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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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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 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 2003-2013 (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.

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

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 (1, 2). To date, most of the research has focussed on the general population while the occupational health impacts on workers have received less attention (3-5). Recent reviews (6-8) 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 (9-12). 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 (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 (13). In Australia, studies in Melbourne (14), and Adelaide (15) 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 (16-20).

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 (21). 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 and illnesses; b) identify susceptible worker subgroups by occupation and their working environment (outdoor vs indoor); and c) quantify the burden of work-related injuries and illnesses in association with hot and cold temperatures in Adelaide, South Australia.

2. Materials and Methods

2.1 Study setting

Adelaide (latitude 34°55'S, 138°35'E) is the capital city of South Australia (SA) 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 (22). 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 (23). The warmest months are January and February with average daily maximum temperatures of 29°C and heatwaves are quite common. During winter (June-August) the average daily maximum temperature is 15-16°C.

2.2. Data sources

2.2.1 Workers compensation claims data

Workers who have experienced a work-related injury or illness in SA can lodge a claim for compensation covering medical expenses and/or loss of wages (24). 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 (24). All reported compensation claims in SA are aggregated and managed by the jurisdictional government-run regulator (SafeWork SA). Since 1987, surveillance of work-related injuries and diseases has been conducted using these data to identify target areas for prevention, as well as to evaluate safety improvement programs (25). Details of each claim are recorded according to the Type of Occurrence Classification System (TOOCS 3.1) (26). Work-related injuries 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 (27). It should be noted that 90% of all compensation claims in Australia are for work-related injuries (27).

The data for the period from 1st July 2003 to 30th 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 S1). Data were aggregated and restricted to the Adelaide metropolitan area (postcodes 5000-5200) (28).

Workers' potential exposure to temperature in the workplace was examined at the industrial and occupational level. Consistent with previous research (15, 29), 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 (30) and the Canadian National Occupational Classification (NOC) system (31) 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 (32, 33) and validated in the Australian context

(14, 34, 35). Additionally, occupational groups were further characterized according to the method of Carey et al. (36).

2.2.2 Meteorological data

Weather data including daily maximum (highest temperature in the 24 hours after 09:00 hours) and minimum temperatures (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.

2.3 Study design

A time-stratified case-crossover design was used to examine the relationship between the risk of daily workers' compensation claims (comprising work-related injuries and illnesses) and daily maximum temperature. 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 (37). 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 worker's compensation claims for a work-related injury 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 case-crossover method was selected which uses a fixed and disjointed window where case days are compared with control days from the same strata (38). 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 case-crossover using a generalized linear model assuming a Poisson distribution.

2.4 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 (39, 40). A natural cubic spline with 3 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 2 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 (20). Subgroup analyses by the worker, work, workplace and injury characteristics were conducted for the compensation claims data to define factors with relatively strong associations with temperature.

Maximum 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, humidex, heat index, Universal Thermal Comfort Index (UTCI), and Wet Bulb Globe Temperature (WBGT) for sensitivity analyses (details provided in the supplementary material).

2.5 Computation of Attributable risk

The burden of workers compensation 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 work-related injury and illness (41). 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 (41). In line with previous studies (20, 41), 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 were obtained for AF and AN using 5000 Monte Carlo simulations assuming a multivariate normal distribution of the reduced coefficients (41).

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 case-crossover design (39, 42). The attributable risks (AF and AN) were calculated using the function 'attrdl' (41).

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

3. Results

3.1 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 S3). About two-thirds of all claims occurred among males and about 48.6% occurred in people aged 35-54 years (see supplementary Table S1-S3).

3.2 Exposure-response relationship

3.2.1 Overall Association

The cumulative association between temperature and workers' compensation claims is shown in Figure 1A. A J-shaped association was observed between all claims and daily T_{max}, with significantly higher relative risk above 25°C. The overall relative risk (RR) for moderately (90^{th} percentile, 33.3°C) and extremely hot temperatures (99^{th} 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 1B). For moderately (10^{th} percentile, 15°C) and extremely cold temperatures (1^{st} percentile, 12.6°C), the overall relative risk were 1.08 (95% CI: 1.01-1.15) and 1.10 (95% CI: 0.99-1.21), respectively. The effects of heat on compensation claims were acute and immediate while that of cold were delayed (see supplementary Figure S4).

