Population vulnerability to heat: A case-crossover analysis of heat health alerts and hospital morbidity data in Victoria, Australia

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Abstract

Objective: From 2010 to 2022, the Victorian Department of Health operated a heat health alert system. We explored whether changes to morbidity occurred during or directly after these alerts, and how this differed for certain population groups.

Methods: We used a space-time-stratified case-crossover design and conditional logistic regression to examine the associations between heat health alerts and heat-related and all-cause emergency department (ED) presentations and hospital admissions at the state-wide level, with models created for the whole population and subgroups. Data were included for the warm season (November-March) from 2014 to 2021.

Results: Increases occurred in heat-related ED presentations (OR 1.73, 95% CI: 1.53-1.96) and heat-related hospital admissions (OR 1.23, 95% CI: 1.16-1.30) on days on or after heat health alerts. Effect sizes were largest for those 65 years and older, Aboriginal and Torres Strait Islander people, and those living in the most disadvantaged areas.

Conclusions: We confirm that increases in morbidity occurred in Victoria during heat health alerts and describe which population groups are more likely to require healthcare in a hospital.

Implications for Public Health: These findings can inform responses before and during periods of extreme heat, data-driven adaptation strategies, and the development of heat health surveillance systems.

Key words: environmental epidemiology, heat-related illness, case-crossover study, extreme heat

Background

Climate change is one of the most important threats to human health, with the impacts of changes in temperatures compared to pre-industrial levels observed in every region and country.[1] There is an established body of evidence on the effects of heat on human health, particularly on mortality.[2,3] Studies have also examined how the associations between heat exposure and health outcomes vary based on individual or community-level characteristics such as age, sex, education level, proportion of the population that is elderly, region, or gross domestic product.[4–7]

In Victoria, the Department of Health (DH) established heat health temperature thresholds for the nine weather forecast districts in 2010. When the daily average temperature forecast for any of the monitoring stations in a weather forecast district reached or exceeded the heat health temperature threshold, the Chief Health Officer issued a heat health alert for that district (Supplementary Materials 1).[8] Responses initiated include those outlined in state and local government heat plans such as notifying health, community, and emergency service partner organisations, including those that interact with people who may be more at risk of heat-related illnesses; advertising designated cool areas to provide respite during extreme heat; sharing heat health messaging; supporting community members at home to take practical steps to stay safe in the heat; and rescheduling outdoor events. Since the heat health alert system was established, there has been an increasing understanding of heat as a risk and actions taken at state and local levels to prepare for and respond to extreme heat.

Noting that the elderly are particularly at risk during heatwaves, the temperature thresholds for the Victorian heat health alert system were identified based on temperatures above which mortality increases substantially in those aged over 65 years.[8–10] However, the

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development of the thresholds did not consider morbidity outcomes or the effects of heat on other groups who may experience adverse health events on days with high temperatures.

National and sub-national heat health warning systems and action plans have been implemented in several settings, though they vary significantly.[11,12] Evaluations in the United States have found that warnings were not associated with a lower risk of mortality but may lead to more individuals seeking or accessing healthcare.[13,14] Other studies have shown that heat plans and warnings are associated with a reduction in heat-related mortality in Italy,[15] and that provinces that implemented more actions in prevention plans in Spain had larger decreases in mortality attributable to extreme heat.[16]

Analyses of Victorian data have described the health impacts of recent heatwaves, estimating that 374 and 167 excess deaths occurred during the 2009[17] and 2014[18] heatwaves, respectively. Other recent studies have analysed emergency department (ED) presentations and hospital admissions related to heat but with a narrow focus, investigating a particular type of condition or injury,[19,20] outcomes at a single hospital,[21] or in one region of the state.[22]

Apart from considering age and sex, studies in Victoria have not examined differences in the effect of heat on health outcomes based on other measures of population vulnerability such as socio-economic disadvantage or country of birth. Understanding which population groups are most at risk will support the development of evidence-based adaptation policies and programmes.

Using state-wide datasets, we aimed to explore population vulnerability to heat-related health outcomes by examining the associations between heat health alerts and ED presentations and hospital admissions for the whole population and specified population subgroups.

Methods

Study setting

The study was conducted in Victoria, Australia, a state with an estimated residential population of 6.5 million people in 2016, with 4.9 million people living in Greater Melbourne.[23] The study period was the warm season (November-March) from 2014 to 2021.

Data sources

Heat health alert data, including the weather forecast district and alert date, were obtained from DH.

