The time course of temperature effects on cardiovascular mortality in Brisbane, Australia

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Word count: 2,300

ABSTRACT

Objective: To quantify the lagged effects of mean temperature on deaths from cardiovascular diseases in Brisbane, Australia.

Design: Polynomial distributed lag models were used to assess the percentage increase in mortality up to 30 days associated with 1°C increase (or decrease) above (or below) the threshold temperature.

Setting: Brisbane, Australia.

Patients: 22,805 cardiovascular deaths registered between 1996 and 2004.

Main outcome measures: Deaths from cardiovascular diseases.

Results: The results show a longer lagged effect in cold days and a shorter lagged effect in hot days. For the hot effect, a statistically significant association was observed only for lag 0–1 days. The percentage increase in mortality was found to be 3.7% (95% CI: 0.4%, 7.1% for people aged ≥65 years and 3.5% (95% CI: 0.4%, 6.7%) for all ages associated with 1 °C increase above the threshold temperature of 24°C. For the cold effect, a significant effect of temperature was found for 10-15 lag days. The percentage estimates for older people and all ages were 3.1% (95% CI: 0.7%, 5.7%) and 2.8% (95% CI: 0.5%, 5.1%), respectively, with 1 °C decrease below the threshold temperature of 24°C.

Conclusions: The lagged effects lasted longer for cold temperatures, but were apparently shorter for hot temperatures. There was no substantial difference in the lag effect of temperature on mortality between all ages and those aged ≥65 years in Brisbane, Australia.

Key words: Cardiovascular deaths; Lagged effect; Temperature.

The association between temperature and cardiovascular deaths (CVD) has long been known. [1] There is an increasing interest in the assessment of this relationship as a response to climate change resulting from increased emissions of anthropogenic greenhouse gases. [2 3]

There is a broad agreement that the relationship between temperature and CVD is V–, U– or J–shaped, with optimum temperature corresponding to the lowest point in the temperature–mortality curve. [4 5] Investigators divide temperature into three linear parts with hot and cold thresholds. The middle section is constrained to a zero slope and the "V" shaped association is the special case when cold and hot thresholds are equal. [6]

A lagged effect of temperature on mortality is well known. [7] The mortality of the current day may be associated with exposure to the temperatures of the current day and of several previous days. [8 9] Recently, a distributed lag model has been applied to explore the lag structure of temperature on mortality. Because there is substantial correlation between temperatures on days close together, investigators have implemented constrained distributed lag models (CDLM) including stratified, polynomial and smoothing constrained distributed lag models to overcome this problem. [6] In addition, CDLM could specify some assumptions on the shape of the distributed lagged effect and provide more precise estimates for individual lag day.[10 11]

The impact of temperature on mortality varies with population because local geographical conditions (i.e. vegetation) and adaptation (i.e. housing) are different. Although the lagged effects of temperature on CVD have been described in Europe and the USA, [6 9 12 13 14 15] A recent review has pointed out that future research of allowance for the delayed temperature effects on CVD is still needed. [15] However, few data are available from the Southern

Hemisphere. Better understanding of these effects will provide useful information for developing public health intervention programs and risk management that will better target those most vulnerable to temperature-related CVD.

This study identified the lagged effects of mean temperature on CVD for all ages and those aged over 65 years (CVD_{65+}) in Brisbane, Australia, which has a typical subtropical climate in the Southern Hemisphere.

METHODS

Data collection

The data on CVD between January 1996 and December 2004 were obtained from the Office of Economic and Statistical Research of the Queensland Treasury. The causes of cardiovascular mortality were classified according to the International Classification of Diseases, ninth version (ICD-9) before December 1996 and ICD-10 between December 1996 and December 2004 (ICD-9:390–499; ICD-10:I00-I99) .

Daily meteorological data including maximum temperature, minimum temperature and mean relative humidity (RH) were obtained from the Australian Bureau of Meteorology. Mean temperature was calculated from maximum temperature and minimum temperature. Air pollution data including mean daily ozone (O_3), nitrogen dioxide (NO_2) and particulate matter with aerodynamic diameter less than 10μm (PM_{10}), recorded in a central monitoring site in Brisbane, were obtained from the Queensland Environmental Protection Agency.

