Original research

Ambient temperatures, heatwaves and out-of-hospital cardiac arrest in Brisbane, Australia

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ABSTRACT

Background The health impacts of temperatures are gaining attention in Australia and worldwide. While a number of studies have investigated the association of temperatures with the risk of cardiovascular diseases, few examined out-of-hospital cardiac arrest (OHCA) and none have done so in Australia. This study examined the exposure–response relationship between temperatures, including heatwaves and OHCA in Brisbane, Australia.

Methods A quasi-Poisson regression model coupled with a distributed lag non-linear model was employed, using OHCA and meteorological data between 1 January 2007 and 31 December 2019. Reference temperature was chosen to be the temperature of minimum risk (21.4°C). Heatwaves were defined as daily average temperatures at or above a heat threshold (90th, 95th, 98th, 99th percentile of the yearly temperature distribution) for at least two consecutive days.

Results The effect of any temperature above the reference temperature was not statistically significant; whereas low temperatures (below reference temperature) increased OHCA risk. The effect of low temperatures was delayed for 1 day, sustained up to 3 days, peaking at 2 days following exposures. Heatwaves significantly increased OHCA risk across the operational definitions. When a threshold of 95th percentile of yearly temperature distribution was used to define heatwaves, OHCA risk increased 1.25 (95% CI 1.04 to 1.50) times. When the heat threshold for defining heatwaves increased to 99th percentile, the relative risk increased to 1.48 (1.11 to 1.96).

Conclusions Low temperatures and defined heatwaves increase OHCA risk. The findings of this study have important public health implications for mitigating strategies aimed at minimising temperature-related OHCA.

INTRODUCTION

The health impact of shifting climate factors is a growing public health concern in Australia and worldwide. Increased mortality and morbidity due to extreme atmospheric temperatures have been described. Acute cardiovascular diseases are among the health conditions that are affected by atmospheric temperatures. A limited number of studies have specifically investigated the effects of temperatures on the risk of out-of-hospital cardiac arrest (OHCA) and reported mixed findings. Kang et al investigated the effect of heatwaves on OHCA risk in the Republic of Korea, and found a positive relationship. In other studies, Onozuka and Hagihara found that temperature-related OHCA was mostly attributable to low temperatures. In contrast, both low and high temperatures were associated with increased OHCA risk in other studies in Japan, Germany and China. The aforementioned studies included only arrests of presumed cardiac aetiology. Non-cardiac causes of arrest such as respiratory disease and drowning have been shown to be influenced by temperatures, and therefore, need to be included.

Furthermore, there remains a lack of data on the exposure–response association between temperatures and OHCA risk in Australia. Such information is essential for formulating mitigation strategies aimed at minimising temperature-related OHCA burden, and subsequently reducing avoidable increase in ambulance demand. This is
particularly important for Australia, as ambulance demand in the country has increased markedly in the past decade. Indeed, the number of ambulance emergency incidents in Australia increased from 1,970,875 in 2010 to 2,813,860 in 2019 (a 43% relative increase). The figures for the state of Queensland alone for the same period were 516,307 and 847,966, respectively (a 64% relative increase). In addition, increases in both day and night-time temperatures are observed across the country in all seasons. More extreme heat events as a result of the shift to a warmer climate have also been reported in recent years.

This study investigated the association of temperatures and cases of OHCA attended by paramedics over a 13-year period in the city of Brisbane, Queensland, Australia. It is the first to quantify OHCA risk in relation to temperature exposures in Australia.

**METHODS**

**Study setting**

Australia is situated in the Southern Hemisphere with December, January and February being the warmest months (summer), and June, July and August being the coldest (winter). Due to its vast land mass (7.7 million km²), the country has several different climate zones. The northern section of Australia has a more tropical climate with hot and humid summers and mild winters, whereas the southern parts have relatively moderate summers and colder winters. The state of Queensland (1.7 million km², 5.1 million people) is located in the north east of Australia. Brisbane is the capital city and the most populous city of Queensland with a population of 1.2 million people. The city has a subtropical climate, with hot summers and mild winters. Online supplemental figure S1 shows the maps of Australia, the state of Queensland and Brisbane city.

**OHCA data**

The Queensland Ambulance Service (QAS) is a single, statewide, government-funded emergency ambulance service that serves the entire state of Queensland, including its capital city Brisbane. Daily counts of OHCA cases occurring in Brisbane and attended by paramedics were extracted from the QAS OHCA database. Detailed description of the database can be found in our previous publications. Briefly, it is a statewide, population-based database that prospectively collects data of all OHCA patients who are attended by QAS paramedics. The present study included all OHCA cases that occurred in Brisbane and attended by paramedics between 1 January 2007 and 31 December 2019.