All public hospital ED presentations were obtained from the Victorian Emergency Minimum Dataset, and all public and private hospital admissions were obtained from the Victoria Admitted Episodes Dataset, both administered by DH.

Hourly average fine particle (PM2.5) measurements from Victorian air monitoring stations were obtained from the Environment Protection Authority Victoria AirWatch dataset.

Victorian public holidays were obtained from the holiday_aus function in the tsibble package in R,[24] and Grand Final Public Holiday dates were added for each year.[25]

Study design

A space-time-stratified case-crossover design was used. The case-crossover design is commonly used to examine acute-onset health events due to short-term exposures such as air pollution and heat, with this approach controlling for fixed or slow-varying confounding variables, such as sex or education level, by design.[26,27]

The heat health alert data were treated as a binary variable, indicating days with or without an alert in each weather forecast district. For each weather forecast district, case days were defined as the day of a heat health alert and the day after, to account for lagged effects. Control days were selected using a time-stratified selection strategy.[26,27] For each case day, all days with the same day of the week, month, and year as case days were selected as control days, provided they were not already included as case days (Supplementary Materials 2).

The number of health outcomes was compared on case and control days within strata defined by the weather forecast district, year, month, and day of the week. This approach also controls for time-varying confounding variables, such as day of the week or season.

Analyses

ED presentations and hospital admissions were assigned to weather forecast districts based on the postcode of residence. The DH postcode locality reference was used to assign local government areas and the corresponding weather forecast district. Postcodes in the Yarriambiack local government area were assigned to the Mallee or Wimmera weather forecast districts based on whether they were north or south of Galaquil East and Galaquil West Road, respectively (Supplementary Materials 1). Presentations and admissions for patients with unknown or non-Victorian residential postcodes were excluded.

Conditional logistic regression models were created using the clogit function in the survival package using R version 4.1.2.[28] Odds ratios (ORs) and 95% confidence intervals were calculated for the association between heat health alerts, and heat-related and all-cause ED presentations, and heat-related and all-cause hospital admissions. Models were created at a state-wide level for the whole population, as well as pre-defined population subgroups based on age, sex, Aboriginal and Torres Strait Islander status, interpreter requirements, country of birth, socio-economic disadvantage, residence in aged care, and primary diagnostic code. Models were also created for the whole population in each weather forecast district. All models controlled for public holidays.

ED presentations and hospital admissions were defined as heat-related if any of the International Classification of Diseases 10th Revision, Australian Modification (ICD-10-AM) diagnosis codes indicated volume depletion (E86), heatstroke and sunstroke (T67), or exposure to excessive natural heat (X30). All-cause ED presentations and hospital admissions were also grouped into categories based on the primary diagnosis code: respiratory (J00-J99), cardiovascular (I00-I99, G45, G46), renal (N00-N39), and mental (F00-F99).

Socio-economic disadvantage was classified using the Australian Bureau of Statistics 2016 Index of Relative Socio-economic Disadvantage (IRSD), based on the postcode of residence. IRSD deciles were grouped into low (1-3), medium (4-7), and high (8-10), with a low ranking indicating a relatively greater disadvantage.

Hourly PM2.5 estimates were available over the study period from seven air monitoring stations, which do not directly correspond to the nine weather forecast districts. Models controlling for averaged daily

PM2.5 measurements from the Alphington air monitoring station were created for the Central weather forecast district.

Results

There were 254 heat health alerts issued in Victoria from November 1, 2014, to March 31, 2021. The most alerts were issued for the Mallee weather forecast district (**Figure 1**). The highest number of alerts were issued in the 2018-19 summer season, with 48 alerts issued in January 2019 alone.

There were 410 district-specific case days and 1,054 district-specific control days included in the study, with an average of 2.6 control days for every case day. There were 1,759 and 1,847 heat-related ED presentations in the case and control periods, respectively (Table 1). There were 5,840 and 12,151 heat-related hospital admissions included in the case and control periods, respectively (Table 1). The number of heat-related ED presentations and hospital admissions in the case and control periods varied by population subgroup (Supplementary Materials 3) and weather forecast district (Supplementary Materials 4).

Heat-related ED presentations and hospital admissions

The odds of presenting to the ED for a heat-related illness during the case period were higher for the whole population (OR 1.73, 95% CI: 1.53-1.96) and all population subgroups compared to the control period (**Figure 2**a). The effect size for heat-related ED presentations was largest for those aged 65 years and older (OR 2.19, 95% CI: 1.82-2.64) and Aboriginal and Torres Strait Islander people (OR 2.16, 95% CI: 1.40-3.34).

