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Ambient high temperature and mortality in Jinan, China: A study of heat thresholds and vulnerable populations

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ABSTRACT

Background: Understanding the health consequences of continuously rising temperatures—as is projected for China—is important in terms of developing heat-health adaptation and intervention programs. This study aimed to examine the association between mortality and daily maximum (T_{max}), mean (T_{mean}), and minimum (T_{min}) temperatures in warmer months; to explore threshold temperatures; and to identify optimal heat indicators and vulnerable populations.

Methods: Daily data on temperature and mortality were obtained for the period 2007–2013. Heat thresholds for condition-specific mortality were estimated using an observed/expected analysis. We used a generalised additive model with a quasi-Poisson distribution to examine the association between mortality and $T_{max}/T_{min}/T_{mean}$ values higher than the threshold values, after adjustment for covariates.

Results: $T_{max}/T_{mean}/T_{min}$ thresholds were 32/28/24 °C for non-accidental deaths; 32/28/24 °C for cardiovascular deaths; 35/31/26 °C for respiratory deaths; and 34/31/28 °C for diabetes-related deaths. For each 1 °C increase in $T_{max}/T_{mean}/T_{min}$ above the threshold, the mortality risk of non-accidental-, cardiovascular-, respiratory, and diabetes-related death increased by 2.8/5.3/4.8%, 4.1/7.2/6.6%, 6.6/25.3/14.7%, and 13.3/30.5/47.6%, respectively. Thresholds for mortality differed according to health condition when stratified by sex, age, and education level. For non-accidental deaths, effects were significant in individuals aged ≥65 years (relative risk = 1.038, 95% confidence interval: 1.026–1.050), but not for those ≤64 years. For most outcomes, women and people ≥65 years were more vulnerable.

Conclusion: High temperature significantly increases the risk of mortality in the population of Jinan, China. Climate change with rising temperatures may bring about the situation worse. Public health programs should be improved and implemented to prevent and reduce health risks during hot days, especially for the identified vulnerable groups.

1. Introduction

High ambient temperature is a well-known environmental and public health hazard (Kovats and Hajat, 2008), particularly in terms of the projected increases in temperature globally (Climate change, 2007). Numerous studies conducted worldwide have demonstrated the significant association between high temperature and a series of health outcomes (Anderson and Bell, 2009; Baccini et al., 2008; Basu, 2009; Basu and Samet, 2002; Amegah et al., 2016; Turner et al., 2012; Guo et al., 2014; Gasparrini et al., 2015). Based on projections, it is

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Abbreviations: T_{max}, maximum temperature; T_{mean}, mean temperature; T_{min}, minimum temperature; China CDC, Chinese Center for Disease Control and Prevention; ICD-10, International Classification of Diseases, 10th revision; GAM, generalised additive model; df, degree of freedom; RR, relative risk; CI, confidence intervals; HHWS, Heat-Health Warning Systems

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estimated that there will be approximately 90,000 heat-related deaths worldwide in 2030 and > 25,000 in 2050 (Simon Hales, 2007). Therefore, to improve public health planning to minimise this deleterious health impact, there is an urgent need for a comprehensive and in-depth understanding of the adverse effects of extreme heat.

The temperature-mortality relationship often exhibits a U-, V-, or J-shaped curve, with increases in mortality when temperatures rise above a threshold (Baccini et al., 2008; Guo et al., 2011; Hajat and kosatky, 2010). When the number of deaths increases above the baseline level owing to temperature increases above the threshold level (Dessai, 2002), it is useful to identify the thresholds for different causes of death (Williams et al., 2012a). Hence, the threshold temperature is a useful indicator to activate heat-health action plans, especially for protecting vulnerable populations in the summer (Health, 2009).

In recent years, some regions have estimated heat threshold temperatures. For the population of Adelaide, Australia, heat-related mortality became apparent above the maximum temperature (T_{max}) threshold of 30 °C (Gosling et al., 2007), whereas heat thresholds for mortality in Sydney, Australia, have been estimated to be in the range of 23–26 °C (Vaneckova et al., 2008). A study regarding the association between threshold temperatures and mortality among the population of four cities in China observed different threshold temperatures in different climatic zones (Li et al., 2014a). However, to the best of our knowledge, most of these studies used T_{max} as the only heat indicator (Gosling et al., 2007; Li et al., 2014a; Williams et al., 2012b; Bai et al., 2014; Susan Williams, 2011; Akanji and Oputa, 1991; Yang et al., 2016a) to evaluate the heat impact on human health. Additional evidence regarding the association of mortality with mean (T_{mean}) and minimum (T_{min}) temperatures is also needed for public health professionals to make comprehensive heat response based on the potential various temperature indicators. Moreover, there is a need identify groups that are particularly vulnerable at higher temperatures. To our knowledge, few studies has been conducted in China regarding the associations between threshold temperatures and mortality (Li et al., 2014a). In particular, the effect of high temperature thresholds on mortality in Jinan, a city named as the one of the four "ovens" in China (Li et al., 2016), remains unclear.