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

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

Compared with 25°C, extremely hot temperatures were associated with increases 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 claims were seen among workers employed in 'medium' and 'heavy' strength occupations and those working in 'regulated indoor climates' (Table 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 2).

As with hot temperatures, cold temperatures had the greatest effect on workers aged 15-24 years and experienced workers. (Table 1). A statistically significant increase in claims was seen in 'food factory' workers at (moderately and extremely) cold temperatures (Table 2). The highest effects of extremely cold temperatures were observed on workers in 'light' and 'heavy' strength occupations (Table 1).

3.2.3 Stratification by industry characteristics

There were significant relationships between maximum temperature and total claims in both outdoor and indoor industries (Table 1). During moderately hot temperatures the highest increase in total 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 claims (Table 1).

3.2.4 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 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 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 3).

3.3 Attributable risk of occupational injury/illness due to temperature

The estimated temperature-related burden on workers compensation claims is shown in Table 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.

3.4 Sensitivity analyses

Results similar to those found using T_{max} were obtained using composite predictive thermal indices, i.e. apparent temperature, humidex, UTCI and WBGT (Figure S5).

4. 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 workers' compensation 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, 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 (7, 43, 44), all compensation claims (accepted by the insurer) for both work-related injuries and illnesses were used in this study, consistent with similar studies (15, 29, 45). Our results support a non-linear relationship between daily T_{max} and total workers' compensation 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 (15, 17, 20, 46-49). This evidence of nonlinearity in our study is also consistent with findings from other Mediterranean climates (17, 20) despite potential differences in labour markets and industries. In contrast to our study, some previous studies

(46, 47) including one from Adelaide (15) 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 (15). However, compliance with such policies, in reality, is unknown as there is no mandatory regulations or guidelines for maximum workplace temperatures in Australia (50).

The time lag for the effects of cold and heat in our study differed in that the effects of cold appeared after a 3-day lag and lasted longer, while that of heat were acute and immediate. The delayed cold effects are in line with population health studies (51, 52); and our findings that heat exposure has immediate occupational health consequences align with previous findings (15, 53).

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 (54). 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 (7, 43). 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 (14, 15). Chronic conditions such as respiratory diseases and skin diseases can also be exacerbated by factors associated with extreme temperatures (43, 55).

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 (15, 53) have found significant associations between high temperatures and injuries among male workers only. However, a study in Melbourne, Australia (14) reported an association between injuries and minimum temperature 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 (22).

Our findings showed young workers (15-24 years) had a higher risks of temperature-related claims, consistent with previous literature (15, 20, 29, 53). 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 (15) 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 (56).

We found an increased risk of work-related injuries 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 (20, 53, 57) while a study in Adelaide (15) 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 work-related injuries 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 (14). This could be due to the relatively lower levels of acclimatization to heat which may render workers susceptible to hot conditions outdoors (58-60).

As for cold, our results showed an increased risk of work-related injuries 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 (16, 20, 43, 44).

Approximately 5% of the total compensation claims in this study could be attributed to temperature. This estimate is higher (2.7%) than those reported by Martinez-Solanas et al (2018) in Spain (20). Extremely hot or cold temperatures contributed to less than 1% of all injuries which is also consistent with Martinez-Solanas et al (2018), while milder temperatures, which occurred on the majority of days, accounted for around 4% of all injuries (20). 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 occupational health and safety 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 generalizable 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 personalized temperature and physiological indicators measurement which is emerging as a direction for future research (61). 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 (62). However, our sensitivity analysis using apparent temperature, WBGT, humidex, heat index and $UTCI_{max}$ (see supplementary material) 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 (63). 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 generalizability 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 work-related injuries 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 case-crossover 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 work-related injuries 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.