The odds of being admitted to the hospital for a heat-related illness during the case period compared to the control period were higher for the whole population (OR 1.23, 95% CI: 1.16-1.30) and all population subgroups, though results for those aged under five years

Table 1: Number of health events during the case and control periods in Victoria, November-March from 2014 to 2021.

Health event	Case period	Control period
Heat-related emergency department presentations	1,759	1,847
Emergency department presentations	232,432	638,289
Heat-related hospital admissions	5,840	12,151
Hospital admissions	315,233	942,521

(OR 1.10, 95% CI: 0.97-1.23) and residents of aged care facilities (OR 1.28, 95% CI: 0.98-1.66) did not reach statistical significance (Figure 2b). The OR for heat-related hospital admissions was highest for Aboriginal and Torres Strait Islander people (OR 1.43, 95% CI 1.06-1.94) and those in the low IRSD deciles (OR 1.39, 95% CI 1.29-1.50).

The odds of presenting to the ED or being admitted to the hospital for a heat-related illness were higher during the case period compared to the control period in all weather forecast districts (Supplementary Materials 5). For heat-related ED presentations, the OR was highest for the Wimmera district (OR 4.96, 95% CI 2.03-12.17), and for heat-related hospital admissions, the OR was highest for the East Gippsland district (OR 2.78, 95% CI 1.06-2.99).

All-cause ED presentations and hospital admissions

For models that included all ED presentations, the odds of presenting to the ED during the case period compared to the control period were higher for those aged under five years (OR 1.02, 95% CI: 1.01-1.03) and those with relatively greater disadvantage (OR 1.01, 95% CI: 1.01-1.02) (Figure 2c). The odds of presenting to the ED in the case period compared to the control period were higher for those with a respiratory complaint (OR 1.02, 95% CI: 1.00-1.03), and lower for those with cardiovascular complaints (OR 0.98, 95% CI: 0.96-1.00). Odds were also higher for those with renal (OR 1.02, 95% CI: 1.00-1.05) and

Figure 1: Total number of heat health alerts issued in Victoria, Australia, by weather forecast district, November-March from 2014 to 2021.

