources to aid in the prevention of heat-related injury.

There are several aspects to the research. Health and safety representatives and health and safety professionals can participate by completing an online questionnaire survey that can be accessed via the project website. The survey will take 10-20 minutes to complete and questions will be centred on heat-associated risks, experiences of injuries, and implications for productivity loss. Workers who have had an injury in the heat can participate in a face-to-face or telephone interview lasting 30-60 minutes. There will also be an opportunity for other workers to make general comments about heat-related issues on the website, without being interviewed. The surveys and interview details are available on the website.

We Are Union: OHS Reps Like Page
October 17, 2017

Do you work in the heat? Have you experienced injury from working in the heat?

Whether you're a worker, OHS Professional, or HSR, a team of researchers at the University of Adelaide want to hear from you!

Funded by the Australian Research Council, the project examines the relationship between hot weather and workplace injury to explore stakeholders' and workers' perceptions. The ultimate aim is to facilitate resources to aid in the prevention of heat-related occupational injuries.

Head to this link to fill out the survey or find out more about this important research for workplace health and safety: http://www.adelaide.edu.au/oeh/heat/

ADELAIDE.EDU.AU
Occupational and Environmental Health Laboratory
The University of Adelaide Occupational and Environmental Health Laboratory (OEHL) was established in 1987 and was set up at its...

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Home › OHS News › OHS and WHS: ground breaking research underway into working in heat

OHS And WHS: Ground Breaking Research Underway Into Working In Heat

by **Kylie Field**
Dec 20, 2017

Share Tweet Google+ Pin it

Researchers at the University of Adelaide are undertaking a national project to better understand the circumstances underpinning workplace injuries that occur in hot working conditions.

Funded by the Australian Research Council, the project is examining the relationship between hot weather and workplace injury, and exploring stakeholders' and workers' perceptions, with the ultimate aim being to facilitate resources to aid the prevention of heat-related occupational injuries.

The project has numerous opportunities for people to participate in the research by answering the following:

- Online questionnaire surveys available for health and safety professionals and health and safety representatives.
- Interested people can also make general comments about their experiences and views on the prevention of heat-related injuries via a online survey.
- People who have had an injury while working in hot conditions can participate in a confidential telephone (or face-to-face) interview lasting 30-60 minutes.

The University can be contacted at http://www.adelaide.edu.au/oeh/heat or contact alana.hansen@adelaide.edu.au or telephone (08) 8313 1043.

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Research: injuries in hot working conditions

Published 8 February 2018

Researchers at the University of Adelaide are conducting a national project to better understand the circumstances underpinning injuries that occur in hot working conditions.

The project, funded by the Australian Research Council, will examine the relationship between hot weather and injuries, and explore perceptions of stakeholders and workers. The ultimate aim is to facilitate resources to help prevent heat-related occupational injuries.

Visit www.adelaide.edu.au/oeh/heat or email alana.hansen@adelaide.edu.au for more information, including how you can assist with the research by completing a survey.

The survey closes Wednesday 28 February 2018.

- **Thermalenvironment.com**

www.thethermalenvironment.com/heat-related-injuries-research/ 80% Search

Heat Stress | Thermal Discussion Topics | Something Completely Different!

Heat Related Injuries Research Survey

By Ross Di Corleto | 1 May, 2017 | No Comments |

Currently the University of Adelaide is heading up a research project looking into heat related injuries in industry. This project is funded by the Australian Research Council and is being conducted by the University of Adelaide, in cooperation with Queensland University of Technology, Monash University, the University of Western Australia, SafeWork SA, SA Health and Safe Work Australia. The aims of the project are to:

1. *Examine the relationship between hot weather and workplace injury, and the influencing factors;*
2. *explore stakeholder perceptions; and*
3. *improve policies and facilitate resources to aid in the prevention of heat-related injury.*

In order to be upfront and provide full disclosure I need to advise that I am involved in this project as a subject matter expert and advisor on the steering committee. However I believe the outcomes of this research project will be of interest to many organisation with workplaces in hot environments or utilising and/or generating heat as part of their process.

Part of the exercise is a survey of Australian industries and their experience with heat and its impacts. The surveys are anonymous and can be completed by H&S managers, advisers or workplace employees. This information will be analysed and utilised as a key part of the research.

If you can spare 15 minutes to answer the questions it would be much appreciated by the research teams and ultimately help all of us with interests in this field.

The link is at www.adelaide.edu.au/oeh/heat

Type KeyWord Search

RECENT POSTS

- Heat stress – it's all about balance.
- The Single Temperature Stop-Work Challenge.
- Heat Related Injuries Research Survey
- Myth busting in heat stress.
- The Predicted Heat Strain Mobile Application: It's here and it's FREE!

RECENT COMMENTS

- Ross Di Corleto on The Predicted Heat Strain Mobile Application: It's here and it's FREE!
- Ross Di Corleto on Heat Stress
- Ross Di Corleto on The Single Temperature Stop-Work Challenge.
- Lee Cherry on The Single Temperature Stop-Work Challenge.
- Hmrc R&D Tax Credits on Heat Stress

ARCHIVES

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Appendix F: Information Pack with Survey Links

THE UNIVERSITY of ADELAIDE

QUT

THE UNIVERSITY OF WESTERN AUSTRALIA

Understanding and Preventing Injuries in Hot Working Conditions

GENERAL INFORMATION ABOUT THE RESEARCH

University of Adelaide Human Research Ethics Committee Approval No. H-2016-085

What is this research about? While we know a lot about heat-induced illness in workers, we know less about injuries that occur in hot weather. These may arise for a number of reasons including loss of concentration, sweaty hands, solar glare, hot surfaces or accumulated fatigue. The aims of this research project are to: *(1) Examine the relationship between hot weather and workplace injury, and the influencing factors; (2) explore stakeholder perceptions; and (3) improve policies and facilitate resources to aid in the prevention of heat-related injury.*

Who is undertaking the research? This project is funded by the Australian Research Council and is being conducted by the University of Adelaide, in cooperation with Queensland University of Technology, Monash University, the University of Western Australia, SafeWork SA, SA Health and Safe Work Australia.

What is involved? There are several aspects to the research. Health and safety representatives and health and safety professionals can participate by completing an **online questionnaire survey** that can be accessed via the project website http://www.adelaide.edu.au/oeh/heat. The survey will take 10-20 minutes to complete and questions will be centred on heat-associated risks, experiences of injuries, and implications for productivity loss. Workers who have had an injury in the heat can participate in a face-to-face or telephone **interview** lasting 30-60 minutes. There will also be an opportunity for other workers to make general comments about heat-related issues on the website, without being interviewed. The surveys and interview details are available on the website.

Are there any risks or costs associated with being in the research? Aside from giving up your time, we do not expect that there will be any potential risks, harms and discomfort or costs associated with taking part in this study.

Are there any benefits with being in the project? Interview participants will receive a $50 gift voucher. Otherwise participation in the project may not result in any direct benefit to you, but has the potential to improve health and safety policy and practice.

Do I have to be in the research? Participation is completely voluntary.

What will happen to information about me that is collected during the research? The surveys and interviews will not capture any personal details or company details. The link to the survey we have provided is a generic link with no unique identifiers. All survey responses will be aggregated and will not be used outside the needs of the current project. With permission from interview participants, interviews will be recorded; however, content of the interviews will be strictly confidential and anonymous. Findings of this project may be published in journals or presented at conferences but individual participants will be anonymous and not identifiable. Data will only be accessible by research team members for research purposes. At the completion of the research all information will be held for a minimum of five years after which the information will be destroyed securely. The research has been approved by the Human Research Ethics Committee at the University of Adelaide (approval no. H-2016-085).

Can I tell other people about the project? Yes, you are welcome to tell others about the project.

Will I be told the results of the project? You have a right to receive feedback about the overall results after the research is finished.

What if I would like further information about the project? Please contact Dr. Alana Hansen, ph: 08 8313 1043, email: alana.hansen@adelaide.edu.au; or Prof. Dino Pisaniello, ph: 08 8313 3571, email: dino.pisaniello@adelaide.edu.au; or visit the project website http://www.adelaide.edu.au/oeh/heat.

What if I have a complaint or any concerns about the project? To contact an independent person, phone the Human Research Ethics Committee's Secretariat on 08 8313 6028, quoting H-2016-085. Complaints or concerns will be treated in confidence and fully investigated. You will be informed of the outcome.