5. Conclusion:

Our study suggests that both cold and hot temperatures increase the risk of work-related injuries 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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Figure legend:

Figure 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.

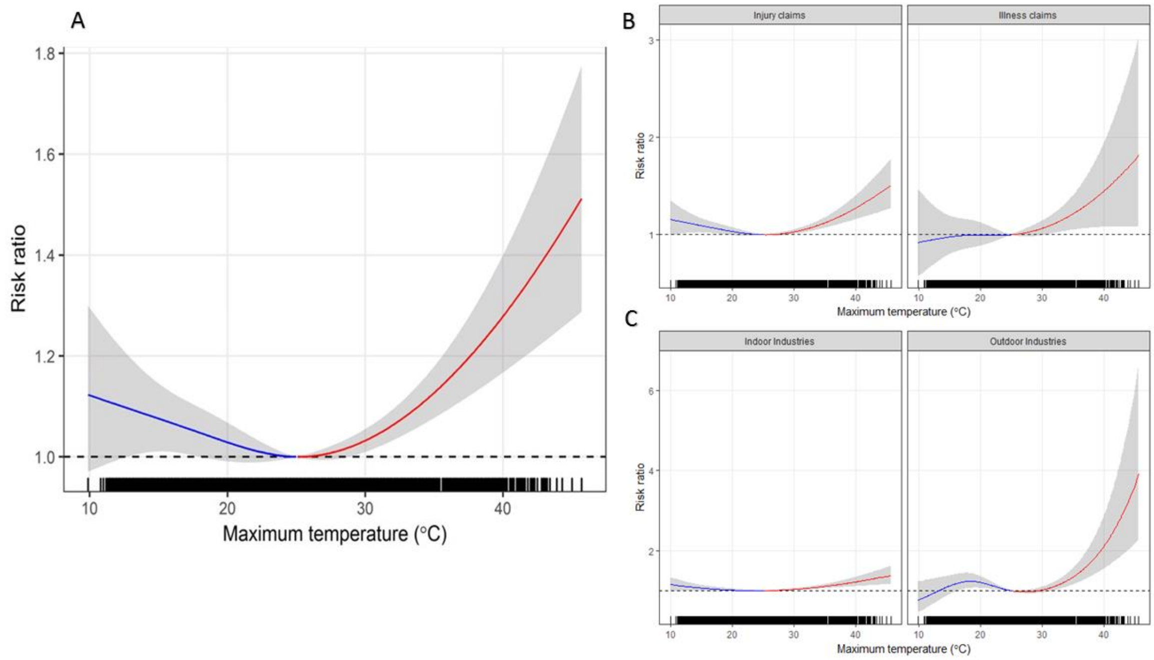

Table 1 The relative risks for workers' compensation claims in hot and cold temperatures stratified by worker, work and work environment characteristics in Adelaide metropolitan area, 2003-2013 (RR with 95% CI).

	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)
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 25.0ºC.
b. The first percentile of temperature (12.6ºC)
c. The 10th percentile of temperature (15ºC)
d. The 90th percentile of temperature (33.1ºC)
e. The 99th percentile of temperature (40.6ºC)

Table 2.The relative risks in hot and cold temperatures for workers' compensation claims 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 25.0ºC.
b. The first percentile of temperature (12.6ºC)
c. The 10th percentile of temperature (15ºC)
d. The 90th percentile of temperature (33.1ºC)
e. The 99th percentile of temperature (40.6ºC)
f. NEC- not elsewhere classified

Table 3 The 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 25.0ºC.
b. The first percentile of temperature (12.6ºC);
c. The 10th percentile of temperature (15ºC)
d. The 90th percentile of temperature (33.1ºC) and
e. the 99th percentile of temperature (40.6ºC).

