



The Threshold Temperature and Lag Effects on Daily Excess Mortality in Harbin, China: A Time Series Analysis

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Abstract

Background: A large number of studies have reported the relationship between ambient temperature and mortality. However, few studies have focused on the effects of high temperatures on cardio-cerebrovascular diseases mortality (CCVDM) and their acute events (ACVDM).

Objective: To assess the threshold temperature and time lag effects on daily excess mortality in Harbin, China.

Methods: A generalized additive model (GAM) with a Poisson distribution was used to investigate the relative risk of mortality for each 1 °C increase above the threshold temperature and their time lag effects in Harbin, China.

Results: High temperature threshold was 26 °C in Harbin. Heat effects were immediate and lasted for 0–6 and 0–4 days for CCVDM and ACCVDM, respectively. The acute cardiovascular disease mortality (ACVDM) seemed to be more sensitive to temperature than cardiovascular disease mortality (CVDM) with higher death risk and shorter time lag effects. The lag effects lasted longer for cerebrovascular disease mortality (CBDM) than CVDM; so did ACBDM compared to ACVDM.

Conclusion: Hot temperatures increased CCVDM and ACCVDM in Harbin, China. Public health intervention strategies for hot temperatures adaptation should be concerned.

Keywords: Mortality; Hot temperature; Extreme heat; Weather; Cardiovascular system; Stroke; China

Introduction

During the 21st century, the earth surface temperature is rising and it will possibly surpass the safe threshold of 2 °C above the preindustrial average temperature.¹ Climate change is projected to increase the global mean

surface temperature by 2–4.5 °C with a probability of 76% and over 4.5 °C with a probability of 14% by 2100 with resultant increase in frequency, intensity and duration of heat waves.² Increasing temperature can directly or indirectly affect human health.^{3,4} For example, in Australian cities, approximately two deaths per 100 000

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population were associated with hot temperature every year and heat-related mortality was projected to increase to around eight per 100 000 population per year.⁵ In the 2003 France heat wave, there were 3096 extra-deaths⁶ and at least 700 excess deaths attributed to heat wave in 1995 Chicago.⁷ Therefore, heat-related mortality has become an environmental issue of increasing public health concern.⁸

Large previous studies have found the associations between hot temperature and mortality in Greece,⁹ Japan,^{10,11} Australia,¹²⁻¹⁵ and USA¹⁶⁻²⁰. For instance, in Michigan, the risk of cardiovascular death among non-married people were 1.21 (95% CI 1.14 to 1.28) times during extreme heat compared with non-extreme heat.²⁰ In Japan, a time series study found that the heat effect lasted for 1–2 days and death attributed to heat was 2.21%.²¹ However, there were little studies focused on developing countries.

Heat effects were quite different across

countries.²¹ The relations between temperature and mortality may be heterogeneous from area to area depending on weather conditions,²² air pollution,²³ socioeconomic status, and demographic characteristics²⁴. Heat exposure can increase cardiovascular and cerebrovascular diseases.^{25,26} Epidemiological studies evaluated heat impacts often use all-cause mortality²⁷ or specific-cause mortality^{12,15} other than their acute events. Whether acute events are more sensitive to heat and its time lag effects is still unknown. The first objective of this study was to establish the heat threshold for mortality outcomes in Harbin, China, an area with a temperate monsoon climate. We also tried to determine the association between each 1 °C increase above the threshold temperature and adverse health outcomes after adjusting for air pollution. We also estimated the time lag effects of high temperature on cardiovascular and cerebrovascular mortality and their acute events.

Materials and Methods

This study was performed in the urban areas of Harbin, which locates in North China with a population of 9.9 million. Harbin has a typical monsoon climate with clearly four seasons and an average annual temperature of 4 °C.