CRICOS PROVIDER 00123M

Welcome to the website for The University of Adelaide research study on **Understanding and Preventing Injuries in Hot Working Conditions.**

About the project

While we know a lot about heat-induced illness in workers, we know less about injuries that occur in hot weather. These may arise for a number of reasons including loss of concentration, sweaty hands, solar glare, hot surfaces or accumulated fatigue.

The aims of this research project are to: (1) Examine the relationship between hot weather and workplace injury, and the influencing factors; (2) explore stakeholder perceptions; and (3) improve policies and facilitate resources to aid in the prevention of heat-related injury.

This national project is funded by the Australian Research Council and is being conducted by the University of Adelaide, in cooperation with Queensland University of Technology, Monash University, the University of Western Australia, SafeWork SA, SA Health and Safe Work Australia.

Your participation

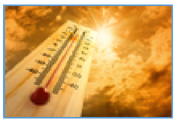
There are several aspects to the research and we welcome your input if have an interest in occupational health and safety and/or have experience working in hot conditions. If you would like to be part of the project you can contribute in a number of ways. Participants and their organisations can be assured of confidentiality and will not be identified. First, click here to read necessary information about the project, confidentiality, the risks and benefits associated with being involved, and what to do if you have any concerns about the project.

- If you are a **health and safety professional** (i.e. your main role is H&S - such as H&S consultants, inspectors, occupational hygienists, etc.) you can participate by completing an online survey that will take 15-20 minutes to complete. Questions are centred on heat-associated risks, experiences of injuries, and implications for productivity loss in workplaces you currently visit. The survey can be accessed here.
- If you are a **health and safety representative** or have another role where H&S is part of, but not your main role (e.g. site supervisors, union officials, etc.) you can participate by completing an online survey that will take 10-15 minutes to complete. Questions are about heat-associated risks, experiences of injuries, and implications for productivity loss in your organisation. The survey can be accessed here
- If you have **worked in hot conditions** and would like to share your views on preventing injuries in the heat, you can complete a brief (5 minute) survey that can be accessed here
- If you have **had an injury in the heat** your experience would be valuable to the research. We invite you to participate in a face-to-face or telephone interview lasting 30-60 minutes, for which you receive a $50 gift voucher. If you would like more information about what is involved or wish to organise an interview, click here

If you would like more details contact Prof. Dino Pisaniello or Alana Hansen

This project has been approved by the Human Research Ethics Committee at the University of Adelaide (approval no. H-2016-085).

Appendix G: Information Sheet for Surveys



Workers' health and safety at high temperatures: New perspectives on injury prevention

INFORMATION SHEET FOR SURVEYS

Understanding and Preventing Injuries in Hot Working Conditions

What is this research about?
While we know a lot about heat-induced illness, there is a limited understanding of heat-associated injuries such as falls and hand injuries in hot weather. These may arise because of loss of concentration, fogging goggles, sweaty hands, non-use of PPE, solar glare, hot surfaces etc. Accumulated fatigue in hot weather may play a role. The aims of the research are to: (1) Examine the relationship between hot weather and workplace injury, and the influencing factors; (2) explore stakeholder perceptions; (3) improve prevention policies and (4) facilitate resources to aid in the prevention of heat-related injury.

Who is undertaking the research?
This project is funded by the Australian Research Council and is being conducted by the University of Adelaide, in cooperation with Queensland University of Technology, Monash University, the University of Western Australia, SafeWork SA, SA Health and Safe Work Australia.

What is involved?
This is an **online questionnaire survey**. The questions will be centered on heat-associated risks, how the company or organisation addresses these risks, details of training and implications of heat health protection policies on productivity loss, as well as direct and indirect injury experience.

The survey will take 10-20 minutes to complete,

Are there any risks or costs associated with being in the research?
Aside from giving up your time, we do not expect that there will be any potential risks, harms and discomfort or costs associated with taking part in this study.

Are there any benefits with being in the project?
Your participation in the project may not result in any direct benefit to you, but has the potential to improve health and safety policy and practice.

Do I have to be in the research?
Participation is completely voluntary.

What will happen to information about me that is collected during the research?
The survey will not capture your personal details and the link to the survey we have provided is a generic link with no unique identifiers. All survey responses will be aggregated and your responses will not be used outside the needs of the current project. Findings of this project may be published in journals or presented at conferences but individual participants will be anonymous and not identifiable. Data will only be accessible by research team members for research purposes. At the completion of the research all information will be held for a minimum of five years after which the information will be destroyed securely. The research has been approved by the Human Research Ethics Committee at the University of Adelaide (approval no. H-2016-085).

Can I tell other people about the project? Yes, you are welcome to tell others about the project.

Will I be told the results of the project? You have a right to receive feedback about the overall results after the research is finished.

What if I would like further information about the project?
Please contact Dr. Alana Hansen, ph: 08 8313 1043, email: alana.hansen@adelaide.edu.au or Prof. Dino Pisaniello, ph: 08 8313 3571, email: dino.pisaniello@adelaide.edu.au

What if I have a complaint or any concerns about the project?
To contact an independent person, phone the Human Research Ethics Committee's Secretariat on 08 8313 6028, quoting H-2016-085. Complaints or concerns will be treated in confidence and fully investigated. You will be informed of the outcome.

University of Adelaide Human Research Ethics Committee Approval No. H-2016-085

Appendix H: Ethics Approvals

This thesis part of a national project funded by the ARC to the primary supervisor (Prof Dino Pisaniello, DP) involved a multi-institutional team of investigators from Queensland University of Technology, The University of Western Australia and Monash University (academic partners) and SWA, SWSA and SA Health (industry partners). Hence, ethics approval for this thesis was sought from each of the four involved universities (see provided approval letters in the order below).

- Appendix H1-H3: University of Adelaide ethics approval letter
- Appendix H4: QUT ethics approval letter
- Appendix H5: UWA ethics approval letter
- Appendix H6: Monash ethics approval letter

Appendix H1: Ethical Approval Letter from the University of Adelaide for Part 1 of the Project (i.e. Analysis of WC Data)

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY
THE UNIVERSITY OF ADELAIDE

LEVEL 4, RUNDLE MALL PLAZA
50 RUNDLE MALL
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FACSIMILE +61 8 8313 3700
EMAIL hrec@adelaide.edu.au

CRICOS Provider Number 00123M

2 May 2016

Professor D Pisaniello
School: School of Public Health

Dear Professor Pisaniello

ETHICS APPROVAL No: H-2016-085

PROJECT TITLE: Workers' health and safety at high temperatures: New perspectives on injury prevention

The ethics application for the above project has been reviewed by the Low Risk Human Research Ethics Review Group (Faculty of Health Sciences) and is deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* involving no more than low risk for research participants. You are authorised to commence your research on **02 May 2016**.

Ethics approval is granted for three years and is subject to satisfactory annual reporting. The form titled *Annual Report on Project Status* is to be used when reporting annual progress and project completion and can be downloaded at http://www.adelaide.edu.au/ethics/human/guidelines/reporting. Prior to expiry, ethics approval may be extended for a further period.

Participants in the study are to be given a copy of the Information Sheet and the signed Consent Form to retain. It is also a condition of approval that you **immediately report** anything which might warrant review of ethical approval including:

- serious or unexpected adverse effects on participants,
- previously unforeseen events which might affect continued ethical acceptability of the project,
- proposed changes to the protocol; and
- the project is discontinued before the expected date of completion.

Please refer to the following ethics approval document for any additional conditions that may apply to this project.

Yours sincerely,

pp

Sabine Schreiber
Secretary, Human Research Ethics Committee
Office of Research Ethics, Compliance and Integrity

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY
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EMAIL hrec@adelaide.edu.au

CRICOS Provider Number 00123M

Applicant:	**Professor D Pisaniello**
School:	**School of Public Health**
Project Title:	**Workers' health and safety at high temperatures: New perspectives on injury prevention**

The University of Adelaide Human Research Ethics Committee
Low Risk Human Research Ethics Review Group (Faculty of Health Sciences)

ETHICS APPROVAL No: **H-2016-085** **App. No.: 0000021589**

APPROVED for the period: **02 May 2016 to 31 May 2019**

It is noted that the project will be conducted in stages and the current approval is for Part 1, the analysis of non-identifiable workers' compensation claims data as per the submitted application. The project will involve Blesson Mathew Varghese, PhD candidate.