Table **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

Supplementary Material

The effects of ambient temperatures on the risk of work-related injuries and illnesses: Evidence from Adelaide, Australia 2003-2013

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Contents

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 (Australian Bureau of Meterology 2017);

$$AT_{air} = T_{air} + 0.348e - 0.70ws + 0.70 \frac{Q}{(ws+10)} - 4.25$$

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

Heat index combining temperature and relative humidity (National Oceanographic and Atmospheric Administration National Weather Service 2014) 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 heat index as it also combines relative humidity and temperature and is used by Canadian meteorologists (Environment and Climate Change Canada 2017) derived as;

Humidex (HX) = Tmax + (0.5555(e-10)*

Where:

e: Vapor pressure (in millibars)

4. Universal Thermal Comfort Index (UTCI) and Wet bulb-globe temperature (WBGT)

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 (Lemke and Kjellstrom 2012).

WBGT (outdoor) = 0.7 × *Tnwb + 0.2 × Tg + 0.1 × Ta*

Where:

Tnwb = natural wet bulb temperature

Tg= globe temperature

Ta= ambient temperature

Claim characteristics

Supplementary Table S1. Claim characteristics by worker details, Adelaide (2003-2013).

Factor	Categories	n	%
		224631	
Age (years)	15-24	37540	16.71
	25-34	46823	20.84
	35-54	109342	48.68
	>55	30814	13.72
Experience	Experienced	192900	85.87
	New	31731	14.13
Gender	Female	75455	33.59
	Male	149176	66.41
Industry	Agriculture, Forestry, Fishing And Hunting	1608	0.72
	Communication	137	0.06
	Community Services	69455	30.92
	Construction	17199	7.66
	Electricity, Gas And Water	1797	0.80
	Finance, Property And Business Services	10156	4.52
	Manufacturing	54124	24.09
	Mining	1414	0.63
	Public Administration And Defence	6543	2.91
	Recreation, Personal And Other Services	12276	5.46
	Transport And Storage	12387	5.51
	Wholesale and Retail Trade	37507	16.70

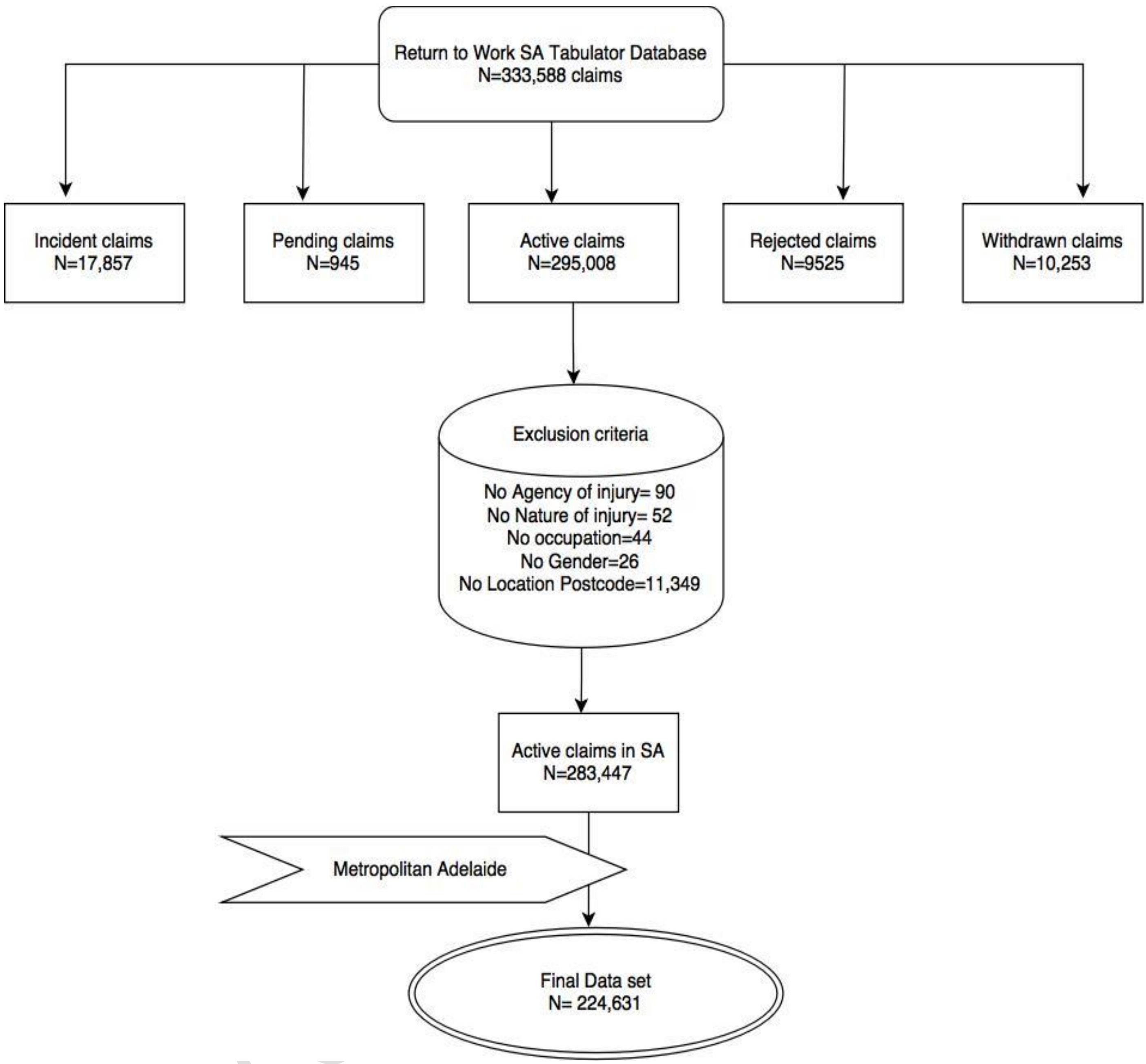
Supplementary Table S2 Claim characteristics by work activity, Adelaide (2003-2013).