Statistical analysis

The use of temperature indicators and thresholds were evaluated through a comparison of Akaike's Information Criterion (AIC) for the corresponding models described in our previous study. [16] Mean temperature was used as an indicator of temperature in this study because the previous study suggested that it performed better than minimum or maximum temperature in estimates of temperature-related mortality. [16]

We plotted the graphs of the relationship between current day's mean temperature and all-cause mortality based on the multivariable model with a thin plate regression splines function of temperature with 3 degrees of freedom. There was a "V" shaped association between temperature and mortality as indicated in fig 1. AIC values were iteratively calculated for generalised additive models (GAMs) using one degree increment in mean temperature from 20 °C to 30 °C which was selected based on the visual inspection of the plots. The temperature corresponding to the model with the lowest AIC value was chosen as the threshold temperature. A similar method has been adopted in many previous studies. [16 17 18]

We applied the GAM model as follows: [19]

$$Log\ (Y_t) = \alpha + \beta_C (T_t - \tau_C) + \beta_H (T_t - \tau_H) + \sum_{j=1}^{p} s(x_{j_t}, 3) +$$

$$\sum_{d=1}^{q} \delta_d x_d + s(time_t, 7 * year) + \varepsilon_t. \qquad 1$$

Where t refers to the day of the observation; (Y_t) denotes the observed daily death counts on day t; T_t denotes daily mean temperature on day t; τ_C and τ_H were the cold and hot thresholds; $s(.)$ denotes thin plate smoothing splines; x_j denotes the covariates of RH, PM_{10}, NO_2 or O_3; x_d represents categorical factors for day of the week (DOW), holidays and

influenza outbreak; α is the intercept term; β and δ are coefficients; and ε_t is the residual. Three degrees of freedom were used to smooth the covariates and

Polynomial distributed lag models were used to analyse the lagged effects of mean temperature on CVD for all ages, and those aged over 65 years old (CVD_{65+}), respectively. In order to overcome the problem of the collinearity, [6 11] the polynomial distributed lag (PDL) model (q,d) was implemented in equation 1 through the following restriction:

$$\beta_C (T_t - \tau_C) / \beta_H (T_t - \tau_H) = \alpha + \beta_0 T_t + \beta_1 T_{t-1} + ... \beta_n T_{t-n}$$

$$\beta_n = \sum_{k=0}^{d} a_k l_n^k , \quad l \in [0, m] \qquad\qquad 2$$

Where d is the degree polynomial, l is the lags and q is the maximum number of lag days. [11] The fourth degree polynomial was selected as the sensitivity analyses show no substantial changes of the results when we applied fifth- or sixth order polynomial. Lags were chosen up to 30 days because longer-term effects may involve longer lags. [24]

All statistical analyses were performed in the packages of "mgcv" and "dlnm" in R2.11.1 (The R Foundation for Statistical Computing, version 2.11.1 http://cran.r-project.org).

RESULTS

The relationships between mean temperature and CVD mortality in both age groups are observed as a "V" shape (fig 1). In a total of 3,274 days, there were 22,805 CVD registered in the study population, among which 91.4% were over 65 years. During the study period, the average value of the mean, maximum, minimum daily temperatures and RH was 20.1°C, 25.2°C, 15.4°C, and 72.5%, respectively. The mean daily average concentration of PM_{10}, NO_2 and O_3 was 16.6 µg/m^3, 12.1 ppb and 11.3 ppb, respectively (Table 1).

The polynomial distributed lag model (df=4) demonstrated a clear pattern of longer lagged effects in the cold temperature range and shorter lagged effects in the hot temperature range (fig 2). The highest percent increases occurred in CVD on the lag of 10–15 days for cold and 0–1 days for heat (fig 3).