Daily mortality data during the hot seasons (June to August) in 2008–2011 were obtained from Harbin Center for Disease Control and Prevention. Cause of death was categorized following International Classification of Diseases 10 (ICD10). The following codes were considered: cardio-cerebrovascular disease mortality (CCVDM), I01-I69.8; cardiovascular disease mortality (CVDM), I01-I51.9; cerebrovascular disease mortality (CBDM), I60-I69.8. Acute events associated with the above conditions included acute cardiovascular disease mortality (ACVDM),

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- There is strong relationship between ambient temperature and mortality of cardio-cerebrovascular diseases and their acute events.
- The relations between temperature and mortality may be quite different across countries depending on weather conditions, air pollution, socioeconomic status, and demographic characteristics.
- There is a significant association between daily mean temperature and time lag effects on daily mortality after controlling for potential confounders.
- The risk corresponding to a 1 °C increase in the mean temperature in summer was significant for those aged 25 years and above.
- Mortality hazard depends not only on exposure to the current temperature of the day, but also on several former days of exposure (time lag effects).

I01, I21-I22, I24, I30.9, I33.0, I40.9; and acute cerebrovascular disease mortality (ACBDM), I60-I64. Acute cardio-cerebrovascular disease mortality (ACCVDM) included codes of ACVDM and ACBDM.

The meteorological data were provided by Harbin Bureaus of Meteorology. Weather variables included daily mean humidity (%), daily mean temperature (°C), daily maximum temperature (°C), and daily minimum temperature (°C).

The air pollutants data were collected from Harbin Environmental Protection Bureaus, which included daily average particulate matter less than 10 μm in aerodynamic diameter (PM_{10} , $\mu\text{g}/\text{m}^3$), daily nitrogen dioxide (NO_2 , $\mu\text{g}/\text{m}^3$) and daily sulfur dioxide (SO_2 , $\mu\text{g}/\text{m}^3$).

An observed/expected analysis was conducted to calculate excess deaths, following the method of Dessai.²⁸ A fixed mean of daily mortality for each summer month for the period 2008–2010 (76.68 deaths in June, 66.12 in July, and 66.70 in August) was used as expected values of deaths. Each observed daily deaths minus the expected value were considered the daily excess mortality. Each number of excess deaths was then grouped into the corresponding 1 °C interval to determine where heat-related deaths were no longer detectable.

Statistical Analysis

We used generalized additive model (GAM) with a Poisson distribution to evaluate mortality outcomes over the threshold and its associated time lag structure. We used 0–7 lag days for the relationship between temperature and CCVDM, 0–6 lag days for the association between temperature and ACCVDM, as most studies have shown that heat effects are usually acute.^{13,29–31} This model contained two types of temperature: one was the daily mean temperature minus the threshold temperature, which was considered ‘0’ when the

threshold temperature was higher than the daily mean temperature;¹⁵ the other was the range of daily temperature, namely the minimum temperature subtracted from the maximum temperature.³² In order to examine the independent effects of mean temperature on excess mortality, the long-term trends, day of the week effect (DOW), and air pollutants were controlled as potential confounders. DOW was formatted as dummy variables in the model; spline smoothed functions were used for other variables. The long-term trends were modeled with six degrees of freedom per year;²⁶ mean humidity with three degrees of freedom;¹³ and air pollutant with four.³² The Spearman's ρ for air pollution and weather condition ranged from -0.117 to 0.524, hence, multicollinearity was not a major concern.¹⁵ Relative risks (RRs) and their 95% CIs of hot temperature at different time lags were estimated.

To identify the robustness of our results, we conducted two sensitivity analyses. First, we examined the effects of temperature on mortality for a time lag with and without adjusting for the air pollutants. Second, we analyzed the data with different the degrees of freedom for time trends.

Data were analyzed with SAS9.2 (SAS Institute Inc, Cary, NC, USA). All statistical tests were two-sided. A p value <0.05 was considered statistically significant.