Sabine Schreiber
Secretary, Human Research Ethics Committee
Office of Research Ethics, Compliance and Integrity

Appendix H2: Ethical Approval Letter from the University of Adelaide for Part 2 of the Project (i.e. Analysis of Stakeholder Surveys)

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY
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EMAIL hrec@adelaide.edu.au

CRICOS Provider Number 00123M

6 July 2016

Professor D Pisaniello
School of Public Health

Dear Professor Pisaniello

ETHICS APPROVAL No: **H-2016-085**

PROJECT TITLE: **Workers' health and safety at high temperatures: New perspectives on injury prevention (parts 2-4)**

Thank you for the information provided by Blesson Varghese on the 4 July 2016 and 5 July 2016 requesting approval for parts 2 to 4 of the above project. This has been reviewed by the Low Risk Human Research Ethics Review Group (Faculty of Health Sciences) and is deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* involving no more than low risk for research participants.
The ethics expiry for this project is the **31 May 2016**.

Ethics approval is granted for three years and is subject to satisfactory annual reporting. The form titled *Annual Report on Project Status* is to be used when reporting annual progress and project completion and can be downloaded at http://www.adelaide.edu.au/ethics/human/guidelines/reporting. Prior to expiry, ethics approval may be extended for a further period.

Participants in the study are to be given a copy of the Information Sheet and the signed Consent Form to retain. It is also a condition of approval that you **immediately report** anything which might warrant review of ethical approval including:

- serious or unexpected adverse effects on participants,
- previously unforeseen events which might affect continued ethical acceptability of the project,
- proposed changes to the protocol; and
- the project is discontinued before the expected date of completion.

Please refer to the following ethics approval document for any additional conditions that may apply to this project.

Yours sincerely,

Amy Lehmann
Human Research Ethics Officer
Office of Research Ethics, Compliance and Integrity

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY
THE UNIVERSITY OF ADELAIDE

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TELEPHONE +61 8 8313 5137
FACSIMILE +61 8 8313 3700
EMAIL hrec@adelaide.edu.au

CRICOS Provider Number 00123M

Applicant:	Professor D Pisaniello
School:	School of Public Health
Project Title:	Workers' health and safety at high temperatures: New perspectives on injury prevention (parts 2-4)

The University of Adelaide Human Research Ethics Committee
Low Risk Human Research Ethics Review Group (Faculty of Health Sciences)

ETHICS APPROVAL No: H-2016-085 App. No.: 0000021589

APPROVED for the period: 06 July 2016 to 31 May 2019

Parts 2, 3 and 4 of the project have been approved.

The project will involve Blesson Mathew Varghese, PhD candidate.

Amy Lehmann
Human Research Ethics Officer
Office of Research Ethics, Compliance and Integrity

Appendix H3: Renewal of the Ethical Approval from the University of Adelaide

THE UNIVERSITY of ADELAIDE

RESEARCH SERVICES
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY
THE UNIVERSITY OF ADELAIDE

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EMAIL hrec@adelaide.edu.au

CRICOS Provider Number 00123M

Our reference 0000021589

24 May 2019

Professor Dino Pisaniello
Public Health

Dear Professor Pisaniello

ETHICS APPROVAL No: H-2016-085
PROJECT TITLE: Workers' health and safety at high temperatures: New perspectives on injury prevention

Thank you for providing the annual report dated the 24/05/2019. The request for ethics extension for HDR write up only has been approved.

The ethics amendment for the above project has been reviewed by the Secretariat, Human Research Ethics Committee and is deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research 2007 (Updated 2018)* involving no more than low risk for research participants.

You are authorised to commence your research on: 02/05/2016
The ethics expiry date for this project is: 31/05/2022

NAMED INVESTIGATORS:

Chief Investigator:	Professor Dino Pisaniello
Student - Postgraduate Doctorate by Research (PhD):	Mr Blesson Mathew Varghese
Associate Investigator:	Professor Peng Bi
Associate Investigator:	Associate Professor Adrian Barnett
Associate Investigator:	J S Heyworth
Associate Investigator:	Dr Scott Hanson-Easey
Associate Investigator:	Shelley Rowett
Associate Investigator:	Dr Monika Nitschke
Associate Investigator:	Dr Alana Hansen
Associate Investigator:	Professor M R Sim
Associate Investigator:	Dr Susan Williams

CONDITIONS OF APPROVAL: This extension approves Higher Degree by Research work by B.Varghese only, no interactions with participants or data collection activities are approved under this extension approval.

Ethics approval is granted for three years and is subject to satisfactory annual reporting. The form titled Annual Report on Project Status is to be used when reporting annual progress and project completion and can be downloaded at http://www.adelaide.edu.au/research-services/oreci/human/reporting/. Prior to expiry, ethics approval may be extended for a further period.

Participants in the study are to be given a copy of the information sheet and the signed consent form to retain. It is also a condition of approval that you immediately report anything which might warrant review of ethical approval including:

- serious or unexpected adverse effects on participants,
- previously unforeseen events which might affect continued ethical acceptability of the project,
- proposed changes to the protocol or project investigators; and
- the project is discontinued before the expected date of completion.

Yours sincerely,

Miss Sarah Harman
Secretary

The University of Adelaide

Appendix H4: Ethical Approval Letter from the Queensland University of Technology

University Human Research Ethics Committee (UHREC)
HUMAN RESEARCH ETHICS APPROVAL CERTIFICATE
NHMRC Registered Committee Number EC00171

Date of Issue:17/7/19 (supersedes all previously issued certificates)

Dear Prof Adrian Barnett

This approval certificate serves as your written notice that the proposal has met the requirements of the *National Statement on Ethical Conduct in Human Research* and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application, subject to any specific and standard conditions detailed in this document.

Project Details

Category of Approval: Administrative Review

Approved From: 9/08/2016 **Approved Until:** 31/05/2019 (subject to annual reports)

Approval Number: 1600000760

Project Title: Workers' health and safety at high temperatures: New perspectives on injury prevention

Investigator Details

Chief Investigator: Prof Adrian Barnett

Other Staff/Students:

Investigator Name	Type	Role
Dr Dino Pisaniello	External	Partner Investigator
Dr Peng Bi	External	Partner Investigator
Prof Malcolm Sim	External	Partner Investigator
Dr Jane Heyworth	External	Partner Investigator
Dr Scott Hanson-Easey	External	Partner Investigator
Ms Shelley Rowett	External	Partner Investigator
Dr Monika Nitschke	External	Partner Investigator
Dr Alana Hansen	External	Project Manager

Conditions of Approval

Specific Conditions of Approval:
As per University of Adelaide

Standard Conditions of Approval:

1. Conduct the project in accordance with the principles of the NHMRC National Statement on Ethical Conduct in Human Research 2007, the Australian Code for the Responsible Conduct of Research, any additional specific conditions defined by the UHREC, any associated NHMRC guidelines and regulations, and the provisions of any legislation which is relevant to the project;
2. Obtain UHREC approval for any proposed variation to the project **prior** to implementation (note that major changes may require a different level of review and/or submission of a new application);
3. Obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations);
4. Maintain research records and data in accordance with MoPP D/2.8 Management of research data.
5. Respond promptly to the requests and instructions of UHREC;
6. Declare all actual, perceived or potential conflicts of interest (NS 5.4);
7. Immediately advise the Office of Research Ethics and Integrity (OREI) of any concerns, complaints or adverse events including (NS 5.5.3):
   - if any unforeseen development or events occur that might affect the continued ethical acceptability of the project;
   - if any complaints are made, or expressions of concern are raised, in relation to the project;
   - if the project needs to be suspended or modified because the risks to participants now outweigh the benefits
   - if a participant can no longer be involved because the research may harm them.
8. Report on the progress of the project at least annually, or at intervals determined by UHREC (NS 5.5.5);
9. Participate in project monitoring activities in accordance with MoPP D/2.4 Monitoring of research approved by a University

RM Report No. E801 Version 4.7 Page 1 of 2

University Human Research Ethics Committee (UHREC)

HUMAN RESEARCH ETHICS APPROVAL CERTIFICATE

NHMRC Registered Committee Number EC00171

Date of Issue:17/7/19 (supersedes all previously issued certificates)

If any details within this Approval Certificate are incorrect please advise the Research Ethics Advisory Team immediately.

