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Assessing the threshold temperatures among different age and cause-of-deaths

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Abstract. The relationship between temperature and mortality is non-linear and the effect estimates depend on the threshold temperatures selected. However, little is known about whether threshold temperatures differ with age or cause of deaths in the Southern Hemisphere. We conducted polynomial distributed lag non-linear models to assess the threshold temperatures for mortality from all ages (D_{all}), aged from 15 to 64 (D_{15-64}), 65-84(D_{65-84}), ⩾85 years (D_{85+}), respiratory (RD) and cardiovascular diseases (CVD) in Brisbane, Australia, 1996–2004. We examined both hot and cold thresholds, and the lags of up to 15 days for cold effects and 3 days for hot effects. Results show that for the current day, the cold threshold was 20°C and the hot threshold was 28°C for the groups of D_{all}, D_{15-64} and D_{85+}. The cold threshold was higher (23°C) for the group of D_{65-84} and lower (21°C) for the group of CVD. The hot threshold was higher (29°C) for the group of D_{65-84} and lower (27°C) for the group of RD. Compared to the current day, for the cold effects of up to 15-day lags, the threshold was lower for the group of D_{15-64}, and the thresholds were higher for the groups of D_{65-84}, D_{85+}, RD and CVD; while for the hot effects of 3-day lags, the threshold was higher for the group of D_{15-64} and the thresholds were lower for the groups of D_{65-84} and RD. Temperature thresholds appeared to differ with age and death categories. The elderly and deaths from RD and CVD were more sensitive to temperature stress than the adult group. These findings may have implications in the assessment of temperature-related mortality and development of weather/health warning systems.

Keywords: Age groups cardiovascular diseases; death categories; respiratory diseases; threshold temperature.

1. Introduction

The relationship between temperature and mortality has been well documented [1]. Generally, the association between temperature and mortality is V–, U– or J–shaped, with optimum temperature corresponding to the lowest point in the temperature–mortality curve [2, 3]. The three-piece segmented linear function is a simpler method to investigate temperature-mortality relationships, which divides temperature into three linear parts with hot and cold thresholds. The middle section is constrained to have a zero slope and the "V" shaped association is the special case when cold and hot thresholds are equal [4]. The slopes on two sides of the optimum temperature are highly dependent on the selected threshold(s) [4]. The threshold temperature indicates that mortality rates are smallest at this temperature (or minimum mortality temperature (MMT)) and mortality levels will increase if the temperature increases or decreases from this point [3].

There have been several ways to estimate the threshold temperature in the previous literature. Kalkstein and Davis calculated the threshold temperature by the smallest total sum of squares (TSS) [3], while Donaldson et al. identified the threshold temperature by computing the mean daily mortality over a range of 31°C at successive 0.11°C intervals for each year of data [5]. Recently, smoothing curves were employed to generate the temperature point at which the minimum mortality occurred [6]. Certain percentiles (e.g., 99th or 90th) of temperature have also been used as the threshold temperatures in a meta-analysis [7]. A method proposed by Muggeo to compute the threshold temperature was proposed in several studies [8, 9].

Another way to divide hot and cold thresholds was according to the four seasons where data were analysed for spring, summer, autumn and winter separately [10, 11].

The effect of temperature on mortality was not only from the current day but also from previous days or weeks [7, 12]. Recently, distributed lag non-linear models have been used to assess the lagged effects of temperature on mortality [13-15].

Many temperature-mortality studies have reported that the threshold temperature varied according to locations [16-18]. However, few studies have identified the threshold temperatures for different age groups and mortality categories and even fewer studies have assessed the threshold temperatures considering the lag effects in a specific location since their sensitivity to temperature might differ [19-21].

2. Methods

2.1. Data sources

Mortality data included daily non-external mortality from 1996 to 2004. Meteorological data included daily mean, minimum and maximum temperatures, and relative humidity. Air pollution data including mean daily ozone (O_3), particulate matter with aerodynamic diameters ≤10µm (PM_{10}) and nitrogen dioxide (NO_2) were recorded in a central monitoring site during the same period as the mortality data.

Mean temperature was found to be a better predictor and was thus used as the temperature indicator based on our previous research [22]. We divided all deaths into four age groups: all ages (D_{all}), 15-64 years (D_{15-64}), 65-84 years (D_{65-84}), over 85 years (D_{85+}) and deaths from cardiovascular (CVD) (ICD-9:390–459; ICD-10:I00-I99) and respiratory diseases (RD) (ICD-9: 460–519; ICD-10: J00-J99) were examined separately.

