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Long-term variations in the association between ambient temperature and daily cardiovascular mortality in Shanghai, China

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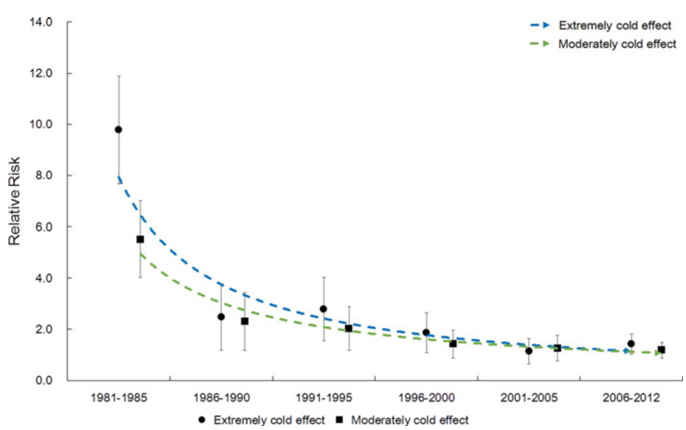
HIGHLIGHTS

- It was unclear how the effects of temperature on CVD mortality varied over time.
- The association between temperature and daily CVD mortality was J-shaped.
- The cold effects persisted for 2 weeks and hot effects had a mortality displacement.
- The cold effects attenuated substantially from 1981 to 2012.
- There were no discernible patterns for long-term variations in the hot effects.

GRAPHICAL ABSTRACT



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ABSTRACT

Objective: The objective of this study was to explore the long-term variation in the association between ambient temperature and daily cardiovascular (CVD) mortality in Shanghai, China.
Materials and methods: We collected daily data on ambient temperature and CVD mortality from a central urban district in Shanghai, China, during the period from 1981 to 2012. We used overdispersed generalized additive Poisson regression together with a distributed lag nonlinear model to estimate potentially lagged and nonlinear effects of temperature on CVD mortality after controlling for the seasonality, relative humidity, day of the week, holidays and population size. To allow for the evaluation of long-term variations in the effects, we divided the entire study period into six sub-periods (1981–1985, 1986–1990, 1991–1995, 1996–2000, 2001–2005, and 2006–2012) and analyzed the effect estimates in each sub-period separately.
Results: The association between temperature and daily CVD mortality was J-shaped with both low and high temperatures increasing the risk of CVD deaths. The effects of extremely low temperatures were delayed and persisted for two weeks, while extreme hot effects were limited to the first five days followed by a significant mortality displacement (9 days). The relative risks (RRs) of extremely low, moderately low, moderately high, and extremely high temperatures comparing the 1st, 10th, 90th, and 99th percentile with the reference temperature (26 °C) over the cumulative lags of 0–14 days were 1.95 [95% confidence interval (CI): 1.84,2.07],

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1.61 (95% CI: 1.57,1.66), 1.03 (95% CI: 1.01,1.05), and 1.14 (95% CI: 1.07,1.21). The RRs for extremely low and moderately low temperature attenuated substantially from 9.78 and 5.52 in 1981–1985 to 1.42 and 1.18 in 2006–2012, respectively, but the RRs remained almost stable for extremely high and moderately high temperatures.

Conclusions: This time-series study suggested that there might have been some human adaptation to low ambient temperature in Shanghai, China, over the last 3 decades.

1. Introduction

Over the last half century, global climate change has had ubiquitous impacts, leading to the increased frequency, intensity and duration of extreme weather events (e.g., heat waves, cold spells, drought and flood) (Barker et al., 2007). To date, climate change has already been recognized as the primary global threat to public health in the 21st century (Costello et al., 2009). Therefore, the increasing risks associated with extreme temperatures remain a great public health concern (Stocker et al., 2013).

Cardiovascular diseases (CVD) are the leading cause of deaths worldwide, accounting for approximately 30% of all deaths (WHO, 2011). Epidemiological studies have identified that both low and high temperatures contributed to the increased risks of cardiovascular mortality (Breitner et al., 2014; Chen et al., 2013; Guo et al., 2013; Urban et al., 2014; Yu et al., 2011). Most previous studies have estimated the risks over a relatively short period and have ignored the potential long-term variability in risks (Cheng and Su, 2010; Lim et al., 2015). This variability may be driven by climatic stress, size of at-risk populations, and adaptation over time. Understanding the association between temperature and human health in a changing climate may provide vital insights in addressing health hazards due to climate change. However, there were limited studies examining the long-term variations in daily cardiovascular mortality risk that was attributable to temperature extremes, especially in developing countries (Carson et al., 2006; Onozuka and Hagihara, 2015).