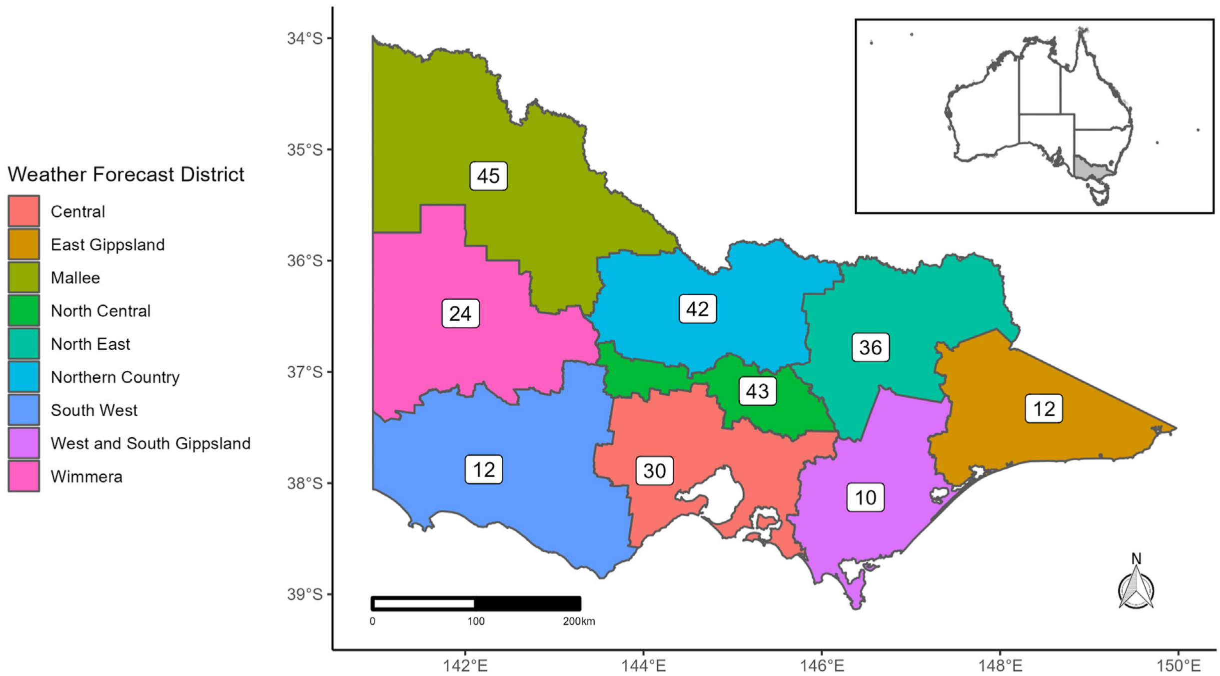
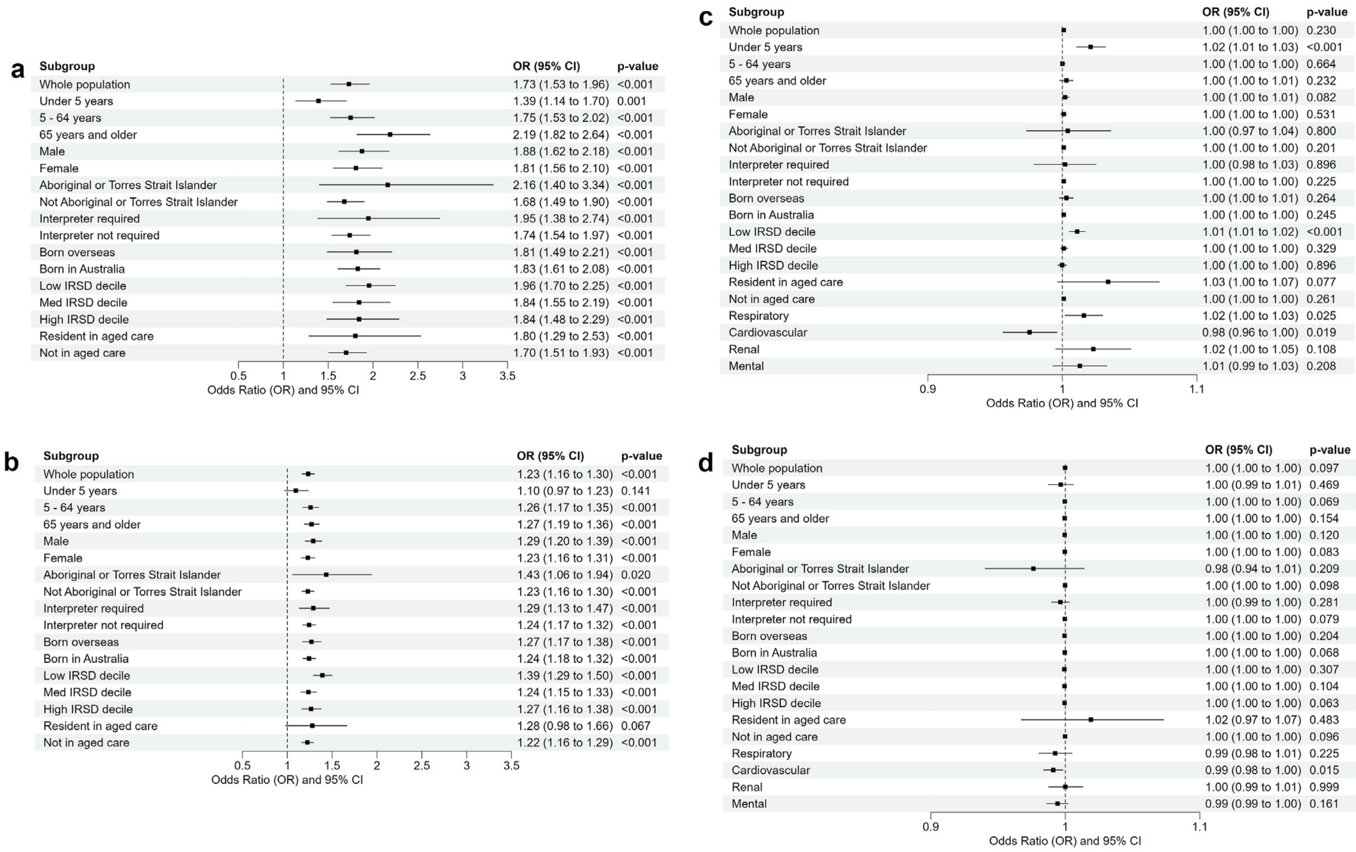


Figure 2: Odds ratios (ORs), 95% confidence intervals, and p-values for the associations between heat health alerts and health events (emergency department (ED) presentation or hospital admission) for specific populations or diagnostic groups, adjusted for public holidays: a) heat-related ED presentations; b) heat-related hospital admissions; c) all-cause ED presentations; d) all-cause hospital admissions.



mental complaints (OR 1.01, 95% CI: 0.99-1.03), though these did not reach statistical significance.