End of Document

Appendix H5: Ethical Approval Letter from the University of Western Australia

THE UNIVERSITY OF WESTERN AUSTRALIA

Human Ethics
Office of Research Enterprise
The University of Western Australia
M459, 35 Stirling Highway
Crawley WA 6009 Australia
T +61 8 6488 3703 / 4703
F +61 8 6488 8775
E humanethics@uwa.edu.au
CRICOS Provider Code: 00126G

Our Ref: RA/4/1/8583

17 August 2016

Professor Dino Pisaniello

Dear Professor Pisaniello

HUMAN RESEARCH ETHICS OFFICE – NOTIFICATION OF ETHICS APPROVAL FROM ANOTHER ETHICS COMMITTEE

Project: Worker's Health and Safety at High Temperatures: New Perspectives on Injury Prevention - Recognition The University of Adelaide HREC Approval H-2016-085

Thank you for your correspondence notifying this office of your project's review and approval by a non-UWA Research Ethics Committee.

It is noted that you have ethics approval from University of Adelaide, approval number H-2016-085.

The students and researchers identified as working on this project are:

Name	***Faculty / School***	***Role***
Professor Dino Pisaniello	University of Adelaide	Chief Investigator
Professor Jane Heyworth	School of Population Health	Co-Investigator
Dr P Bi	University of Adelaide	Co-Investigator
A/Prof Adrian Barnett	Queensland University of Technology	Co-Investigator
Professor Malcolm Sim	Monash University	Co-Investigator
Dr Scott Hanson-Easey	University of Adelaide	Co-Investigator
Ms Shelley Rowatt	SA: South Australia	Co-Investigator
Dr Monika Nitschke	SA Department of Health	Co-Investigator
Dr Alana Hansen	University of Adelaide	Co-Investigator

Student(s): Blesson Varghese

Although The University of Western Australia reserves the right to subject any research involving its staff and students to its own ethics review process, in this case, the UWA Human Ethics Office recognizes the existing approval of the non-UWA ethics committee.

1. *Approving HREC to receive annual reports, amendments and notification of adverse events*

You are reminded that the approving ethics committee remains the monitoring committee for this project. You must correspond with them for matters regarding amendments, adverse events, annual and final reporting.

If you have any queries, please contact the HEO at humanethics@uwa.edu.au.

Please ensure that you quote the file reference – RA/4/1/8583 – and the associated project title in all future correspondence.

Yours sincerely

Appendix H6: Ethical Approval Letter from the Monash University

MONASH University

Monash University Human Research Ethics Committee

Confirmation of Registration

Project Number: 0895
Project Title: Workers' health and safety at high temperatures: New perspectives on injury prevention
Chief Investigator: Professor Malcolm Sim
Expiry Date: 13/09/2021

Terms:

1. Registration is valid whilst you hold a position at Monash University and approval at the primary HREC is current.
2. End of project: You should notify MUHREC at the conclusion of the project or if the project is discontinued before the expected date of completion.
3. Retention and storage of data: The Chief Investigator is responsible for the storage and retention of the original data pertaining to this project in accordance with the *Australian Code for the Responsible Conduct of Research*.

Thank you for your assistance.

Professor Nip Thomson

Chair, MUHREC

Appendix I: ANSZCO Codes to 30 Occupational Groupings

Table I1 Occupational groups associated with ANZSCO codes.

Group	ANZSCO codes
Farmers	1211–1214 Farmers and Farm Managers
Hospitality	1411–1419 Accommodation and Hospitality Managers
	4311–4319 Hospitality Workers
Engineers	2321 Architects and Landscape Architects
	2322 Cartographers and Surveyors
	2331–2339 Engineering Professionals
	3121–3129 Building and Engineering Technicians
Scientists	2341–2349 Natural and Physical Science Professionals
	3111–3114 Agricultural, Medical and Science Technicians
	3993 Gallery, Library and Museum Technicians
	4513 Funeral Workers
Painters	3322 Painting Trades Workers
	3995 Performing Arts Technicians
Teachers	1343 School Principals
	2411–2415 School Teachers
	2421–2422 Tertiary Education Teachers
	2491–2493 Miscellaneous Education Professionals
Nurses	2541–2544 Midwifery and Nursing Professionals
	4114 Enrolled and Mothercraft Nurses
Other Health Professionals	2511–2519 Health Diagnostic and Promotion Professionals
	2521 Chiropractors and Osteopaths
	2523–2527 Health Therapy Professionals
	2531–2539 Medical Practitioners
	4112 Dental Hygienists, Technicians and Therapists
Metal Workers	3221–3223 Fabrication Engineering Trades Workers
	3232–3234 Mechanical Engineering Trades Workers
	3994 Jewellers
	8217 Structural Steel Construction Workers
	8391 Metal Engineering Process Workers
Plumbers	3341 Plumbers
	8211 Building and Plumbing Labourers
Vehicle Workers	3211–3212 Automotive Electricians and Mechanics
	3231 Aircraft Maintenance Engineers
	3241–3243 Panel beaters, and Vehicle Body Builders, Trimmers and Painters
	8994 Motor Vehicle Parts and Accessories Fitters
Carpenters	3312 Carpenters and Joiners

Group	ANZSCO codes
	3933 Upholsterers
	3941–3942 Wood Trades Workers
	3991 Boat Builders and Shipwrights
	8394 Timber and Wood Process Workers
Construction	3311 Bricklayers and Stonemasons
	3321 Floor Finishers
	3331–3334 Glaziers, Plasterers and Tilers
	8212–8215 Construction and Mining Labourers
Electrical	3411 Electricians
	3421–3424 Electronics and Telecommunications Trades Workers
Food Factory	3511–3512 Food Trades Workers
	8311–8313 Food Process Workers
Food Service	3513–3514 Food Trades Workers
	8511–8513 Food Preparation Assistants
Printers	3921–3923 Printing Trades Workers
	3996 Signwriters
	7114 Photographic Developers and Printers
	8995 Printing Assistants and Table Workers
Animal and Horticultural	3611–3613 Animal Attendants and Trainers, and Shearers
	3621–3624 Horticultural Trades Workers
	8411–8419 Farm, Forestry and Garden Workers
Health and Personal Support	2522 Complementary Health Therapists
	2726 Welfare, Recreation and Community Arts Workers
	3911 Hairdressers
	4113 Diversional Therapists
	4115–4117 Health and Welfare Support Workers
	4211 Child Carers
	4221 Education Aides
	4231–4234 Personal Carers and Assistants
	4511 Beauty Therapists
	4515 Personal Care Consultants
	4518 Other Personal Service Workers
Emergency Workers	1392 Senior Non-Commissioned Defence Force Members
	4111 Ambulance Officers and Paramedics
	4411–4413 Defence Force Members, Fire fighters and Police
	4421–4422 Prison and Security Officers
Outdoor Work NEC	2312 Marine Transport Professionals
	4514 Gallery, Museum and Tour Guides
	4521–4524 Sports and Fitness Workers
	5995 Inspectors and Regulatory Officers
	6111 Auctioneers and Stock and Station Agents
	6217 Street Vendors and Related Salespersons
	8992 Deck and Fishing Hands
Machine Operators	3931–3932 Textile, Clothing and Footwear Trades Workers

Group	ANZSCO codes
	3992 Chemical, Gas, Petroleum and Power Generation Plant Operators
	3999 Other Miscellaneous Technicians and Trades Workers
	7111–7113 Machine Operators
	7115–7119 Machine Operators
	7123 Engineering Production Systems Workers
	7129 Other Stationary Plant Operators
	8321–8322 Packers and Product Assemblers
	8392–8393 Miscellaneous Factory Process Workers
	8399 Other Factory Process Workers
Automobile Drivers	4512 Driving Instructors
	5612 Couriers and Postal Deliverers
	6113 Sales Representatives
	6121 Real Estate Sales Agents
	7311 Automobile Drivers
	8997 Vending Machine Attendants
Heavy Vehicle Drivers	7121 Crane, Hoist and Lift Operators
	7211–7212 Mobile Plant Operators
	7219 Other Mobile Plant Operators
	7321 Delivery Drivers
	7331 Truck Drivers
	8216 Railway Track Workers
	8996 Recycling and Rubbish Collectors
Miners	7122 Drillers, Miners and Shot Firers
	8219 Other Construction and Mining Labourers
Warehousing	7213 Forklift Drivers
	7411 Storepersons
	8911 Freight and Furniture Handlers
Cleaners	8111–8116 Cleaners and Laundry Workers
Handypersons	8993 Handypersons
	8999 Other Miscellaneous Labourers
Passenger Transport	2311 Air Transport Professionals
	4517 Travel Attendants
	7312–7313 Automobile, Bus and Rail Drivers
Office	1111–1113 Chief Executives, General Managers and Legislators
	1311 Advertising and Sales Managers
	1321–1325 Business Administration Managers
	1331–1336 Construction, Distribution and Production Managers
	1341–1342 Education, Health and Welfare Services Managers
	1344 Other Education Managers
	1351 ICT Managers
	1391 Commissioned Officers (Management)
	1399 Other Specialist Managers
	1421 Retail Managers
	1491–1499 Miscellaneous Hospitality, Retail and Service Managers