Factor	Categories	n 224631	%
Occupational groups	Animal And Horticultural	6653	2.96
	Automobile Drivers	1640	0.73
	Carpenters	5730	2.55
	Cleaners	6870	3.06
	Construction	3933	1.75
	Electrical	5954	2.65
	Emergency Workers	6069	2.70
	Engineers	1457	0.65
	Farmers	224	0.10
	Food Factory	5536	2.46
	Food Service	7545	3.36
	Handypersons	3977	1.77
	Health And Personal Support	17781	7.92
	Heavy Vehicle Drivers	12172	5.42
	Hospitality	3387	1.51
	Machine Operators	24380	10.85
	Metal Workers	23764	10.58
	Miners	701	0.31
	Nurses	9719	4.33
	Office	32530	14.48
	Other Health Professionals	1028	0.46
	Outdoor Work Not Elsewhere Classified	1224	0.54
	Painters	597	0.27
	Passenger Transport	1748	0.78
	Plumbers	6429	2.86
	Printers	1339	0.60
	Scientists	1422	0.63
	Teachers	8328	3.71
	Vehicle Workers	8075	3.59
	Warehousing	14406	6.41
Physical demands of work	Limited (≤ 5kg)	49646	22.10
	Light (5-10kg)	39407	17.54
	Medium (10-20kg)	86644	38.57
	Heavy (>20 kg)	48929	21.78

Supplementary Table S3 Claim characteristics by workplace, Adelaide (2003-2013).