Therefore, the objective of this study was to explore the long-term variation in the association between temperature and daily CVD mortality using a long time-series dataset (32 years) from Shanghai, China.

2. Materials and methods

2.1. Data collection

Shanghai has a humid subtropical climate and experiences four distinct seasons. Winters are chilly and damp, and cold northwesterly winds from Siberia can cause nighttime temperatures to drop below freezing. Summers are hot and humid, with an average of 8.7 days exceeding 35 °C, with occasional typhoons. The most pleasant seasons are spring, although changeable and often rainy, and autumn, which is generally sunny and dry.

We collected the data from a central urban district (Xuhui) of Shanghai, which has a land area of 54.76 km^2 and a population of 1.13 million according to the 2013 census. We selected this district because it has had a relatively stable demographic structure over the past few decades and because it has a well-established death registry and a renowned meteorological station (Xujiahui Station).

We obtained daily CVD deaths between January 1, 1981, and December 31, 2012, from the Xuhui's Center for Disease Control and Prevention. According to the regulations of Chinese governments, all of the related institutions are mandated to provide death data under the detailed quality assurance and quality control programs. Death certificates were completed at the time of death either by community doctors for deaths at home or by hospital doctors for deaths at hospitals or in ambulance cars. The causes of CVD deaths were classified according to the International Classification of Diseases 9th Revision (ICD-9 codes: 390-459) before August 2004 and according to the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) after August 2004 (ICD-10 codes: I00-I99).

Daily meteorological data, including the daily mean temperature, daily maximum temperature, daily minimum temperature, and relative humidity during the study period, were collected from Xujiahui Station under the Shanghai Meteorological Bureau.

2.2. Statistical analysis

The time-series approach has been broadly applied in environmental epidemiology to evaluate the association between short-term environmental exposure and daily aggregate health outcomes (Chen et al., 2014; Peng et al., 2006). Specifically, we used generalized additive quasi-Poisson models to estimate the association between daily mean temperature and CVD mortality. As previous studies have shown that the short-term association between ambient temperature and CVD mortality is generally non-linear and lagged (Chen et al., 2013; Ma et al., 2014), we therefore applied the distributed lag non-linear models (DLNM) to investigate the delayed and non-linear effects of temperatures on CVD mortality simultaneously (Armstrong, 2006; Gasparrini et al., 2010).

We used a natural cubic spline with 5 degrees of freedom (*df*) to adjust for the nonlinear effects of the mean temperature in the 'cross-basis' matrix of DLNM (Gasparrini, 2011). We also incorporated the following covariates in the GAM to control for their potential confounding effects: (1) a smooth function of natural cubic splines with 7 df per year for calendar time to exclude unmeasured long-term and seasonal trends in CVD mortality (Peng et al., 2006); (2) a cross-basis function for relative humidity with a natural cubic spline of 3 *df* and a lag of 3 days to control for the potential non-linear lagged effects of humidity (Chen et al., 2013, 2014; Ma et al., 2014). A maximum lag of 3 days was selected because previous air pollution studies commonly controlled for humidity for 0 to 3 lag days (Dominici et al., 2006); (3) an indicator variable for "day of the week" to account for the periodic variation of CVD mortality within one week; (4) a binary variable for holidays; and (5) an offset term of annual population size in this district.

It is difficult to select a predefined lag for accurately estimating the effects of temperature. Because a number of previous studies have reported a shorter lag (days) for hot effects and a longer lag (2 to 4 weeks) for cold effects (Bai et al., 2014; Braga et al., 2002; Breitner et al., 2014; Tian et al., 2012), we decided to use a priori a maximum lag of 14 days (2 weeks) in the basic models. We also plotted the lag pattern for the association between temperature and CVD mortality using a broad range of 28 lag days (4 weeks) and separately estimated its effects at different lags in this range. This wide range of lags allowed for the exploration of the potential "harvesting effects" (mortality displacement) of temperatures. We used a cubic spline with 5 *df* for all of the lags in the "cross-basis" matrix (Gasparrini, 2011). We also used the same smooth functions to model all of the lags.

After the basic model was built, we plotted the associations between temperature and CVD mortality. To quantify the effects of temperature on CVD mortality, we calculated the relative risks (RRs) at a temperature cutoff (percentile) compared with the reference temperature. The reference temperature was chosen by visual inspection according to the temperature–mortality curve (Xu et al., 2014). We then defined the extremely low (1st percentile of temperature distribution),