Results

Table 1 summarizes the characteristics of daily mortality values, weather, and air pollutants variables in Harbin between 2008 and 2011. There were a total of 25 672 non-accidental deaths. On average, daily CCVDM, CVDM, CBDM, ACCCDM, ACVDM, ACBDM-related deaths were 69.8, 35.2, 34.5, 45.2, 15.4, 29.8, respectively. The ratio of female to male mean daily mortality was 0.68. The deaths for

Table 1: Summary statistics of daily weather, mortality, and air pollution in Harbin, China (2008–2011)

Variables	Mean	SD	Min	Max	Percentile				
					1	25	50	75	99
Demographic characteristic									
Male	41.4	9.4	19.0	77.0	22.7	35.0	41.0	47.0	69.0
Female	28.3	6.3	13.0	50.0	15.0	24.0	27.0	32.0	46.6
0–64 years	23.7	6.6	10.0	44.0	10.7	19.0	23.0	27.0	42.6
≥65 years	46.1	9.1	27.0	76.0	28.0	40.0	45.0	52.0	73.3
Disease classification*									
CCVDM	69.8	13.3	40.0	115.0	44.4	61.0	68.0	78.0	112.3
CVDM	35.2	7.7	19.0	62.0	20.0	30.0	34.5	40.0	57.6
CBDM	34.5	7.7	14.0	63.0	18.0	29.0	33.0	39.8	56.3
ACCVDM	45.2	10.0	20.0	77.0	25.0	38.0	44.0	52.0	71.6
ACVDM	15.4	4.7	5.0	30.0	6.0	12.0	15.0	18.8	28.3
ACBDM	29.8	7.1	10.0	53.0	15.7	25.0	29.0	34.8	47.6
Weather factor									
Mean temperature (°C)	22.8	3.1	11.2	30.6	13.9	21.0	23.0	24.9	29.7
Max temperature (°C)	27.7	3.6	13.2	37.8	17.5	25.5	27.8	29.9	37.0
Min temperature (°C)	18.1	3.2	9.0	24.8	10.2	16.0	18.5	20.4	24.3
Mean humidity (%)	72.5	13.6	28.0	100.0	32.0	66.0	75.0	82.0	95.0
Air pollution									
PM ₁₀ (µg/m ³)	69.5	32.9	18.0	212.0	19.9	42.4	65.2	91.9	161.3
SO ₂ (µg/m ³)	26.8	9.2	10.0	63.0	13.2	21.0	24.8	30.5	58.6
NO ₂ (µg/m ³)	42.3	19.3	11.0	124.0	14.7	29.3	38.9	48.1	110.9

*CVDM cardiovascular disease mortality
 CBDM cerebrovascular disease mortality
 CCVDM cardio-cerebrovascular disease mortality, including CVDM and CBDM
 ACVDM acute cardiovascular disease mortality
 ACBDM acute cerebrovascular disease mortality
 ACCVDM acute cardio-cerebrovascular disease mortality, including ACVDM and ACBDM

individuals above 65 years accounted for 66.1% of the total number of deaths. The average daily mean temperature, daily minimum temperature, daily maximum temperature, and mean humidity were 22.8 °C, 18.1 °C, 27.7 °C, and 72.5%, respectively. Mean concentration of PM₁₀,

SO₂, and NO₂ were 69.5, 26.8, and 42.3 µg/m³, respectively.

