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Vulnerability to the impact of temperature variability on mortality in 31 major Chinese cities☆

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ABSTRACT

Few studies have analyzed the health effects of temperature variability (TV) accounting for both interday and intraday variations in ambient temperature. In this study, TV was defined as the standard deviations of the daily minimum and maximum temperature during different exposure days. Distributed lag non-linear Poisson regression model was used to examine the city-specific effect of TV on mortality in 31 Chinese municipalities and provincial capital cities. The national estimate was pooled through a meta-analysis based on the restricted maximum likelihood estimation. To assess effect modification on TV-mortality association by individual characteristics, stratified analyses were further fitted. Potential effect modification by city characteristics was performed through a meta-regression analysis. In total, 259 million permanent residents and 4,481,090 non-accidental deaths were covered in this study. The effect estimates of TV on mortality were generally increased by longer exposure days. A 1 °C increase in TV at 0−7 days' exposure was associated with a 0.60% (95% CI: 0.25−0.94%), 0.65% (0.24−1.05%), 0.82% (0.29−1.36%), 0.86% (0.42−1.31%), 0.98% (0.57−1.39%) and 0.54% (−0.11-1.20%) increase in non-accidental, cardiovascular, IHD, stroke, respiratory and COPD mortalities, respectively. Those with lower levels of educational attainment were significantly susceptible to TV. Cities with dense population, higher mean temperatures, and relative humidity and lower diurnal temperature ranges also had higher mortality risks caused by TV. This study demonstrated that TV had considerable health effects. An early warning system to alert residents about large temperature variations is recommended, which may have a significant impact on the community awareness and public health.

1. Introduction

Climate change is becoming one of the biggest challenges to global public health in the 21st century (Costello et al., 2009), as it, directly and indirectly impacts the vast majority of the global population. The hazardous effects of future climate change have attracted mounting attention from policymakers and epidemiological researchers worldwide (Frumkin and McMichael, 2008).

Understanding climate-related impacts on human health have major implications in coping with future climate change. Climate change increases average global temperatures on a long-term scale. Previous studies in both high-income and low-income countries have demonstrated that the future heat-related burden will be exacerbated by future temperature increases. More importantly, global temperature variability would be amplified by climate change (Thornton et al., 2014), which contributes to increases in the

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frequency, duration, and intensity of extreme weather events, such as heat waves, cold spells and droughts. Human populations can be acclimatized to future slow changes in climate through alterations in physiological, behavioral and cultural terms. Thus, it is important to assess the health risks of temperature variability for determining policy action on protecting public health.

Previous studies have mostly focused on the health effect of temperature variation in intraday, using diurnal temperature range (difference between maximum and minimum temperature) as exposure (Cheng et al., 2014; Ding et al., 2016; Yang et al., 2013, 2018), and temperature variation in interday, using temperature change between neighboring days as exposure (Guo et al., 2011; Lin et al., 2013). Little evidence has been collected on the synthesized effects of temperature variation during interday and intraday periods (Guo et al., 2016; Vicedo-Cabrera et al., 2016; Zhang et al., 2017); and the effect modifications of individual and city characteristics were not well elucidated. However, this information may have practical implications for identifying vulnerable populations and could help policymakers with the development of mitigation strategies for reducing the vulnerability of the city and residents from climate change.

In the present study, we aimed to examine the effects of TV on daily mortality in 31 major cities in China, and to test whether the risk was modified by personal and city-level socioeconomic factors.

2. Methods

2.1. Study sites

In the present study, the population included the residents of 31 large cities in mainland China, which includes around 259,900,000 permanent citizens, according to China's 2010 population census. The distribution of these sites is presented in the Supplementary Fig. A1.

Data on the daily counts of deaths from January 1, 2007 to 31 December 31, 2013 were collected from the Chinese Center for Disease Control and Prevention (China CDC). The cause of death was coded using the 10th revision of the International Classification of Diseases as follows: non-accidental cause (ICD-10: A00-R99), cardiovascular disease (I00-I99), ischemic heart disease (IHD, I20-I25), stroke (I60-I69), respiratory disease (J00-J99), and chronic obstructive pulmonary diseases (COPD, J40-47). In addition, we stratified the above non-accidental, cardiovascular and respiratory mortalities by sex, age (0−64 and 65 + years), and educational attainments (primary education or lower, and secondary or higher education).