**Meteorological data**

Half-hourly (ie, every 30 min) meteorological data on temperatures (°C) and relative humidity (percent) for Brisbane, during the period 1 January 2007 and 31 December 2019, were acquired from the Australian Bureau of Meteorology. All meteorological data were obtained from a single weather station situated approximately in the centre of the city (online supplemental figure S1). There was no missing meteorological data. Daily average temperature was calculated by averaging the half-hourly temperatures for each day (48 data points per day) during the study period. Daily minimum and daily maximum temperatures were determined as the lowest and highest half-hourly temperatures, respectively, for each day. Diurnal temperature range was calculated as the daily maximum temperature minus the daily minimum temperature.

**Data analysis**

We investigated the overall effect of temperatures on the risk of OHCA occurrence using daily average temperatures, as this temperature index has been shown to be a better predictor of health impacts than other temperature indices in Brisbane and other settings. This effect represents the relative risk (RR) of OHCA associated with temperatures (as a continuous variable) compared with the reference temperature, which was chosen to be the temperature of minimum risk. This optimal temperature was determined to be 21.4°C, which corresponded to the 51st percentile of the distribution of daily average temperatures of the whole study period.

Additionally, we investigated the effect of heatwaves on OHCA risk. To date, there remains a lack of universal definitions for heatwaves. For consistency with previous studies, we defined heatwaves as daily average temperatures at or above a predefined heat threshold for at least two consecutive days. A range of heat thresholds were considered using extreme value markers and included: 90th, 95th, 98th and 99th percentile of the yearly temperature distribution across the study period. Heatwaves were coded as a binary variable of 1 (heatwave day) or 0 (non-heatwave day) for each calendar day. We described the risk of OHCA due to heatwaves by decomposing the effect of heatwaves into a ‘main effect’ due to independent effect of daily high temperatures, and an ‘added effect’ due to sustained duration of heatwaves. The main effect of heatwaves was calculated as the RR of the median value of temperature distribution among heatwave days compared with the reference temperature (21.4°C). The added effect was calculated as the RR between heatwave days and non-heatwave days.

A quasi-Poisson regression model coupled with a distributed lag non-linear model (DLNM) was employed to investigate the association of temperatures and the risk of OHCA. The former was used to account for the Poisson overdispersion of daily OHCA counts $Y_t$, and the latter to simultaneously describe the non-linear and lagged (ie, delayed) effects that temperatures have on OHCA risk. The DLNM used a natural cubic spline function with a maximum lag of 21 (days). The df for the temperature and lag dimensions of the DLNM were chosen by the Quasi Akaikes’s information criterion, which suggested that 8 df for both temperature and lag dimensions best fit the data. The model adjusted for the following potential confounding factors: diurnal temperature range, relative humidity, long-term temporal trends and seasonality and day of the week. A natural cubic spline function with 7 df per year was applied to control for long-term temporal trends and seasonality. The same function with 1 df was chosen for diurnal temperature range and 3 df for relative humidity. These choices of model configurations were motivated by previous time-series analyses of weather parameters and health outcomes. The robustness of the model to changes in these modelling choices was examined in sensitivity analysis. The model took the following form:

$$Y_t \sim \text{quasi-Poisson} \left( \mu_t \right), \quad \mu_t = E \left( Y_t \right).$$

$$
\log \left[ E \left( Y_t \right) \right] = \alpha + \beta_1 \ast D_{t} + \beta_2 \ast H_{t} + \beta_3 \ast \mu_{t} (DTR_{t}, df = 1)
+ \beta_4 \ast \mu_{t} (RH_{t}, df = 3) + \beta_5 \ast \mu_{t} (Time_{t}, df = 7 \text{ per year}) + \beta_6 \ast DOW_{t}.
$$

where $E(Y_t)$ was the expected number of OHCA cases on day $t$; $\alpha$ was the intercept; $\beta_{1-5}$ were the coefficients for OHCA risk associated with each of the variables included in the model; $D_{t}$ was a matrix obtained by applying the ‘cross-basis’ DLNM function to temperatures ($T$) and the lag space ($l$); $H_{t}$ was the heatwave indicator on day $t$; $DTR_{t}$ was diurnal temperature range on day $t$; $RH_{t}$ was relative humidity on day $t$; $Time_{t}$ was a continuous variable for long-term temporal trends and seasonality, ranging from 1 on the first day of observation (1 January 2007) to 4748 on the final day of observation (31 December 2019).
RESULTS

Figure 1 describes the summary statistics of temperature and OHCA data. The mean and median of daily average temperatures for the entire study period was 20.9°C (range 10.4°C–30.1°C) and 21.2°C (IQR 17.6°C–24.2°C), respectively. A total of 13,141 OHCA incidents occurred during the study period with an average of 3 (range 0–11) cases per day.

The effect of temperatures on OHCA risk at different lag periods (ie, days delayed between observed temperature and OHCA events) is shown in figure 2. The effect of high temperatures (above the reference temperature) was not statistically significant across all lags. Low temperatures (below the reference temperature) did not affect OHCA risk at lag 0. At lags 1–3, low temperatures increased the risk of OHCA with the most significant risk observed at lag 2. Specifically, at lag 2 and at 15°C, the risk of OHCA increased 1.06 times (95% CI 1.01 to 1.11). When temperatures reduced to 12°C, OHCA risk further increased 1.09 times (95% CI 1.02 to 1.17). The effect of low temperatures was not statistically significant at lag 4 and became negligible at lag 5. These results indicated that the effect of low
temperatures was delayed for 1 day and sustained up to 3 days, peaking at 2 days following exposures. Online supplemental table S1 shows the numerical results for specific temperatures at different lag periods.