Temperature Thresholds for Mortality

To fully capture the impact of temperature and time lag effects on mortality,

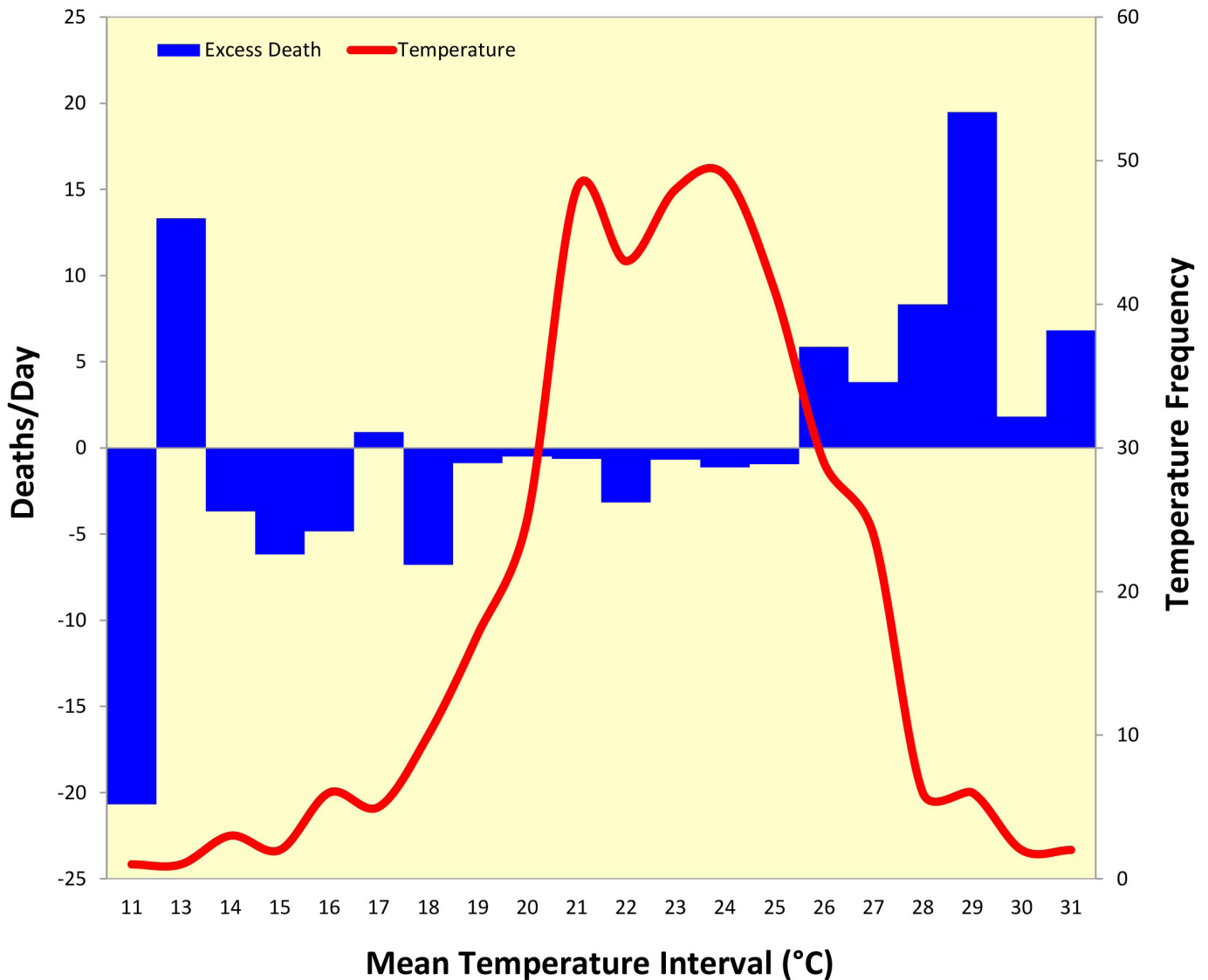


Figure 1: Mean daily excess mortality associated with daily mean temperatures interval

we grouped daily mean temperature into 1–6 °C intervals. The mean temperature thresholds with 1, 3, and 5 °C interval were 26, 28, and 30 °C, respectively. According to the threshold temperature, the indicator of heat temperature increased in daily mortality and acute-mortality of 0.6%–9.6% and 0.8%–13.1%, respectively. Daily excess deaths for significant temperature interval are presented in Tables S1 and S2. The mean temperature threshold for the

mean daily excess death for each 1 °C interval was 26 °C (Fig 1). The temperature frequency curve shows that very high mean temperature interval rarely happened between 2008 and 2011 (*eg*, a temperature of 31–32 °C happened only twice).

Association between Daily Mean Temperature and Mortality

Significant associations between the daily mean temperature and CCVDM, CVDM,

Tables S1 and S2 are available in online version of the article.