Group	ANZSCO codes
	2111–2114 Arts Professionals
	2121–2124 Media Professionals
	2211–2212 Accountants, Auditors and Company Secretaries
	2221–2223 Financial Brokers and Dealers, and Investment Advisers
	2231–2233 Human Resource and Training Professionals
	2241–2249 Information and Organisation Professionals
	2251–2254 Sales, Marketing and Public Relations Professionals
	2323–2326 Architects, Designers, Planners and Surveyors
	2611–2613 Business and Systems Analysts, and Programmers
	2621 Database and Systems Administrators
	2631–2633 ICT Network and Support Professionals
	2711–2713 Legal Professionals
	2721–2725 Social and Welfare Professionals
	3131–3132 ICT and Telecommunications Technicians
	4516 Tourism and Travel Advisers
	5111 Contract, Program and Project Administrators
	5121–5122 Office and Practice Managers
	5211–5212 Personal Assistants and Secretaries
	5311 General Clerks
	5321 Keyboard Operators
	5411–5412 Call or Contact Centre Information Clerks
	5421 Receptionists
	5511–5513 Accounting Clerks and Bookkeepers
	5521–5523 Financial and Insurance Clerks
	5611 Betting Clerks
	5613–5619 Clerical and Office Support Workers
	5911–5912 Logistics Clerks
	5991–5994 Miscellaneous Clerical and Administrative Workers
	5996–5999 Miscellaneous Clerical and Administrative Workers
	6112 Insurance Agents
	6211–6216 Sales Assistants and Salespersons
	6219 Other Sales Assistants and Salespersons
	6311 Checkout Operators and Office Cashiers
	6391–6399 Miscellaneous Sales Support Workers
	8912 Shelf Fillers
	8991 Caretakers

Source: Adapted from Carey RN et al. [407]

Appendix J: Data Analysis Plan—Part 1

Date of plan: 17/11/2016

Study name: Worker's health and safety at high temperatures: new perspectives on injury prevention

Chief investigators: Prof Dino Pisaniello, Prof Peng Bi, Prof Adrian Barnett, Prof Malcolm Sim, Prof Jane Heyworth and Dr Scott Hanson-Easey

Person conducting analysis: Blesson Varghese (Quantitative), Dr Alana Hansen (Qualitative)

Research Team: Ms Shelley Rowett, Dr Monika Nitschke, Dr Alana Hansen, Blesson Varghese

BACKGROUND TO THE STUDY AND ANALYSIS

With the predicted increase in the frequency and intensity of extremely hot weather, workplace heat exposure will present an increasing challenge to Australian worker's health and safety. Research has shown high temperature exposure can cause heat-related illnesses in workers, which is often the well-known adverse effect of heat exposure. However, the influence of this hazard on the occurrence of injuries is poorly characterised, and may represent a large human and economic cost. The literature suggests that injuries are most likely in moderately hot weather rather than extremely hot conditions. Therefore, understanding this important, but counterintuitive, phenomenon and developing relevant preventive/adaptive strategies represents the basis of this proposal.

The proposed research will involve analysis of worker's compensation data obtained from Safe Work jurisdictions in Adelaide, Brisbane, Melbourne and Perth. The analysis will document the injury profile of workers in each jurisdiction and explore the association between meteorological parameters (daily maximum temperature) and compensation claims. In a second stage, using a national survey of regulators, experts, union officials, and health and safety representatives in industries, their experiences and perceptions in regards to dealing with a work-related injury during hot weather will be explored.

It is expected that this research will provide supporting evidence for recommendations that may assist injury reduction targets and help reduce losses in productivity by elucidating and tackling this under-investigated area of occupational health.

Phase 1: Workers' compensation claims data

<u>Data details</u>

- **Datasets:**
  - Temperature and injury analysis (Adelaide)
    - Return to Work SA (RTWSA) Tabulator data
  - Temperature and injury analysis (multi-city study)
    - National dataset for compensation based statistics (NDS3) from Safe Work Australia.
  - Heatwave severity using Excess heat factor (EHF)
    - Adelaide:
      - Return to Work SA Tabulator data
      - Work-related ambulance call-outs data
    - Other cities: National dataset for compensation based statistics (NDS3) from Safe Work Australia.
- **Analysis packages**: Stata 14 and R 3.3.2
- **Study population:** Workers that have lodged compensation claims in four metropolitan cities; Adelaide, Melbourne, Brisbane or Perth.
- **Inclusion/exclusion criteria:** All claims and (accepted) injury claims that are during the study period 2006-2015 (NDS data) and 2004-2013 (RTWSA data)
- **Exposure variables:**
  - Maximum daily temperature (Tmax)
  - Other meteorological indices that take humidity into account:
    - WBGT, Apparent temperature, Heat index (USA), Humidex (Canada), and Universal Thermal Comfort Index (UTCI).
  - Excess heat factor for heatwave severity
    - Low-intensity heatwave
    - Moderate-intensity heatwave
    - High-intensity heatwave
- <u>Adelaide metropolitan area</u>: One weather station (Kent Town) will be used as per in earlier studies (Xiang et al 2014, Williams et al 2012, Nairn & Fawcett 2013, Milazzo et al 2016).

- Perth metropolitan areas: One station (Perth metropolitan weather station (number 009225) in Mount Lawley), was used by Scalley et al 2015 to determine the increases in health care utilisation in Perth, WA.
- Melbourne metropolitan area: One station (station: 086071) as per Loughnan ME et al 2008
- Brisbane metropolitan area: One station (station: 040913) as per Qiao Z, Guo Y, Yu W and Tong S 2015
- **Outcome measure:** number of daily work-related injuries
- **Sub-groups:**
  - **Worker**- age, gender, experience, industry
  - **Work-** occupation, work location (outdoor or indoor), workplace hazards and physical demands
  - **work environment-** worksite location (CBD, suburbs), size of business
  - **Injury characteristics-** agency of injury, mechanism of injury, body location of injury and nature of injury (coded by TOOCS3.1)

Proposed analytical strategy:

- **Descriptive statistics**
- **Relationship between temperature and all claims and injury claims for the study sites**
  - **Study design:** time-stratified case-crossover design
    - Narrow 7-day window strata used to account for week-to-week changes in the number of workers and for seasonal changes in injury risk that are unrelated to temperature.
    - Case days compared to control days from same strata
    - Fit the case-crossover using a generalized linear model assuming a Poisson distribution
  - **Statistical modelling for temperature**
    - Distributed lag nonlinear model (DLNM)
      - Maximum lag of 6 days assessed as the longest possible delay between exposure and injury
      - Natural cubic spline of 3 df for non-linear temperature effects to capture the expected U-shaped risk and 2 df for

lagged effects and potential non-linear decay in risk over time

- Days of week, public holidays controlled for to adjust for reductions in worker numbers on weekends and holidays
- Residuals plotted, assessed for normality, outliers and autocorrelations and variance inflation factor used to check for collinearity.
- Lowest point of exposure-response curve = optimal temperature (OT) as reference value for cross-basis.
- Relative risks (95%CI) tabulated for all cities for moderate heat (90^{th} percentile) and extreme heat (99^{th} percentile) compared with OT.
- The exposure-response curves will be plotted for each city to examine where risks increase and whether there is a common pattern across cities.

- **The association between heatwave severity (using Excess Heat Factor) and all claims/injuries**
    - Same study design as temperature analyses. GLM models will be performed with the dependent variable (injuries) and categorical independent variable (heatwave severity). EHF severity categories are 0-1; >1-2; >2. The comparator is EHF <0 (i.e. non-heatwave). Analysis will be restricted to the warm months of the year. (See Nairn and Fawcett, 2013 for details of EHF)

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Toloo GS, Yu W, Aitken P, FitzGerald G, Tong S. The impact of heatwaves on emergency department visits in Brisbane, Australia: a time series study. Crit Care. 2014;18(2):R69.

Wang XY, Guo Y, FitzGerald G, Aitken P, Tippett V, Chen D, et al. The Impacts of Heatwaves on Mortality Differ with Different Study Periods: A Multi-City Time Series Investigation. PLoS One. 2015;10(7):e0134233.

Tong S, FitzGerald G, Wang XY, Aitken P, Tippett V, Chen D, et al. Exploration of the health risk-based definition for heatwave: A multi-city study. Environ Res. 2015;142:696-702.