2.2. Threshold analysis

This study explored a simple, new method to identify threshold temperatures for different age and death groups.

Firstly, the threshold range was chosen separately for the groups of D_{all}, D_{15-64}, D_{65-84}, D_{85+}, RD and CVD by visual inspection of smoothing plots of the temperature-mortality distribution. The distribution between temperature and each mortality category was approximately "U" or "V" shaped based on the equation 1 (Figure 1).

As indicated in Figure 2, if the assumed hot threshold is 24°C and the assumed cold threshold is 20°C, the relative risk (RR) in mortality is the highest when comparing 30°C to the hot threshold. The RR must become lower when comparing 30°C to 28°C. Correspondingly, the RR is also the highest if we estimate the risk at 14°C relative to the cold threshold. The RR must be lower when comparing 14°C to 18°C. There is no substantial change if selecting the temperatures between hot and cold thresholds (i.e. 22°C).

Secondly, we calculated the RRs with one degree of temperature change within the temperature range for each category. The temperature with the highest RR relative to 30°C was selected as the hot threshold and the temperature with the highest RR relative to 14°C was selected as the cold threshold temperature. The cold threshold and hot threshold will merge if the association is V-shaped.

All analyses were performed in R2.11.1 (The R Foundation for Statistical Computing, version 2.11.1 http://cran.r-project.org).

3. Results

3.1. Descriptive information for Brisbane data

In total, there were 53,316 deaths (22,805 CVD and 4,625 RD) registered in the study population. 82% of total deaths were the elderly aged over 65 years and 33.3% of these were aged 85 years and over. During the study period, the daily mean, maximum and minimum temperature, and the relative humidity were 20.1°C (SD: 4.0), 25.2°C (3.5), 15.4°C (3.8) and 72.5% (10.8), respectively. The mean daily concentrations of PM_{10}, NO_2 and O_3 were 16.6 µg/m^3 (7.9), 12.1 ppb (5.8) and 11.3 ppb (4.8), respectively.

3.2. The sensitivity analyses for temperature thresholds

For current-day effects, there were two turning points for all groups. The cold threshold was 20°C and the hot threshold was 28°C for the groups of D_{all}, D_{15-64} and D_{85+}. The cold threshold was 23°C for the group of D_{65-84}, 20°C for the group of RD and 21°C for the group of CVD. The hot threshold was 29°C for the group of D_{65-84}, 27°C for the group of RD and 28°C for the group of CVD.

For the lags of 15-days, the cold thresholds for D_{all}, D_{15-64}, D_{65-84}, D_{85+}, RD and CVD were 20°C, 18°C, 27°C, 23°C, 26°C and 28°C, respectively. For the lag of 3 days, the hot thresholds for these groups were 28°C, 29°C, 27°C, 28°C, 26°C and 28°C, respectively (Table 2).

4. Discussion

Since the distribution of temperature on mortality is nonlinear and usually has a U-, V- or J-shape, the key issue for the study of temperature-related mortality is to define the turning point, which determines the magnitude of the estimated risk below or above the threshold [3, 18]. The threshold temperature is often different for different locations and populations. This study, to our knowledge, is first to explore the threshold temperatures for various age and death groups and also considered lag effects in both cold and hot days in a city with a typical humidity subtropical climate.

We found that different threshold temperatures were suitable for different age groups and death categories. Normally, the vulnerable groups (i.e. the elderly and pre-existing diseases) have lower hot thresholds and higher cold thresholds compared to the group of all ages.

Generally, the threshold temperature is related to local climate because of population acclimatisation and adaptation facilities [23, 24]. Moreover, locations with a variety of socio-economic status may have different threshold temperatures even their climate and latitude are similar [16]. People may become less sensitive to the effects of temperature because of increasing economic development [25]. In addition, cultural and demographic characteristics may also affect the threshold temperature [21]. In Brisbane, different age and death groups have various cold and hot thresholds. Cold thresholds for the elderly (D_{65-84} and D_{85+}), RD and CVD were higher, while the adult group (D_{15-64}) had a lower threshold compared to the all-age groups. When lagged to 15 days compared to their thresholds on the current day, the threshold of the adult became lower and thresholds of the elderly, RD and CVD were higher. On the contrary, hot thresholds for the elderly were higher, while the threshold for RD was slightly lower than the threshold for all ages. When lagged to 3 days compared to the current day, the hot threshold for the adult was higher and thresholds for the elderly and RD were lower.