Table 2: Relationship of mean temperature on mortality in Harbin, China

Variable	RR (95% CI)
Disease classification*	
CCVDM	1.060 (1.038 to 1.082)
CVDM	1.052 (1.021 to 1.084)
CBDM	1.069 (1.037 to 1.100)
ACCVDM	1.059 (1.032 to 1.086)
ACVDM	1.064 (1.018 to 1.111)
ACBDM	1.056 (1.023 to 1.090)
Gender	
Male	1.016 (1.014 to 1.017)
Female	1.018 (1.016 to 1.020)
Age (yrs)	
0–24	1.009 (0.981 to 1.037)
25–45	1.024 (1.018 to 1.031)
46–64	1.019 (1.017 to 1.021)
≥65	1.016 (1.015 to 1.018)
*CVDM cardiovascular disease mortality CBDM cerebrovascular disease mortality CCVDM cardio-cerebrovascular disease mortality, including CVDM and CBDM ACVDM acute cardiovascular disease mortality ACBDM acute cerebrovascular disease mortality ACCVDM acute cardio-cerebrovascular disease mortality, including ACVDM and ACBDM	

CBDM, ACCVDM, ACVDM, ACBDM were observed in Harbin (Table 2). Increasing of 1 °C in the daily mean temperature above the threshold temperature, brought an increase of about 6.0% (RR 1.060, 95% CI 1.038 to 1.082) in CCVDM, 5.2% (RR 1.052, 95% CI 1.021 to 1.084) in CVDM, 6.9% (RR 1.069, 95% CI 1.037 to 1.100) in CBDM, 5.9% (RR 1.059, 95% CI 1.032 to 1.086) in ACCVDM, 6.4% (RR 1.064, 95% CI 1.018 to 1.111) in ACVDM, and 5.6% (RR 1.056, 95% CI 1.023 to 1.090) in ACBDM.

Both female and male CCVDM mortalities showed significant relationships with

high temperatures; the risk in females (RR 1.018, 95% CI 1.016 to 1.020) was slightly higher than that in males (RR 1.016, 95% CI 1.014 to 1.017). The mortalities for the people above 25 years showed significant association with high temperature. Compared to those aged 40–64 years and those over 65 years, the group aged 25–45 years had a slight higher increase in mortality with a 1 °C increase in the mean temperature in summer above the threshold.

Time Lag Structures for the Hot Effects

We found significant associations between temperatures and excess mortality in different lag periods (Fig 2). Heat effects were immediate and lasted for 0–6 and 0–4 days for CCVDM and ACCVDM, respectively. A 1 °C increase in temperature (lag 0 day) above the threshold was associated with an increase of 6.0% in CCVDM, 5.2% in CVDM, and 6.8% in CBDM; it was also associated with an increase of 5.9% in ACCVDM, 6.4% in ACVDM, and 5.6% in ACBDM. There was a relatively attenuated increase in CCVDM and ACCVDM related to each lag day increase in the mean temperature. The ACVDM seems to be more sensitive to temperature than CVDM, with higher mortality risks and shorter lag effects. Above the threshold temperature, excess CVDM disappeared at lag 0–5, while excess CBDM disappeared at lag 0–7. The time lag effect seemed to last longer on CBDM than CVDM.

Sensitivity Analysis

In the sensitivity analyses, the estimate of lag effects by different degrees of freedom of time trends and air pollutions remained largely unchanged (Tables S3–S6). We therefore concluded that the models used in this study could adequately capture the main effects of high temperature on mortality.

Tables S3–S6 are available in online version of the article.