Leone M, D'Ippoliti D, De Sario M, Analitis A, Menne B, Katsouyanni K, et al. A time series study on the effects of heat on mortality and evaluation of heterogeneity into European and Eastern-Southern Mediterranean cities: results of EU CIRCE project. Environ Health. 2013;12:55.

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Barnett AG, Williams GM, Schwartz J, Neller AH, Best TL, Petroeschevsky AL, et al. Air pollution and child respiratory health: a case-crossover study in Australia and New Zealand. Am J Respir Crit Care Med. 2005;171(11):1272-8.

Barnett AG, Williams GM, Schwartz J, Best TL, Neller AH, Petroeschevsky AL, et al. The effects of air pollution on hospitalizations for cardiovascular disease in elderly people in Australian and New Zealand cities. Environ Health Perspect. 2006;114(7):1018-23.

Excess heat factor methods:

Nairn JR, Fawcett RJ. The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity. Int J Environ Res Public Health. 2014;12(1):227-53.

Scalley BD, Spicer T, Jian L, Xiao J, Nairn J, Robertson A, et al. Responding to heatwave intensity: Excess Heat Factor is a superior predictor of health service utilisation and a trigger for heatwave plans. Aust N Z J Public Health. 2015;39(6):582-

Appendix K: Additional Material

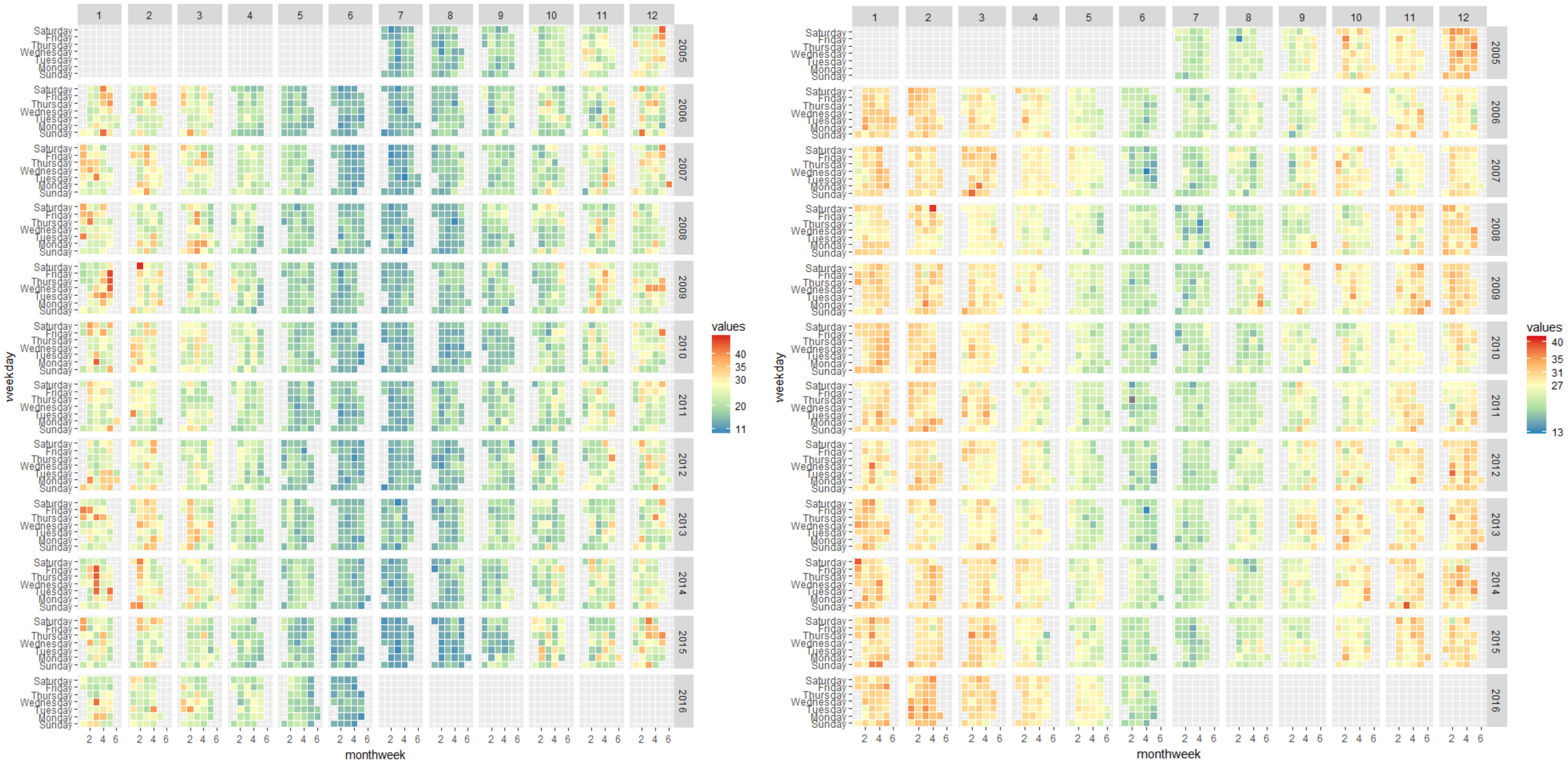

Figure K1 Calendar heat map of daily maximum temperatures in Melbourne (A) and Brisbane (B) between 1 July 2005 and 30 June 2016.

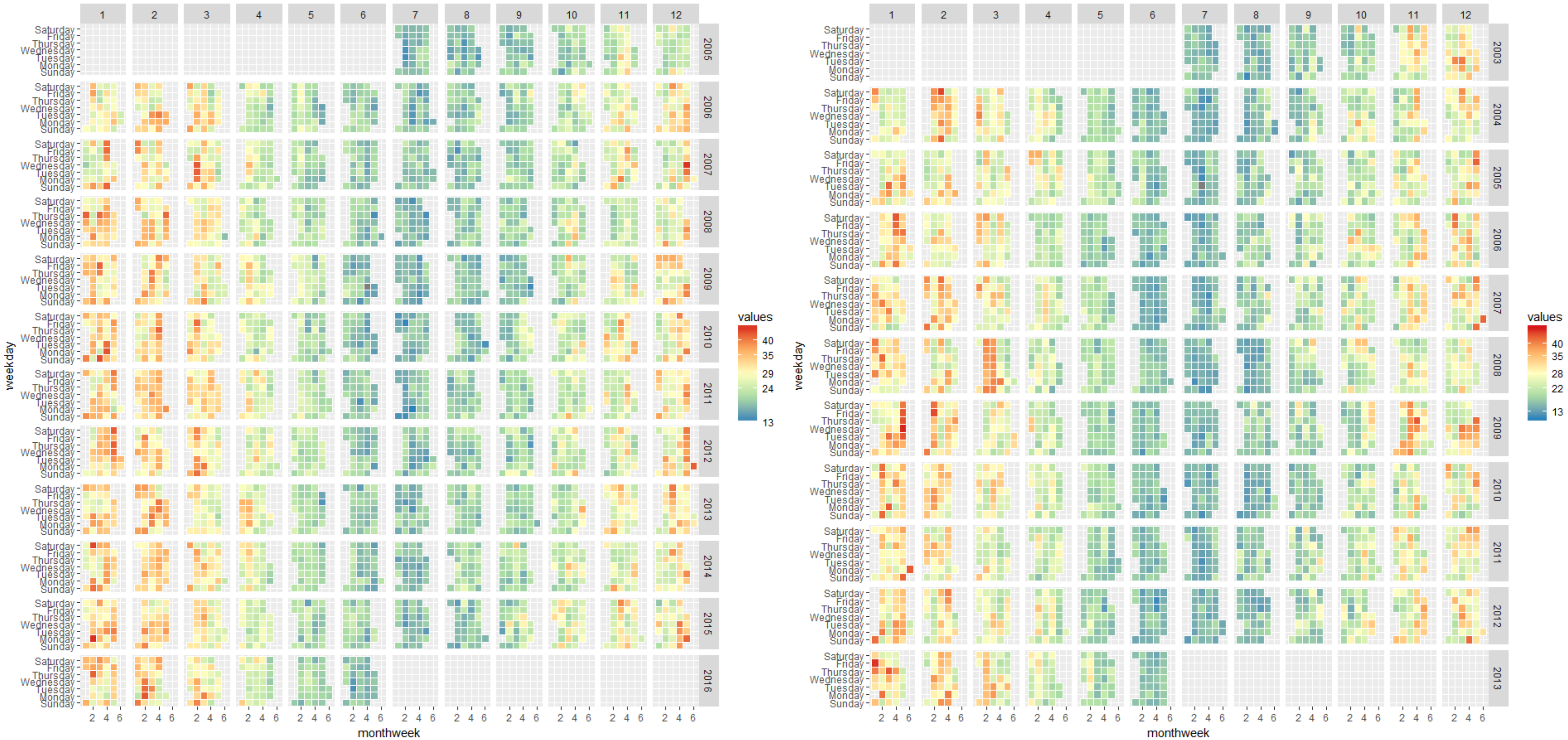

Figure K2 Calendar heat map of daily maximum temperatures in Perth (A) between 1 July 2005 and 30 June 2016 and Adelaide (B) between 1 July 2003 and 30 June 2013.