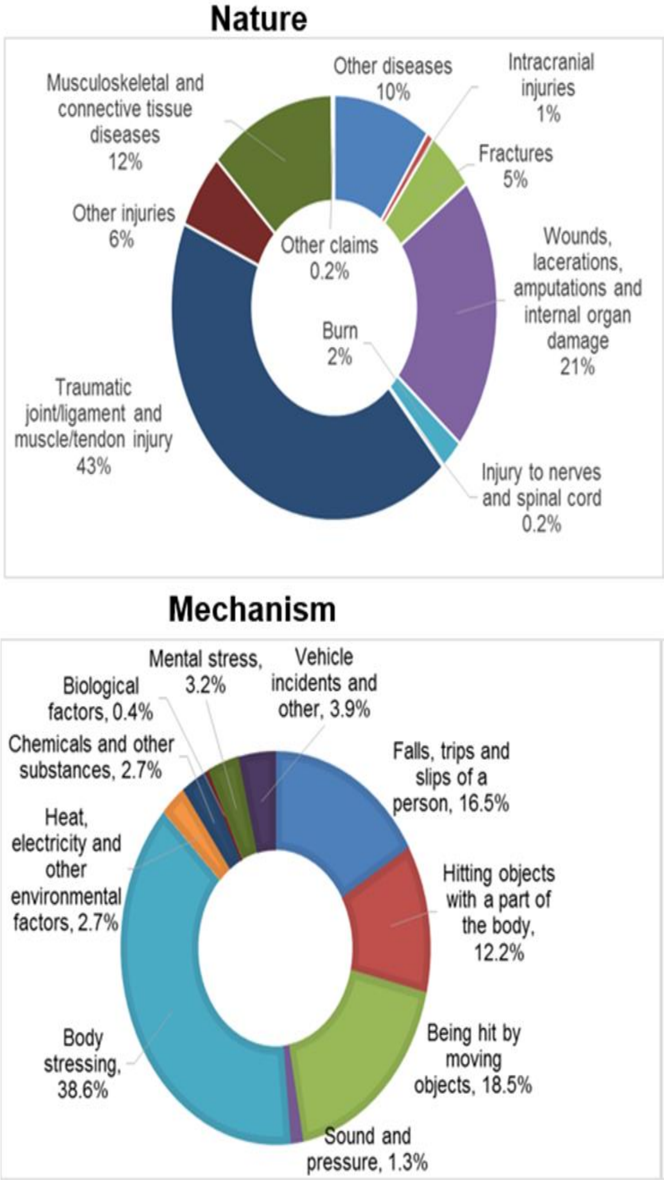
Factor		n	%
	Categories	224631	
Potential workplace temperature exposure	Regulated indoors	153218	68.21
	Unregulated indoors	559	0.25
	Outside	1486	0.66
	In a vehicle or cab	11001	4.90
	Multiple locations	58362	25.98
Size of business	Small (1-19 employees)	33240	14.80
	Medium (20-199 employees)	73253	32.61
	Large ((≥ 200 employees)	118138	52.59
Season	Warm (October-March)	111254	49.53
	Cold (April-September)	113377	50.47
Day of week	Monday	42720	19.02
	Tuesday	42919	19.11
	Wednesday	42170	18.77
	Thursday	40041	17.83
	Friday	35091	15.62
	Saturday	12565	5.59
	Sunday	9125	4.06
Public holidays	Yes	2645	1.18
	No	221986	98.82

Workers' compensation claims data



Supplementary Figure S1. Flow diagram of inclusion and exclusion criteria for data selection.