For hot effects, a 1°C of temperature increase above the threshold temperature was associated with the overall increases of 3.5 % (95% CI: 0.4%, 6.7%) and 3.7 % (95% CI: 0.4%, 7.1%) in CVD mortality at lags 0-1, respectively, for all ages and those aged over 65 years; and at lags 0-21 days, 8.4 % (95% CI: 1.1%, 16.2%) and 8.0 % (95% CI: 0.3%, 13.2%), respectively. For cold effects, a 1°C of temperature drop below the threshold temperature was associated

with the overall increases of 2.8%, 95% CI: 0.5%, 5.1%) and 3.1% (95% CI: 0.7%, 5.7%) in CVD mortality at lags 0-15, respectively, for all ages and those aged over 65 years (Table 2).

Table 1. Characteristics of mortality, weather condition, and air pollutants in Brisbane between 1996 and 2004.

| | Mean(SD) | Minimum | Percentile | | | Maximum |
			25%	50%	75%	
CVD						
All ages	7.0 (3.0)	0	5	7	9	31
65+	6.4 (2.8)	0	4	6	8	31
Meteorological measures						
24-h mean temperature (°C)	20.1 (4.0)	9.8	16.8	20.5	23.4	31.9
Daily relative humidity (%)	72.5 (10.8)	23.8	67.1	73.6	79.6	98.4
Air pollutant concentration						
PM_{10} ($\mu g/m^3$)	16.6 (7.9)	2.1	12.1	15.3	19.3	162.1
NO_2 (ppb)	12.1 (5.8)	2.0	8	11	16	35.8
O_3 (ppb)	11.3 (4.8)	0	8	11	14	45

Abbreviations: PM_{10}: particulate matter with an aerodynamic diameter less than 10 μm; NO_2: nitrogen dioxide; O_3: ozone; SD: standard deviation; CVD: cardiovascular deaths.

Table 2. The lagged effect of temperature on CVD among all ages and over 65 years in Brisbane from 1996-2004.

Lag days	Hot effects (≥24°C) Overall % increase[a] (95% CI)	Cold effects (<24°C) Overall % increase[b] (95% CI)
All CVD		
0-1	3.5 (0.4, 6.7) *	0.1 (-1.0, 1.2)
0-7	3.0 (-1.8, 8.1)	0.6 (-1.2, 2.4)
0-15	4.5 (-1.7, 11.0)	2.8 (0.5, 5.1)*
0-21	8.4 (1.1, 16.2)*	3.2 (0.6, 5.9)*
0-30	7.4 (-0.6, 15.9)	3.4 (0.6, 6.3) *
CVD_{65+}		
0-1	3.7 (0.4, 7.1)*	0.1 (-1.0, 1.2)
0-7	2.5 (-2.7, 7.8)	1.0 (-0.8, 3.0)
0-15	3.3 (-3.1, 10.2)	3.1 (0.7, 5.7)*
0-21	8.0 (0.3, 13.2)*	3.2 (0.4, 6.2)*
0-30	6.0 (-2.3, 15.0)	3.2 (0.1, 6.5)*

Abbreviations: CVD: deaths from cardiovascular diseases; CVD_{65+}: deaths from cardiovascular diseases and over 65 ages.

[a] the percent increase with 1°C of temperature increase above 24°C;

[b] the percent increase with 1°C of temperature decrease below 24 °C;

* p<0.05.

DISCUSSION

To our knowledge, this is the first attempt to quantify the lagged effects of temperature on CVD in a city with a subtropical climate in the Southern Hemisphere. This study may fill a

knowledge gap because the characteristics of climate, adaptation and socio-demographic patterns in Brisbane are likely to differ from the cities in Europe or the USA. We investigated lagged effects up to 30 days on all for both cold and hot effects. An approximately two-week delayed effect was observed for cold temperatures but the apparent hot effects were identified at lags 0-1 days.

