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Temperature-related mortality in 17 large Chinese cities: How heat and cold affect mortality in China

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ABSTRACT

Few multicity studies have been conducted to investigate the acute health effects of cold and hot temperatures in China. We aimed to examine the relationship between temperature and daily mortality in 17 large Chinese cities. We first calculated city-specific effect of temperature using time-series regression models combined with distributed lag nonlinear models; then we pooled the city-specific estimates with the Bayesian hierarchical models. The cold effects lasted longer than the hot effects. For the cold effects, a 1 °C decrease from the 25th to 1st percentiles of temperature over lags 0–14 days was associated with increases of 1.69% [95% posterior intervals (PI): 1.01%, 2.36%], 2.49% (95% PI: 1.53%, 3.46%) and 1.60% (95% PI: 0.32%, 2.87%) in total, cardiovascular and respiratory mortality, respectively. For the hot effects, a 1 °C increase from the 75th to 99th percentiles of temperature was associated with corresponding increases of 2.83% (95% PI: 1.42%, 4.24%), 3.02% (95% PI: 1.33%, 4.71%) and 4.64% (95% PI: 1.96%, 7.31%). The latitudes, number of air conditioning per household and disposable income per capita were significant modifiers for cold effects; the proportion of the elderly was a significant modifier for hot effects. This largest epidemiological study of temperature to date in China suggested that both cold and hot temperatures were associated with increased mortality. Our findings may have important implications for the public health policies in China.

1. Introduction

The impact of temperature variations on human health aroused increasing concerns in light of global climate change. The 2013 Intergovernmental Panel on Climate Change has projected that global mean surface temperature at the end of the 21st century would increase by 1.0–3.7 °C relative to the reference period of 1986–2005 (http://www.ipcc.ch/report/ar5/wg1). Optimal adaptation strategies to climate change require a comprehensive and in-depth understanding of the nature of the effect of temperature on human health.

Previous studies have identified a nonlinear U, V or J-shaped relationship between temperature and mortality, suggesting that mortality is usually lowest around a certain temperature and increases at lower or higher temperatures (Anderson and Bell, 2009; Curriero et al., 2002; Zanobetti and Schwartz, 2008). This relationship varied by locations, study design and model specifications. Most previous studies were conducted in developed countries, such as the United States and Europe (Analitis et al., 2008; Anderson and Bell, 2009; Baccini et al., 2008, 2011; Basu, 2009). There remains a need for studies in cities of developing countries, where socio-demographic status of local residents (e.g. air conditioning use, disease pattern, and socio-economic characteristics) may be different from developed countries.

As the largest developing country, China emits the most carbon dioxide annually in the world, but few studies have been conducted in the country to address the temperature-related health impact (Kan et al., 2012). The relationship between temperature and daily mortality has been examined in several large Chinese cities, including Beijing (Liu et al., 2011), Shanghai (Ma et al., 2012), Tianjin (Guo et al., 2011), and Guangzhou (Yang et al., 2012). However, these single-city studies adopted different study designs and model specifications, limiting the ability to compare the results across cities. In this study, we aimed at examining the relationship between temperature and daily mortality in 17 large Chinese cities, using a standardized analytic protocol.

2. Materials and methods

2.1. Data collection

We collected daily number of deaths, weather conditions and air pollution in Anshan, Beijing, Fuzhou, Guangzhou, Hangzhou,

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Hong Kong, Lanzhou, Nanjing, Shanghai, Shenyang, Suzhou, Taiyuan, Tangshan, Tianjin, Urumqi, Wuhan, and Xi'an. The latitude varied from 22 col of Hong Kong to 41f Ho of Shenyang. The study periods varied between 1996 and 2008 from city to city, depending on the data availability. Our study areas were restricted to the urban areas because the Death Registry had not been well established in suburban and rural areas in China during the study periods.

The daily mortality data of urban residents were obtained from the Municipal Center for Disease Control and Prevention (CDC) in each city. The causes of death were coded by CDC in each city according to the *International Classification of Diseases,* Tenth Revision (ICD-10). The mortality data were classified as deaths due to total non-accidental causes (ICD-10: A00-R99), cardiovascular disease (ICD-10: I00-I99), and respiratory disease (ICD-10: J00-J98). The cause-specific mortality is not available in Lanzhou.

We obtained data on mean temperature and relative humidity from the Meteorological Bureau in each city. To control for potential confounding from outdoor air pollution, we also obtained daily data of air pollution from the National Air Pollution Monitoring System. We included 3 air pollutants in the analyses: particulate matter less than 10 μm in aerodynamic diameter, sulfur dioxide, and nitrogen dioxide. The Chinese government has mandated detailed quality assurance and quality control programs at each monitoring station providing air pollution data.

To allow for the analysis of city-level effect modifiers, we also collected the data on the use of air conditioning, the proportion of green space, the proportion of the elderly (aged 65 years or more) and the disposable income per capita from the "China Statistical Yearbook".