Table 1 displays statistical summary of heatwave days for different definitions. The main effect and added effect of heatwaves on OHCA risk were numerically shown in table 1 and visualised in figure 3. Only the main effect was significant, and

Figure 2  Relative risk of out-of-hospital cardiac arrest at specific lags. The shaded area indicates 95% CI. solid vertical line represents the reference temperature (temperature of minimum risk, 21.4°C). Broken vertical lines represent fifth (left) and 95th (right) percentiles of daily average temperatures across the entire study period. Colour figure is published online, black and white figure is published in print.
Cold temperatures have also been shown to trigger biochemical responses by increasing blood cell counts, plasma cholesterol, C reactive protein, plasma fibrinogen concentration and platelet viscosity—all of which compound the risk of an acute cardiovascular event and a sudden cardiovascular collapse through increased cardiac workload and reduced ischaemic threshold.31–33

We found that heatwaves increased OHCA risk by up to two-fold, depending on the heat threshold used. To date, there is a lack of Australian data on temperatures and OHCA risk to which our results may be compared, whereas direct comparison with international data is challenging due to climatic differences. Nevertheless, the patterns of our findings are consistent with those of international studies. A study in Paris (France) used a hard temperature cut-off to define heatwaves and found that heatwaves were associated with a 2.5 time increase in OHCA risk.34 In another study in South Korea, Kang et al9 reported that heatwaves, defined as temperatures above the 98th percentile for at least two consecutive days, increased the risk of OHCA by 14%. Under this definition, we estimated a 38% increase in OHCA risk (RR 1.38, 95% CI 1.09 to 1.75). There is a lack of OHCA-specific studies that used 90th, 95th and 99th percentiles for defining heatwaves to which our results may be compared.

Heat-induced disorders of thermoregulatory mechanisms have been proposed to explain heat-related OHCA. Exposure to heat can cause dehydration, leading to hydroelectrolytic disorders and potentially a state of myocardial hyperexcitability.34 Sweating in response to exposure to high temperatures also increases skin blood flow and volume depletion, resulting in diminished cardiac preload and afterload.35 Additionally, elevated heart rate and cardiac contractility as a result of heat can increase myocardial oxygen consumption.3 Heat may also cause mental stress, which in turn increases OHCA risk.36

We found that the main effect of heat waves (ie, intensity of heatwave days) was stronger than the added effect (duration of heatwave days). This finding is similar to that observed in a study in 108 communities in the USA, in which the added effect was small and only apparent after four consecutive days.27 Similarly, Zeng et al37 found that the main effect of heatwaves (excess risk 8.2%) was greater than the added effect (0.0%).

The health impacts of temperatures and heatwaves are gaining attention both in Australia and worldwide. Increased frequency and intensity of extreme high temperatures and heatwaves has been observed in many parts of the world.1 It is estimated that every 0.85°C increase in global temperatures leads to a four- to five-fold increase in the probability of heatwaves.38 Our findings reinforce the relationship between temperatures and OHCA risk. As heatwaves in Brisbane (as well as Australia and the greater world) are observed with increasing frequency, it can be expected that the rate of OHCA will also increase.

Our findings should be interpreted in the context of the following limitations. Due to a lack of data, we did not control for other climatic parameters such as air pollutants and atmospheric pressure, nor did we consider factors such as susceptibility, resilience, socioeconomic status, community characteristics, physiological acclimatisation, and outdoor and indoor circumstances of patients. Further research designed to generate such data and incorporate these data into a temperature-OHCA model is warranted. The findings of our study may not be applicable to geographic areas that have climatic conditions differing to those of Brisbane. Nevertheless, our model is readily adapted to incorporate data from other regions within Australia and globally, when available.
Queensland, similar to many regions worldwide, is facing an ever-increasing demand for emergency ambulance care, forcing policy-makers to find ways to minimise risk factors associated with this increasing demand. Therefore, there is a pressing need to establish a better understanding of the association between temperatures and OHCA risk. By addressing this knowledge gap, our findings are essential to guiding the development of mitigation strategies aimed at minimising OHCA burden related to adverse temperatures, and subsequently, reducing avoidable increase in ambulance demand. Our results suggest that timely preventive measures could reduce the risk of OHCA due to heatwaves and low temperature extremes. Potential strategies during periods of heatwaves may include staying in air-conditioned environments, increasing fluid intake, reducing physical activity and implementing early warning systems. Staying indoors and wearing warm clothing may reduce OHCA risk during periods of low temperatures. Furthermore, our model is readily adapted to research that expands beyond OHCA to examine the impact of temperatures on total emergency ambulance demand to inform demand management strategies.

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