Several hypotheses have been proposed to explain the mechanism of the association between temperature and cardiovascular mortality. Environmental temperature has an inverse relation with blood pressure. [26] Cold temperature may exert a direct effect on heart or have an indirect effect via changes in blood pressure. [27] An increase in plasma cholesterol and plasma fibrinogen with cold temperatures, coupled with a higher blood pressure, could lead to thrombosis through haemoconcentration and trigger an acute cardiac event. [13 28 29] Whereas in hot weather, the heat balance of the body is sustained by enlarging skin vessels and increased sweating which in turn increases the cardiac work and loss of fluid and salt. This may lead to haemoconcentration, increased blood viscosity and the risk of thrombosis. [30 31]

In addition, the different types of CVD may have different sensitivity to higher and lower temperatures. For example, cold temperature can induce deaths from myocardial ischemia and acute myocardial infarction, [32 33] while in people with congestive heart failure, the extra heat load may lead to fatal consequences. [30 31]

In this study, the strongest hot effects were found shortly after exposure among both age groups. This is in agreement with results from earlier heat-related mortality studies which identified temperature-related CVD from recent exposure (i.e. same day and a few days

previously) in Europe and the USA. [4 28 34 35] Heat seems to induce an acute event in CVD for advanced forms of illness (e.g. myocardial infarction and stroke) among people who may be expected to die within a short period. [36] On the contrary, cold-related mortality did not occur immediately but was observed after approximately a week, persisting for approximately two weeks among both groups. Other researchers reported similar findings. [24 37 38 39]

The results illustrate that the relationship between temperature and mortality was similar amongst all ages and those aged over 65 years. Similarly, other studies also found that the effect of temperature on CVD did not vary with age. [13 40] Although the ability of older adults to maintain core temperature is usually compromised, other factors such as living conditions including being equipped with air conditioning, family and/or social cares as well as medical support can be modifiers of the effect of temperature on the elderly mortality. [41] One possible explanation for this finding is that the members of susceptible group of CVD_{65+} modify their behavioral patterns in cold or hot weather (i.e. spending less time outdoor or using air conditioning). [13] Another explanation is that the majority of CVD in Brisbane (91.4%) is experienced by people aged over 65 years.

It has long been known that there is an association between air pollution and increased CVD mortality in different parts of the world. [42] Pollution exposure leads to disturbances in the autonomic control of the heart, reflecting altered balance of the sympathetic and parasympathetic nervous systems. [43] Ambient temperature and air pollution levels often influence human health on a daily basis. Thus, the actual association between ambient temperature and mortality should be assessed after adjustment for air pollutants in the models. [44]

This study has three major strengths. Firstly, to our knowledge, this is the first research on the lag structure of temperature on CVD in a city in the Southern Hemisphere. Secondly, this study examined both cold and hot lagged effects on mortality up to 30 days for both all ages and the elderly. Thirdly, the polynomial distributed lag model was applied to overcome the collinearity of the temperatures on days close together. The sensitivity analyses were used to evaluate the outputs of polynomial distributed lag model with different degree polynomial.

This study also has two limitations. Firstly, although we found that hot temperature effects were acute but cold temperature effects lasted longer, the specific lag structures used here were intended to be representative, not to reflect the exact lag measurements appropriate for temperature-mortality relationship. Secondly, we only focused on one city, and therefore the results of this study have limited generalisability.

These findings on the lag structure of temperature on CVD may have implications for policy-making. The identified lags signify the need for targeted temperature-mortality prevention efforts. Results on lags for different subpopulation are particularly important for estimating temperature-related mortality from climate change.

CONCLUSIONS

In summary, the lagged effects of temperature on CVD lasted longer during cold days, but were shorter during hot days. The cardiovascular vulnerability to temperature stress was similar for all ages and over 65 years in this study.

Competing interests

There are no competing interests.

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Figure legends

Figure 1: The relationships between mean temperature and CVD among all ages and those aged over 65 years in Brisbane, 1996–2004.

Figure 2. The relationships between mean temperature and cardiovascular deaths in Brisbane, 1996-2004.

Figure 3. The relative risks in CVD with 1°C of mean temperature increase (or decrease) in Brisbane, 1996-2004.