Only several previous articles have identified the threshold temperatures from different age and death groups. Muggeo and Hajat estimated the thresholds for all-cause mortality from 0-64 years and ≥65 years, and from CVD and RD in Santiago and Palermo [20]. The trend was similar to this study that the threshold in adult was lower than the elderly, RD and CVD. Kim et al. also explored the hot thresholds from all ages and ≥65 years which showed the threshold for the elderly was lower than that for all ages [21]. Huynen et al. identified the threshold temperature was 16.5°C for total mortality, CVD, RD and mortality among those ≥65 years of age, whereas for mortality in the younger age group, the threshold temperature was 14.5°C [19]. In this study, the lower hot thresholds and higher cold thresholds for the elderly, CVD and RD might suggest that these individuals are more vulnerable than younger individuals to temperature stress.

Even fewer studies considered lag effects when analysing threshold temperatures for various groups. Muggeo and Hajat estimated cold thresholds with 3-10 day's lag [20] and Kim et al. valuated hot threshold with the lag of 1 day [21]. The lower hot threshold of the current day compared with the threshold lagged for 3 days among the group of D_{15-64} can be explained by the fact that the current day's exposure has a more immediate effect than the previous 3 day's heat exposure. The hot thresholds were lower than those on the current days for the groups of D_{65-84} and RD illustrate a higher risk of heat effects on both groups after 3 days previous. On the contrary, higher cold thresholds of the current day compared with the thresholds lagged for 15 days can be explained more delayed cold effect than the current day's exposure among the groups of D_{65-84}, D_{85+}, RD and CVD.

This research has three strengths. Firstly, we selected a wide range of age and death groups to examine thresholds both for cold and hot weather. Secondly, we considered lag effects when assessing the threshold temperatures. Thirdly, the thresholds selected were based on the prior understanding and knowledge. In modelling these data, we used relative risk as a guide but not as a rigid optimization criterion.

However, two limitations should also be acknowledged. Firstly, the data we used was collected from one city and thus cannot be used to generalise. Secondly, the validation of the method to identify the threshold temperature from other databases is still needed.

From the public health perspective, estimating the temperature threshold is important because mortality is expected to rise from that temperature point. Public policies and government actions may be dependent on the temperature threshold. Our study implies that the temperature threshold varied by age and death categories. Understanding these differences may help in understanding both the sensitive populations and the mechanisms of action.

5. Conclusions

In summary, different age groups and death categories contained different temperature thresholds. The elderly, respiratory and cardiovascular deaths were more vulnerable to temperature stresses.

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Figure 1. The relationships between mean temperature and mortality in Brisbane, 1996-2004.

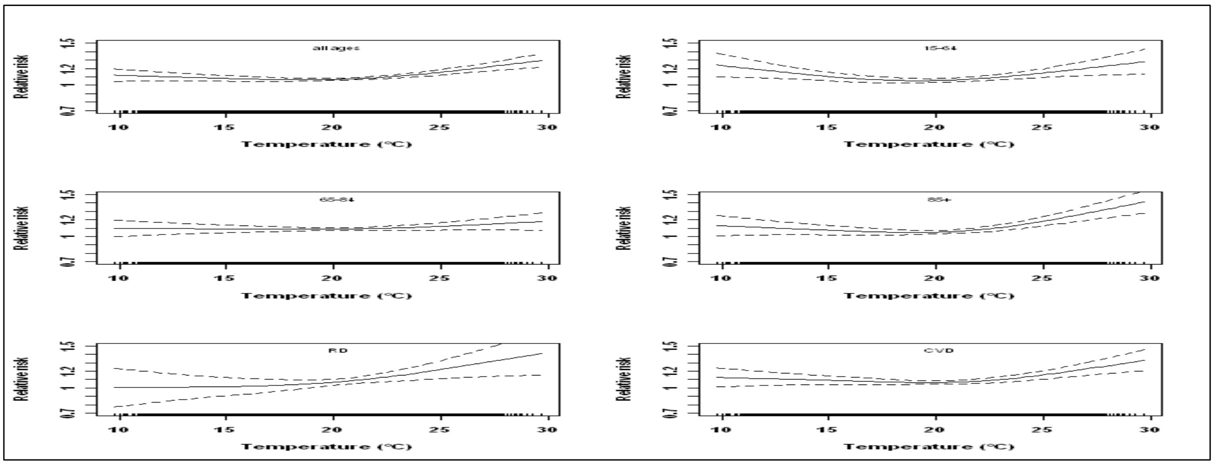

Figure 2. The U-shape relationship between temperature and mortality with cold threshold of 20 °C and hot threshold of 24°C.