Alternative stations comparisons

Table K1 Relative risks for WC claims due to heat and cold according to weather stations used.

City	Stations	Extreme cold	Extreme heat
Adelaide	Average of stations	1.09 (0.98–1.20)	1.30 (1.17–1.43)
	23090T_{max} ✦	1.10 (0.99–1.21)	1.30 (1.18–1.44)
	23034T_{max}	1.08 (0.98–1.19)	1.33 (1.20–1.47)
	23083T_{max}	1.11 (1.01–1.22)	1.29 (1.17–1.42)
	23013T_{max}	1.12 (1.01–1.23)	1.29 (1.17–1.42)
	23887T_{max}	1.06 (0.96–1.17)	1.27 (1.15–1.40)
	23885T_{max}	1.04 (0.94–1.14)	1.32 (1.19–1.45)
	23733T_{max}	1.10 (0.99–1.21)	1.29 (1.16–1.43)
Brisbane	Average of stations	0.91 (0.83–0.99)	0.96 (0.88–1.05)
	40913T_{max} ✦	0.89 (0.81–0.98)	0.98 (0.89–1.09)
	40958T_{max}	0.99 (0.92–1.09)	0.95 (0.87–1.05)
	40211T_{max}	1.01 (0.93–1.09)	0.95 (0.86–1.05)
	40854T_{max}	0.86 (0.76–0.98)	0.97 (0.89–1.07)
	40842T_{max}	0.93 (0.84–1.03)	0.95 (0.87–1.04)
Melbourne	Average of stations	0.96 (0.88–1.06)	1.13 (1.02–1.25)
	86071T_{max} ✦	0.99 (0.90–1.09)	1.14 (1.03–1.25)
	87031T_{max}	0.97 (0.89–1.07)	1.16 (1.04–1.28)
	86351T_{max}	0.95 (0.87–1.04)	1.14 (1.03–1.26)
	86282T_{max}	0.95 (0.87–1.04)	1.13 (1.03–1.25)
	86104T_{max}	0.97 (0.89–1.05)	1.11 (1.00–1.23)
	86077T_{max}	0.99 (0.91–1.08)	1.13 (1.02–1.25)
	86068T_{max}	0.97 (0.89–1.06)	1.12 (1.02–1.24)
	86038T_{max}	0.95 (0.87–1.04)	1.14 (1.04–1.26)
Perth	Average of stations	0.96 (0.88–1.05)	1.01 (0.92–1.10)
	9225T_{max} ✦	0.96 (0.88–1.05)	1.02 (0.93–1.11)
	9021T_{max}	0.96 (0.88–1.05)	1.01 (0.93–1.11)
	9215T_{max}	0.97 (0.89–1.07)	1.02 (0.94–1.11)
	9172T_{max}	0.97 (0.89–1.06)	1.02 (0.93–1.11)
	9240T_{max}	0.95 (0.87–1.04)	0.98 (0.90–1.08)

Note: ✦ indicates the estimate for the main station used in Chapters 4–7.

Appendix L: Abstracts of published manuscripts

Safety Science 110 (2018) 380–392

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review

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A R T I C L E I N F O

Keywords:
Environmental temperature
Occupational injuries
Health and safety
Climate change
Heat stress
Workplace heat exposure

A B S T R A C T

Rationale: There is increasing concern about occupational illness, injury and productivity losses due to hot weather in a changing climate. Most of the current understanding appears to relate to heat-induced illness, and relatively little regarding injuries.

Objectives: This paper sought to summarise the evidence on the relationship between heat exposure and injuries, to describe aetiological mechanisms and to provide policy suggestions and further research directions.

Methods: A literature review was conducted using a systematic search for published and grey-literature using Embase, PubMed, Scopus, CINAHL, Science Direct and Web of Science databases as well as relevant websites.

Results and conclusions: There was a diversity of studies in terms of occupations, industries and methods utilised. The evidence suggests an imprecise but positive relationship between hot weather and occupational injuries, and the most likely mechanism involves fatigue, reduced psychomotor performance, loss of concentration and reduced alertness. The findings reflect an increased awareness of injury risk during hot weather and the economic benefits associated with averting injury, poor health outcomes and lost productivity.

Implications: More work is required to characterise specific injuries and the workers at risk. Policymakers and employers should be aware that heat exposure can lead to occupational injuries with information and training resources developed to aid prevention.

1. Introduction

Global average temperatures have risen about 0.85 °C over the last 100 years with temperatures further projected to increase by an estimated average of 3 °C by 2100 to reach 1.8–4 °C above pre-industrial times (IPCC, 2014). As a result, extremely hot days and warm nights have increased in number over recent decades and indications suggest that this trend will continue (IPCC, 2014; Steffen and Hughes, 2013).

In addition to the adverse effects of heat exposure on the general population, occupational health and safety is also affected (Song et al., 2017; Kovats and Hajat, 2008; Page et al., 2012). Workers in industrial sectors such as agriculture, forestry, fisheries and construction are exposed to outside temperatures and solar heat load making them vulnerable to the adverse health effects of heat exposure in hot weather (Lundgren et al., 2013; Heidari et al., 2015). Furthermore, those working in hot indoor environments without air-conditioning – such as manufacturing, smelting plants, bakeries, laundries, and restaurant kitchens can also be affected (Lundgren et al., 2013; Heidari et al., 2015; Health Council of the Netherlands, 2008). Heat-related illnesses (HRI) such as heat cramps, heat syncope, fatigue, heat exhaustion, heat stroke and heat shock are often the well-known and documented adverse direct effects of heat on health (Jackson and Rosenberg, 2010). These outcomes have been reported in the occupational setting among, for example, surface mine workers (Miller and Bates, 2007; Hunt et al., 2013), construction workers (Dutta et al., 2015), agricultural workers (Bethel and Harger, 2014; Kearney et al., 2016; Mirabelli et al., 2010; Spector et al., 2015) and radiation decontamination workers (Kakamu et al., 2015).

There is now increasing evidence that occupational heat stress is strongly associated with injuries, as an indirect effect of heat exposure (Tawatsupa et al., 2013; Morabito et al., 2006; Harduar Morano et al., 2015; Harduar Morano et al., 2016; Basu, 2009; Fogleman et al., 2005; The National Institute for Occupational Safety and Health, 2015). Work-related injuries/accidents in hot conditions can be caused by physical discomfort and altered behaviour, fatigue, declining psychomotor performance, loss of concentration and reduced alertness (Jackson and Rosenberg, 2010). However, the extent of injury occurrence in hot weather is poorly characterised and understood, and may represent a notable human and economic cost when combined with HRI.

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Original article

The effects of ambient temperatures on the risk of work-related injuries and illnesses: Evidence from Adelaide, Australia 2003–2013

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A R T I C L E I N F O

Keywords:
Occupational Health
Temperature
Injuries
Case-crossover design
Attributable risk
Distributed lag non-linear model

A B S T R A C T

Background: The thermal environment can directly affect workers' occupational health and safety, and act as a contributing factor to injury or illness. However, the literature addressing risks posed by varying temperatures on work-related injuries and illnesses is limited.

Objectives: To examine the occupational injury and illness risk profiles for hot and cold conditions.

Methods: Daily numbers of workers' compensation claims in Adelaide, South Australia from 2003 to 2013 (n = 224,631) were sourced together with daily weather data. The impacts of maximum daily temperature on the risk of work-related injuries and illnesses was assessed using a time-stratified case-crossover study design combined with a distributed lag non-linear model.