2.2. Statistical analysis

The statistical analyses included 2 stages: in the first stage, we calculated city-specific estimates of cold effects and hot effects using time-series regression models; and in the second stage, we obtained the national average effects by pooling city-specific results with the Bayesian Hierarchical models (Anderson and Bell, 2009).

For the city-specific analyses, we used quasi-Poisson generalized additive models (GAM) because daily deaths typically followed an over-dispersed Poisson distribution. We incorporated several covariates in the GAM: (1) a natural cubic smooth function of calendar time with 7 degrees of freedom (*df*) per year to exclude unmeasured long-term and seasonal trends in daily mortality; (2) air pollutants (inhalable particles, sulfur dioxide, and nitrogen dioxide) and relative humidity, and (3) an indicator variable for "day of the week" (Peng et al., 2006). In order to flexibly account for the potential lagged and nonlinear effects of temperature on mortality, we incorporated temperature as a "cross-basis" function in the GAM, which was constructed using a distributed lag nonlinear model (DLNM) (Gasparrini et al., 2010). DLNM can estimate the cumulative effects of temperature within a few days after an exposure after accounting for the strong collinearity of temperature using a smooth spline. For the DLNM, we applied a cubic spline with 5 *df* to model the non-linear association between temperature and mortality, a cubic spline with 5 *df* to model the lagged effect of temperature. We a priori used a maximum lag of 14 days (Chen et al., 2013) because previous studies suggested that the hot effects were limited within the first several days, but the cold effects may last for 2–4 weeks (Armstrong, 2006; Guo et al., 2011). Similarly, we also included air pollutants and relative humidity as "cross-basis" functions with 3 *df* for the non-linear association, 4 *df* for the lag space and a maximum lag of 3 days (Gasparrini, 2011).

We first flexibly plotted the relative risks (RR) of the temperature–mortality association in each city with the RR defining as the risk at each temperature comparing with that at the "minimum-mortality temperature". Given the nonlinear relationship between temperature and daily mortality, we measured the temperature's effects by extracting portions of the nonlinear temperature–mortality relationship curves (Anderson and Bell, 2009). We firstly calculated the relative risks (RR) comparing a percentile to another percentile of temperature, and then provided estimates per an absolute change of temperature (1 °C) in this range. For the cold effects, we calculated the relative risk (RR) for mortality comparing the 1st and 25th percentile of temperatures; for the hot effects, we calculated the RRs comparing the 99th and 75th percentile of temperatures in each city. Furthermore, to quantify the effect estimates per an absolute change (1 °C) of temperature, we calculated the effect as the log-RR divided by the range of temperature percentiles in each city. In brief, cold effects referred to percent increases in mortality per 1 °C decrease from the 25th to 1st percentile of temperature; hot effects referred to percent increases in mortality per 1 °C increase from the 75th to 99th percentile of temperature

In the second stage, we applied the Bayesian hierarchical models to pool the city-specific effect estimates (Anderson and Bell, 2009; Dominici et al., 2006). This approach provides a flexible tool to combine effect estimates while accounting for within-city statistical error and between-city range (heterogeneity) of the "true" effects. The model generated a posterior probability distribution of the "true" estimates, from which we reported the combined the cold effects and hot effects as the posterior means and 95% posterior intervals (PIs). We performed this hierarchical model by using 2-level normal independent sampling estimation with uniform priors.

We calculated the I^2 statistic to evaluate the heterogeneity of city-specific estimates. Furthermore, we examined the effect modifications of city-level characteristics. Firstly, the cities were categorized into two levels with 9 cities in the low level and 8 cities in the high level according to the percentiles of a potential modifier; secondly, we compared their pooled effect estimates in two levels; lastly, we included each city characteristic as a covariate to test whether heterogeneity in city-specific estimates could be explained by that characteristic in meta-regression analysis (Medina-Ramon and Schwartz, 2007).

To check the stability of our main findings, we conducted several sensitivity analyses. First, we used alternative maximum lag of 3 or 28 days in the temperature-DLNMs. Second, we used alternative maximum lag of 7 days in the air pollutants-DLNM. Third, we controlled for current-day concentrations of air pollutants. Fourth, we changed the *df* per year from 4 to 8 in the smoothness of time.

The statistical tests were two-sided, and effects of $P<0.05$ were considered statistically significant. All models were fitted with the R software (version 2.15.1): the "*mgcv*" package for GAMs, the "*dlnm*" package for DLNMs, and "*tlnise*" for Bayesian hierarchical models.

3. Results

Table 1 shows the descriptive data on population size, daily mortality and temperature in 17 Chinese cities. Our study included more than 70 million urban residents with daily mean total non-accidental deaths ranging from 11 to 119 in various cities. There were no missing data in our dataset (except for Lanzhou). On average, cardiorespiratory diseases accounted for 49% of the total deaths in these cities. The annual mean temperature ranged from 8.2 °C in Shenyang to 23.7 °C in Hong Kong, which may capture most of the temperature variations in China. This study included cities with relatively moderate climates (for example, Hong Kong, Guangzhou, and Fuzhou) and climates with both extreme heat and cold (for example, Anshan, Nanjing, Urumqi, and Wuhan).