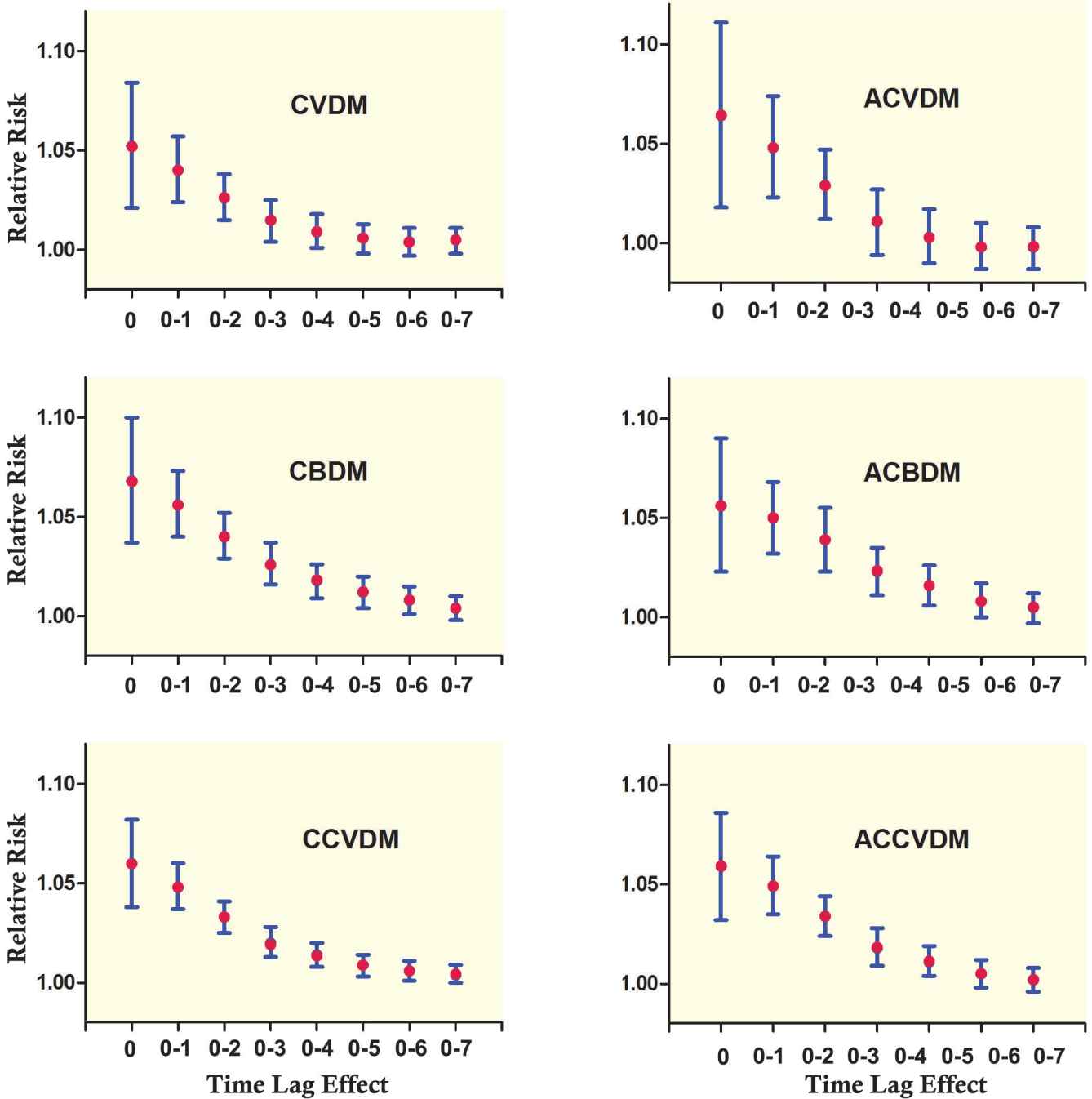


Figure 2: The overall time lag effect on cardio-cerebrovascular disease (left) and acute cardio-cerebrovascular disease (right). Error bars represent 95% CI.

Discussion

We evaluated the associations between high temperature and mortality outcomes

using time-series model in Harbin, China, after adjusting for confounding variables such as air pollution, weather condition, day of the week (DOW), and long-term

trends. To the best of our knowledge, this is the first study in China to examine the threshold temperatures and assess the impacts of lag days on human death, especially on ACCVDM. The results indicated significant association between daily mean temperature and lag effects on daily mortality after controlling for potential confounders.

This study has three strengths: first, air pollution data were taken from 12 monitor locations reflecting atmospheric pollution of Harbin. We controlled air pollution as a confounding variable because some previous studies have found that air pollution contributes significantly to human mortality, meanwhile air pollution is related to temperatures.^{33,34} Second, we analyzed not only CCVDM but also various health outcomes including their acute events because we postulated ACCVDM were more liable to heat temperature. Third, we investigated the time lag structure of higher temperature and heat to observe whether mortality happened after a severe heat episode.