Results: The minimum number of workers' compensation claims occurred when the maximum daily temperature was 25 °C. Compared with this optimal temperature, extremely hot temperatures (99th percentile) were associated with an increase in overall claims (RR: 1.30, 95%CI: 1.18–1.44) whereas a non-significant increase was observed with extremely cold temperatures (1st percentile, RR: 1.10 (95%CI: 0.99–1.21). Heat exposure had an acute effect on workers' injuries whereas cold conditions resulted in delayed effects. Moderate temperatures were associated with a greater injury burden than extreme temperatures.

Conclusion: Days of very high temperatures were associated with the greatest risks of occupational injuries; whereas moderate temperatures, which occur more commonly, have the greatest burden. These findings suggest that the broader range of thermal conditions should be considered in workplace injury and illness prevention strategies.

1. Introduction

The relationship between temperature extremes and adverse effects on population health is well documented, with increased risks for vulnerable groups such as the elderly, and those with chronic morbidities (Song et al., 2017; Schulte and Chun, 2009). To date, most of the research has focussed on the general population while the occupational health impacts on workers have received less attention (Kjellstrom, 2016; Kjellstrom et al., 2016; Applebaum et al., 2016). Recent reviews (Bonafede et al., 2016; Varghese et al., 2018; Otte im Kampe et al., 2016) indicate that while studies have considered the effects of either high or low temperatures on work-injuries, there is limited research on the effects of both heat and cold conditions on injury risks for workers, thus calling for more research in this area.

In addition to heat or cold related illnesses, occupational injuries can occur when an individual's coordination, strength, vision, endurance, or judgement are influenced by temperature-induced physiological changes (Kjellstrom et al., 2009; Xiang et al., 2014a; Spector et al., 2014; Grandjean and Grandjean, 2007). A US study examining the association between temperature and injury risk found that compared to ambient temperatures of 10–16 °C, the odds ratios (OR) of acute injury risks in aluminium smelter workers were: 2.28 (95% CI:1.49–3.49) between 32 °C and 38 °C; and 3.52 (95% CI: 1.86–6.67) above 38 °C (Fogleman et al., 2005). In Australia, studies in Melbourne (McInnes et al., 2017), and Adelaide (Xiang et al., 2014b) have also shown increased risks for workers in hot weather and during

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Geographical variation in risk of work-related injuries and illnesses associated with ambient temperatures: A multi-city case-crossover study in Australia, 2005–2016

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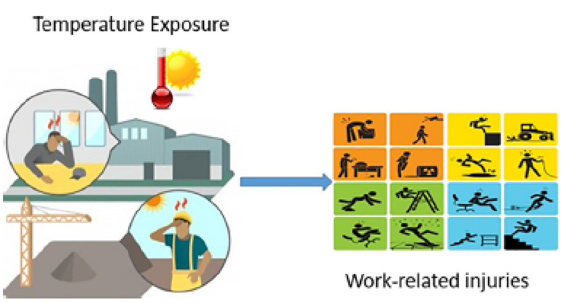
HIGHLIGHTS

- The association of ambient temperatures with workers compensation claims was quantified in three Australian cities
- Relationships between temperature and work-related injuries and illnesses varied by location and climate
- Cooler day time maximum temperatures were associated with reduced risks to workers in all three cities
- The avoidable burden of temperature was higher in sub-tropical Brisbane than in temperate Melbourne and Perth

GRAPHICAL ABSTRACT



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ABSTRACT

Background: The thermal working environment can have direct and in-direct effects on health and safety. Ambient temperatures have been associated with an increased risk of occupational injuries but it is unknown how the relationship can vary by weather, location and climate.
Objectives: To examine the relationship between ambient temperatures and work-related injury and illness compensation claims in three Australian cities: Melbourne and Perth (temperate climate) and Brisbane (subtropical climate) in order to determine how hot and cold weather influences the risk of occupational injury in Australia.
Methods: Workers' compensation claims from each city for the period 2005 to 2016 were merged with local daily weather data. A time-stratified case-crossover design combined with a distributed lag non-linear model was used to quantify the impacts of daily maximum temperature (T_{max}) on the risk of work-related injuries and illnesses.
Results: Compared to the median maximum temperature (T_{max}), extremely hot temperatures (99th percentile) were associated with a 14% (95%CI: 3–25%) increase in total workers' compensation claims in Melbourne, but

Abbreviations: RR, relative risk; DLNM, distributed lag non-linear model; T_{max}, maximum temperature; PAF, population attributable fraction.

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ORIGINAL ARTICLE

Heatwave and work-related injuries and illnesses in Adelaide, Australia: a case-crossover analysis using the Excess Heat Factor (EHF) as a universal heatwave index

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Abstract

Purpose Heatwaves, or extended periods of extreme heat, are predicted to increase in frequency, intensity and duration with climate change, but their impact on occupational injury has not been extensively studied. We examined the relationship between heatwaves of varying severity and work-related injuries and illnesses. We used a newly proposed metric of heatwave severity, the Excess Heat Factor (EHF), which accounts for local climate characteristics and acclimatization and compared it with heatwaves defined by daily maximum temperature.

Methods Work-related injuries and illnesses were identified from two administrative data sources: workers' compensation claims and work-related ambulance call-outs for the years 2003–2013 in Adelaide, Australia. The EHF metrics were obtained from the Australian Bureau of Meteorology. A time-stratified case-crossover regression model was used to examine associations between heatwaves of three levels of severity, workers' compensation claims, and work-related ambulance call-outs.

Results There was an increase in work-related ambulance call-outs and compensation claims during low and moderately severe heatwaves as defined using the EHF, and a non-significant decline during high-severity heatwaves. Positive associations were observed during moderate heatwaves in compensation claims made by new workers (RR 1.31, 95% CI 1.10–1.55), workers in medium-sized enterprises (RR 1.15, 95% CI 1.01–1.30), indoor industries (RR 1.09, 95% CI 1.01–1.17), males (RR 1.13, 95% CI 1.03–1.23) and laborers (RR 1.21, 95% CI 1.04–1.39).

Conclusions Workers should adopt appropriate precautions during moderately severe heatwaves, when the risks of work-related injuries and illnesses are increased. Workplace policies and guidelines need to consider the health and safety of workers during heatwaves with relevant prevention and adaptation measures.

Keywords Workers' compensation claims · Case-crossover design · Heatwaves · Occupational health · Worker safety

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Introduction

The detrimental effect of temperature upon human health assessed in terms of increased mortality and morbidity is well-established (Song et al. 2017). Major heatwaves (extended periods of unusually high temperatures) have been associated with an increased health burden in populations over recent years. For example, heatwaves in Australia in 2009 (Nitschke et al. 2011; Zhang et al. 2013, 2016) and Europe in 2003 (Le Tertre et al. 2006) have drawn increasing interest among researchers, governments and policy makers. The majority of health research has predominantly focussed on the general population, while the occupational health effects have been largely overlooked despite their potential economic costs and impact on quality of life.

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ARTICLE

Characterising the impact of heatwaves on work-related injuries and illnesses in three Australian cities using a standard heatwave definition- Excess Heat Factor (EHF)

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Abstract

Background and Aims: Heatwaves have potential health and safety implications for many workers, and heatwaves are predicted to increase in frequency and intensity with climate change. There is currently a lack of comparative evidence for the effects of heatwaves on workers' health and safety in different climates (sub-tropical and temperate). This study examined the relationship between heatwave severity (as defined by the Excess Heat Factor) and workers' compensation claims, to define impacts and identify workers at higher risk.
Methods: Workers' compensation claims data from Australian cities with temperate (Melbourne and Perth) and subtropical (Brisbane) climates for the years 2006–2016 were analysed in relation to heatwave severity categories (low and moderate/high severity) using time-stratified case-crossover models.
Results: Consistent impacts of heatwaves were observed in each city with either a protective or null effect during heatwaves of low-intensity while claims increased during moderate/high-severity heatwaves compared with non-heatwave days. The highest effect during moderate/high-severity heatwaves was in Brisbane (RR 1.45, 95% CI: 1.42–1.48). Vulnerable worker subgroups identified across the three cities included: males, workers aged under 34 years, apprentice/trainee workers, labour hire workers, those employed in medium and heavy strength occupations, and workers from outdoor and indoor industrial sectors.
Conclusion: These findings show that work-related injuries and illnesses increase during moderate/high-severity heatwaves in both sub-tropical and temperate climates. Heatwave forecasts should signal the need for heightened heat awareness and preventive measures to minimise the risks to workers.

Keywords: Heatwave · Morbidity · Workers health and safety

Introduction

Extreme heat events (heatwaves) represent the most common cause of weather-related deaths in Australia and the

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