The city-specific daily meteorological data during the corresponding period was obtained from the China Meteorological Data Sharing Service System (http://data.cma.cn). The daily weather data include daily minimum temperature (°C), daily mean temperature (°C), daily maximum temperature (°C), and daily mean relative humidity (%). The city-specific weather data was acquired from a basic national weather monitoring station in each city.

Demographic data for each city were collected from China's 2010 population census and included the population size, the percentage of those unemployed, > 64 years old, and the illiterate. City-level economic data, such as gross regional domestic product (GDP) and number of hospital per 100,000 population were collected from the Chinese National Bureau of Statistics (http://www.stats.gov.cn/tjsj/ndsj/). The detailed information of city-level variables is presented in Supplementary Table A1.

2.2. Exposure definition

Previous evidence suggested that temperature variation could persist up to several days (Ding et al., 2016; Yang et al., 2013, 2018). We applied a recently proposed indicator to calculate the standard deviations of daily minimum temperature and daily maximum temperature during different exposure days as TV (Guo et al., 2016). For example, TV for the two days' exposure was calculated by a standard deviation of minimum and maximum temperatures at the current and previous days.

2.3. Statistical analysis

2.3.1. Temperature variability on mortality

In this study, a two-stage analysis was applied to assess the risk of TV on daily mortality.

In the first stage, a quasi-Poisson regression model allowing for over-dispersed death counts was applied to obtain city-specific estimate of TV on mortality after potential confounders were controlled. The city-specific model is as follows:

$$Log[E(Y_t)] = \alpha + S(Time, 7*7) + S(Hum_t, 3) + \gamma Dow_t + \nu Holiday_t + \beta_1 Temp_{t,l} + \beta_2 TV_t$$

where $E(Y_t)$ is the expected counts of death at day t; α is the model intercept; $S()$ denotes smooth function, and natural cubic spline (NS) was used in the present study, which was in accordance with previous studies (Guo et al., 2016; Yang et al., 2013; Zhang et al., 2017); NS with 7 degrees of freedom (df) per year for time variable (1, 2, 3, …, 2557) was used to adjust for the long-term and seasonal trends of daily death; NS with 3 df was applied for relative humidity; public holidays and day of the week as categorical variables were also included in the model; a two dimensional cross-basis matrix ($Temp_{t,l}$) using NS function with 4 df respectively for daily mean temperature and lag (maximum lag of 21 days) was applied to control for the non-linear and distributed lag effects of ambient temperature, which was produced by a distributed lag non-linear model (Gasparrini et al., 2010). The above model specifications were confirmed in previous studies (Guo et al., 2016; Yang et al., 2015, 2016a, 2016b). Then, the TV at different exposure days was separately introduced as a linear function, which was in accordance with previous studies (Guo et al., 2016; Yang et al., 2013; Zhang et al., 2017). The optimal exposure day for TV was based on the minimum value of the sum of the Akaike information criterion for quasi-Poisson (Q-AIC) values for all cause-/gender-/age-/education-specific mortality across 31 cities.

In the second stage, a meta-analysis using the method of restricted maximum likelihood estimation was applied to produce the pooled estimates of TV on cause-/gender-/age-/education-specific mortality across these 31 cities. The impact of TV was computed as the percentage change in death rate with one centigrade degree increase in TV. The between-city heterogeneity and the percentage of variation due to the true differences across cities were respectively tested by Cochran's Q test and the I^2 statistics (Viechtbauer, 2010).

2.3.2. Difference test on individual characteristics

The effects among individual characteristics were pooled separately by the analyses above. The difference among the estimates in the subpopulation was tested via the Z-test with following formula.

$$Z = \frac{E_1 - E_2}{\sqrt{SE(E_1)^2 + SE(E_2)^2}}$$

where E_1 and E_2 are the estimates (the regression partial coefficient) for the two categories (eg, males and females), and SE (E_1)