We found the mean temperature threshold for death was 26 °C, approximately corresponded to 85th percentile of mean temperature distribution. Harbin is located in northern China, a place with a higher latitude where the temperature thresholds are lower than southern China.³⁵ This was in line with other studies such as Guo³⁶ who found that compared with Guangzhou and Wuhan, temperature thresholds were lower in Tianjin and Beijing. Li³² also found that temperature thresholds for all-cause mortality were higher in southern China than in northern China. Previous studies focused on the association between disease mortality and relatively hot regions, but not relatively comfortable areas. Although in Harbin high temperature threshold was lower than in southern China, we still found significant association between high temperature and CCVDM. This means

that even people living in Harbin who may adapt to relatively comfortable temperature in summer may still suffer from hot temperature above a certain threshold.

Previous studies focused on high temperature exposure have identified the elderly to be a high risk group,^{16,34,37,38} but few studies have considered young^{32,39}. The results of our research showed that the risk corresponding to a 1 °C increase in the mean temperature in summer was significant for those aged 25 years and above. For those aged 25–45 years, there was a higher risk of death. People aged 25–45 years are more likely to experience extreme temperature as they work daytime, even though they may be more resistant to heat; moreover, less protective consciousness and measures relative to the elderly may also cause higher mortality.⁴⁰ Older people (≥ 46 years) may have less tolerance and thermoregulatory capacity than younger people. The inconsistency exists in the age group of the vulnerable population may be partly due to different age categorization used in various studies. These findings suggested that both exposure and the inadequate thermoregulation are important risk factors contributing to the CCVDM associated with extreme temperatures. The elderly and young people who were group-watch should be especially targeted to reduce heat-related mortality. We observed light stronger temperature-associated mortalities in women than men. This was consistent with other studies.^{13,41} This might be attributed to thermoregulatory and physiological imparity with different sexes.

Mortality hazard depends not only on exposure to the current temperature of the day, but also on several former days of exposure (time lag effects).³⁹ It is noteworthy that in our study, heat effects on cardiovascular and cerebrovascular diseases appeared when we modeled the hot threshold using an average measure of lags 0–7.

For CCVDM, there was a decreasing trend with increasing lag days, with the maximum overall effect appeared at lag '0.' This finding was similar to those reported from the USA⁴² and Russia³⁴ that revealed the effect of high threshold temperature is associated with the current day of the death (lag 0). We also found that the ACCVDM lasted shorter than CCVDM, and that the CBDM lasted longer than CVDM. These results indicated that the hot temperatures had more acute effects on ACCVDM and CVDM. High temperature causes sweating with resultant exfoliation of the skin, dehydration, and increased hematocrit. However, the underlying physiological mechanisms for different time lag effects for extreme heat remain unclear yet.

Few previous research studies have focused on the effects of temperature on cardio-cerebrovascular deaths. From a study conducted in China, Wang¹³ reported that the temperature threshold for increased cardiovascular mortality is 32.6 °C and that the risk associated with extremely hot temperature was high (RR 1.67, 95% CI 1.45 to 1.92) over time lags of 0–3 days. Recich³⁴ reported that 1 °C increase in temperature above the threshold (18 °C) is associated with 4.7% increase in cerebrovascular mortality on the current day (lag 0). Though different research methods may result in different associations reported between heat and mortality, the findings consistently demonstrated that high temperature increase the risk of cardio-cerebrovascular disease.

There are several limitations in this study. First, we conducted ecological study to research on groups rather than individual exposure levels of air condition; there may exist an ecological fallacy. Second, modifications from some factors such as incomes, ozone level, and influenza were not analyzed due to limited data availability. Third, the study period was a little short. However, our findings warrant

conduction of more studies using longer research periods. Cardio-cerebrovascular diseases and their acute events increased significantly in hot temperature in Harbin, China. Not only older people but also younger population was at risk of death during hot weather. Effective public health intervention policy must be implemented that specifically target high risk population, during hot weather.

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Conflicts of Interest: None declared.

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