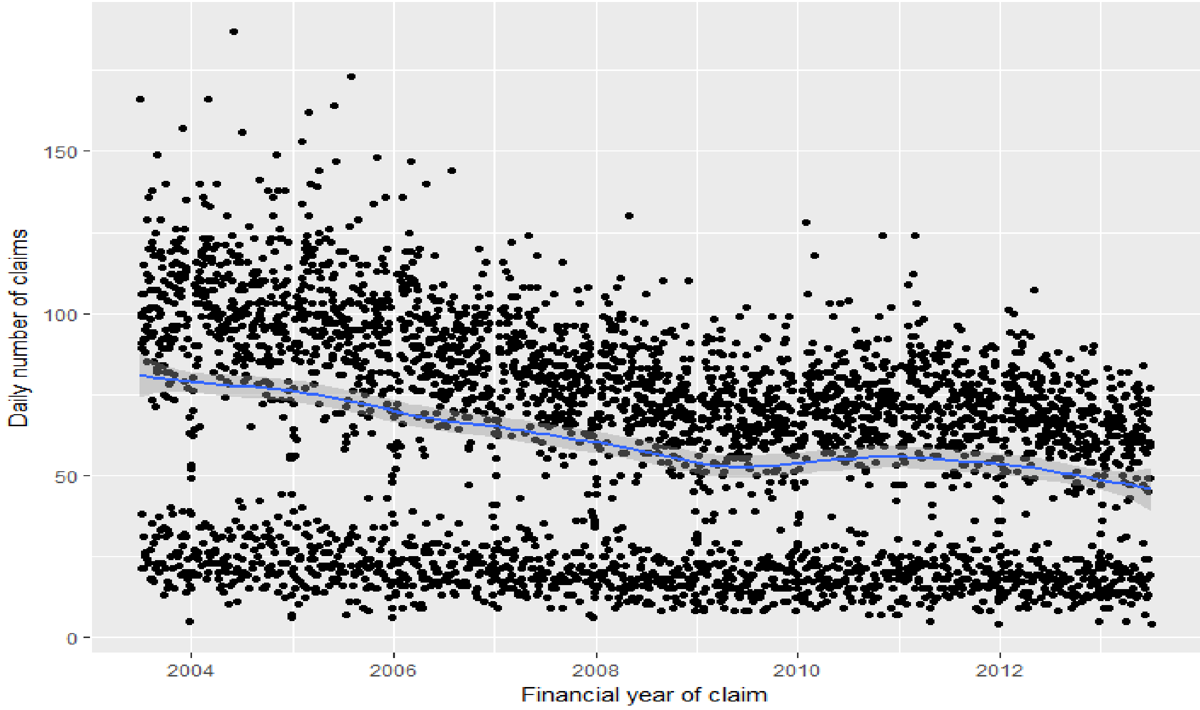
Injury characteristics



Supplementary Figure S2. Injury characteristics by nature, agency, mechanism and body location, Adelaide (2003-2013).

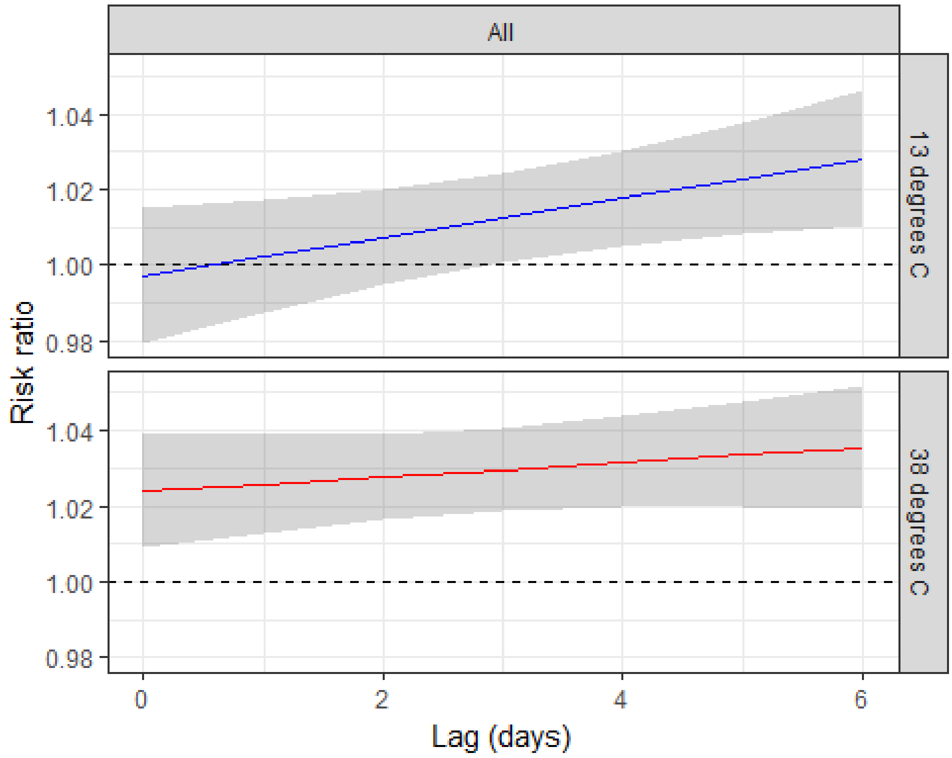
Time trends over time

From Figure S3, it can been sen 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).