The aims of this study were 1) to investigate effects of threshold temperatures within the warmer months on mortality related to the following four conditions: non-accidental mortality, cardiovascular diseases, respiratory disease, and diabetes; 2) to assess the relationship between cause-specific mortality and $T_{max}/T_{mean}/T_{min}$; and 3) to identify the vulnerable groups in the warmer season. These results will contribute to a better understanding of the health impacts of temperature in the warm season and provide more evidence for policymakers to develop heat-health plans to reduce the adverse health impact during hot days.

2. Materials and methods

2.1. Study area

Jinan, the capital of Shandong province, is located in the mid-west, south of Mount Tai and north of the Yellow River (geographical coordinates, 36°40′N and 117°00′E, Fig. 1). Jinan covers an area of 8177.21 km^2 and had a total population of 7.06 million in 2015. Its climate is characterised as sub-humid and warm, with obvious continental monsoon weather and four distinct seasons. The annual mean temperature is 13.8 °C, and precipitation is 685 mm.

2.2. Health data

Daily mortality data were obtained from the China Information System of Death Register and Report of the Chinese Center for Disease Control and Prevention (China CDC) from 1 January 2007 to 31 December 2013. The cause of death was coded by the China CDC according to the International Classification of Diseases, 10th revision (ICD-10), as follows: non-accidental (ICD-10: A00-R99), total cardiovascular (ICD-10: I00-I99), respiratory (ICD-10: J00-J99), and diabetes (ICD-10: E10-E14) related death. In addition, the data were stratified into groups according to sex (male and female), age (0–64 years and ≥65 years), and education level (low level [illiterate and primary school] and high level [junior high school and above]).

2.3. Meteorological data

Daily meteorological data—$T_{max}/T_{mean}/T_{min}$, relative humidity, and atmospheric pressure during 2007–2013—were acquired from the China Meteorological Data Sharing Service System (http://cdc.nmic.cn/home.do).

2.4. Data analysis

An observed/expected analysis was used to estimate the heat threshold for mortality. A 31-day moving average, including 15 days before and after the index day, was used as an estimate of expected daily mortality. Daily excess deaths were calculated as the difference between the observed and expected daily values. To evaluate the associations between excess mortality and daily temperature, the days were grouped into intervals of 1 °C for $T_{max}/T_{mean}/T_{min}$ after rounding to the nearest whole degree, and the mean number of daily excess deaths was calculated for each 1 °C temperature interval. The temperature threshold was defined as the temperature interval below which excess events were not discernible (Gasparrini et al., 2015). Only the warmer months, 1 May to 30 September, during the period 2007–2013 were considered in the analyses. To identify vulnerable sub-populations, we separately repeated the above observed/expected analysis by sex, age, and education level categories.

A semi-parametric generalised additive model (GAM) with a quasi-Poisson regression was used to analyse the association between daily temperatures over the thresholds and mortality, including all non-accidental-, cardiovascular-, respiratory-, and diabetes-related deaths, and sex-, age-, and education-specific mortality rates. Linear terms for elevated (over threshold) temperatures were included. The temperature term in the GAM was the daily $T_{max}/T_{mean}/T_{min}$ minus the threshold temperature: This term was set as 0 if the daily temperature was lower than the threshold temperature. Models took into account the following potential confounders: day of week, holiday, time, relative humidity, and atmospheric pressure. Day of week and holiday were formatted as indicator variables, and spline smoothed functions were applied to the other variables. The minimum value of the sum of the Akaike information criterion for quasi-Poisson (Q-AIC) values for all-cause mortality was used to select the degree of freedom (df) for time, relative humidity, and atmospheric pressure (Yang et al., 2013a; Gasparrini et al., 2012). Finally, based on the best fit, we used 5 df for time to control the long term trend, 3 df for relative humidity and 4 df for atmospheric pressure (Tables S1–S3). We used the daily Tmax/Tmean/Tmin, respectively, to estimate the effect of high temperature on cause-specific mortality.

The Pearson's correlation test was performed to estimate multi-collinearity of meteorological variables; multi-collinearity was not a major concern (Table S4). The effects of temperature were estimated as the percent increase in daily mortality in relation to a 1 °C increase in the daily temperature. Relative risks (RR) and 95% confidence intervals (CI) were reported as the estimated effect.

We tested for statistical differences between effect estimates of the strata of a potential effect modifier (e.g., the differences between low education and high education) by calculating the 95% CI as follows:

$$(\widehat{Q_1} - \widehat{Q_2}) \pm 1.96\sqrt{(\widehat{SE_1})^2 + (\widehat{SE_2})^2}$$

where $\widehat{Q_1}$ and $\widehat{Q_2}$ are the estimates for the two categories, and $\widehat{SE_1}$ and