For models that included all hospital admissions, there were no significant differences in the odds of being admitted to hospital in the case period compared to the control period for any population subgroup, apart from a small but significant decrease in cardiovascular admissions (OR 0.99, 95% CI: 0.98-1.00) (Figure 2d).

Adjusting for air pollution

Adjusting for PM2.5 concentration (when restricting the analysis to the Central weather forecast district only) resulted in ORs with point estimates closer to the null but did not affect the significance of any of the observed associations for heat-related ED presentations or hospital admissions (Supplementary Materials 6).

Discussion

We demonstrate an increase in heat-related ED presentations and hospital admissions in Victoria during heat health alert days compared to non-heat health alert days in the same month and year. The variation observed between the subgroups indicates that some population groups are more vulnerable to extreme heat. The largest effect sizes for heat-related ED presentations were observed for those aged 65 years and older and Aboriginal and Torres Strait Islander people, and for heat-related hospital admissions for Aboriginal and Torres Strait Islander people and those living in the most disadvantaged areas.

The findings across all population groups and weather forecast districts indicate that the heat health alert system was not associated with reductions in heat-related morbidity compared to non-heat health alert periods. The increase in heat-related presentations and admissions on the day and day after a heat health alert is consistent with findings reported in Australia and internationally, with increased exposure to heat resulting in increased morbidity in the population.[3] Studies in other settings have suggested that warning systems have reduced heat-related mortality[15,16] and morbidity,[29] though these systems do not necessarily lead to behaviour change or completely eliminate the health impacts of extreme heat.[30] Our results highlight that alert systems are one of a range of measures needed to minimise the impacts of extreme heat on the population.

Our findings also support existing studies that have identified indicators for population vulnerability to heat in Australia, particularly age over 65 years and low socio-economic status.[31–33] The relatively large increase in heat-related presentations and admissions for those aged over 65 years is supported by other studies that find older populations are more vulnerable to heat.[34,35] The findings for Aboriginal and Torres Strait Islander people contrast a study in Brisbane that found no differences in infant hospitalisations during heatwaves between Aboriginal and Torres Strait Islander people and non-Indigenous people,[36] but are supported by work from New South Wales that reports Aboriginal populations are disproportionately exposed to climate extremes, including heat, and experience higher rates of climate-sensitive health conditions.[37] However, there is limited evidence specifically investigating the effects of heat on morbidity for Aboriginal and Torres Strait Islander people, highlighting the importance of further research.[38,39] The differences in effect size for those in low and high IRSD deciles indicate that socio-economic disadvantage influences the risk of morbidity, as shown in analyses of heatwave fatalities in Australia[40] and heat-related morbidity in Adelaide.[32] These results emphasise that these population groups should be targeted for protective actions. Interestingly, our finding of a decrease in cardiovascular ED presentations and admissions contrasts the results of other studies, with increases in these events in response to extreme heat reported by several Australian studies.[33]

Differences in our results may be explained by the design of the analysis or the limitations of the available data. Classifying the health events and defining the population subgroups relied on the accuracy of diagnostic coding and the availability and completeness of variables in the datasets. Heat-related illness is often underdiagnosed.[32,41] Although we classified events as heat-related if a relevant ICD-10-AM code was included in any of the diagnosis codes, some heat-related illnesses may have been missed or classified as another condition that was caused or exacerbated by exposure to heat. Alternatively, coding practices may have varied in different health services or been influenced by high temperatures or the presence of a heat health alert, resulting in additional events being included as heat-related. The classification of individuals as residents of aged care facilities may have varied for the two datasets used, as the usual place of residence is recorded for ED presentations but only the source of admission is available for hospital admissions, meaning some residents of aged care facilities may have been misclassified. The associations observed for specific diagnostic groups, particularly the decreases in cardiovascular presentations during the case period, may be explained by the wide range of diagnostic codes included in this category (whereas increases may be observed when only examining specific illnesses such as cardiac arrest[42–44]), if increases in these illnesses only occur in older age groups,[34] or if there are increases in pre-hospital mortality that may not be recorded in these datasets, for example, due to out-of-hospital cardiac arrest.[43,45] There may also be additional lagged or cumulative effects on cardiovascular illness not captured by our study design.[35,46,47]