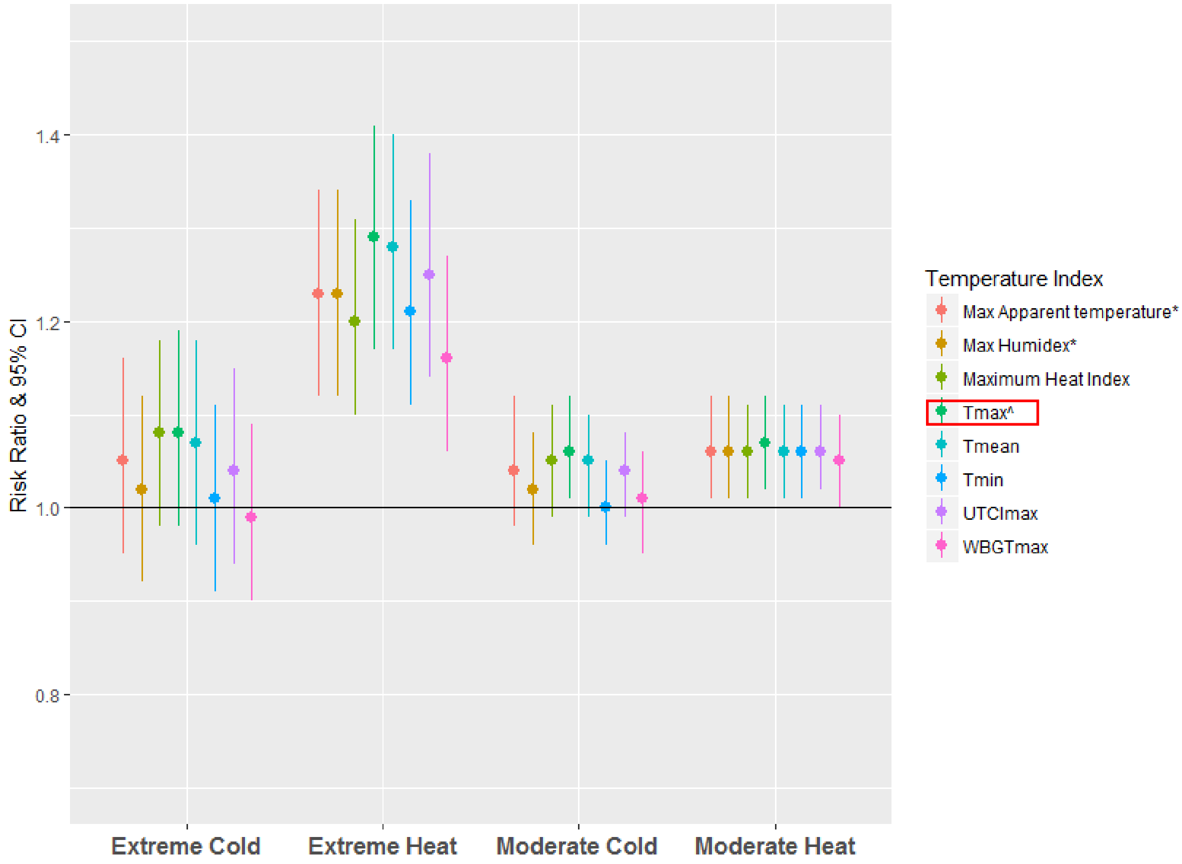
Supplementary Figure S3. Characteristics of the workers' compensation (Adelaide, South Australia, 2003-2013).

Lag effects



Supplementary Figure S4. The effects of hot and cold temperatures on worker's compensation claims (Adelaide, South Australia, 2003-2013) along the lag days at selected temperatures: 1st percentile (13°C) and 97.5th

Sensitivity analyses



Supplementary Figure S5. Sensitivity analysis of RR estimates by different

References

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National Oceanographic and Atmospheric Administration National Weather Service. 2014. The Heat Index Equation. Available: http://www.wpc.ncep.noaa.gov/html/heatindex.shtml [accessed 10 August 2017].

Figure 1