As individual exposure data were unavailable, the exposure was classified based on place of residence. Exposure misclassification may have occurred if individuals were not located in their weather forecast district of residence when they experienced illness. Furthermore, given the design of the heat health alert system, this study measured the effect of temperature forecasting on or over a threshold on health outcomes on that day and the day after and did not account for relative humidity. For most weather forecast districts, heat health alerts were issued based on the temperature forecast for a single weather station (Supplementary Materials 1). For other districts, alerts were issued when the forecast for at least one monitoring station met or exceeded the threshold. These forecasts will not reflect the actual exposure for the whole population. Many other studies of the health impacts of heat compare "heat wave" and "non-heat wave" periods, using a variety of definitions,[7,48,49] which could explain the differences in our results, as some associations may be more apparent during consecutive days of high temperatures. Additionally, as air pollution data were not available for each of the space-strata included in the study, we were unable to adjust for this potential confounder,[6,50] apart from when analysing a subset of the data.

These findings confirm, using state-wide data for Victoria, that increases in morbidity occurred when the temperature forecast reached or exceeded the heat health thresholds. They can be used to support both short-term and longer-term adaptation actions, including informing actions from various stakeholders when heat health thresholds are reached. These could include increasing promotion of targeted messaging in a range of languages; providing support to groups identified as most at risk, such as those aged over 65 years, those caring for young children, and those on low incomes; and enhancing health and emergency services preparedness for possible increases in demand during days of extreme heat. Holistic approaches to minimise the health effects of climate change and extreme heat are needed such as improvements to the thermal comfort and safety of homes, including social housing dwellings,[51] increased investment in urban greening and cooling initiatives,[52] and measures to support low-income households to cool their homes.[53] These results indicate the need to increase investment in initiatives that build the heat resilience and adaptive capacity of Victoria communities. They can also support local councils in prioritising actions to address risks to disproportionately impacted groups through their municipal public health and wellbeing plans and local heat health action plans.

Our findings also support actions outlined in *the Health and Human Services Climate Change Adaptation Action Plan 2022–2026,* which commits to improving the evidence base and monitoring of climate-related health impacts through expanding surveillance to inform data-driven adaptation strategies.[54] Results from this study support including a variety of population vulnerability indicators in future heat health surveillance systems in Victoria and demonstrate that routinely collected datasets could be used to monitor some heat-related health outcomes.

Whilst we have shown that some population groups are more or less likely to require healthcare in hospitals during days of high temperatures, additional analyses are required to better understand the impacts of heat in Victoria. Further studies could explore other factors related to population vulnerability such as underlying comorbidities (which are not well captured in the datasets used in this analysis) or the effect of heat on more specifically defined illnesses and injuries. Studies could also include other measures of heat-related illness by using data sources for ambulance callouts, pharmacies, general practice, or health helplines such as NURSE-ON-CALL. Although some evidence suggests the lagged effects of heat on morbidity may decrease after one day,[4,5] studies could also explore whether the associations we have observed change when longer time periods after days of high temperatures are included. Temporal variations in these associations could also be explored through the analysis of data from a longer period. Future work would benefit from using a standardised exposure definition such as the excess heat factor,[33] and from more granular meteorological data to measure heat exposures and possible confounding variables. Notably, from the 2022-23 summer season, DH has aligned the heat health alerts with the Australian Bureau of Meteorology's heatwave warnings, which use the excess heat factor to categorise heatwave severity and also consider observed temperatures over the previous 30 days.[55] This national system will support more localised warnings and provide standardised data for future research on vulnerability to heat across Australia.

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Ethical approval

Ethical approval was received from the Australian National University Human Research Ethics Committee (Protocol 2022/374).

Author contributions

Tilda N. Thomson: Conceptualization; Formal analysis; Methodology; Visualization; Writing – original draft; Writing – review and editing.

Rayiky Rupasinghe: Conceptualization; Writing – review and editing.

Daneeta Hennessy: Methodology; Supervision; Writing – review and editing.

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Conflicts of interest

The authors have no competing interests to declare.

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Appendix A Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.anzjph.2023.100092.