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Association of cold temperature and mortality and effect modification in the subtropical plateau monsoon climate of Yuxi, China

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ABSTRACT

Background: Consistent evidence has shown excess mortality associated with cold temperature, but some important details of the cold–mortality association (e.g. slope and threshold) have not been adequately investigated and few studies focused on the cold effect in high-altitude areas of developing countries. We attempted to quantify the cold effect on mortality, identify the details, and evaluate effect modification in the distinct subtropical plateau monsoon climate of Yuxi, a high plateau region in southwest China.
Methods: From daily mortality and meteorological data during 2009–2014, we used a quasi-Poisson model combined with a “natural cubic spline–natural cubic spline” distributed lag non-linear model to estimate the temperature–mortality relationship and then a simpler “hockey-stick” model to investigate the cold effect and details.
Results: Cold temperature was associated with increased mortality, and the relative risk of cold effect (1st relative to 10th temperature percentile) on non-accidental, cardiovascular, and respiratory mortality for lag 0–21 days was 1.40 (95% confidence interval: 1.19–1.66), 1.61 (1.28–2.02), and 1.13 (0.78–1.64), respectively. A 1 °C decrease below a cold threshold of 9.1 °C (8th percentile) for lags 0–21 was associated with a 7.35% (3.75–11.09%) increase in non-accidental mortality. The cold–mortality association was not significantly affected by cause-specific mortality, gender, age, marital status, ethnicity, occupation, or previous history of hypertension.
Conclusions: There is an adverse impact of cold on mortality in Yuxi, China, and a temperature of 9.1 °C is an important cut-off for cold-related mortality for residents.

1. Introduction

Cold-related mortality is an important public health problem throughout the globe (Analitis et al., 2008; Fowler et al., 2015; Gasparrini et al., 2015; Lin et al., 2013). The association of ambient temperature with mortality has been consistently found to be U-, V-, W-, J-, or inverse J-shaped, with increased mortality at both cold and hot temperatures, and with the shape of the association varying greatly by geographic conditions, climatic zones, and population characteristics (Anderson and Bell, 2009; Gasparrini et al., 2015; Guo et al., 2014; Ma et al., 2014, 2015; McMichael et al., 2008). In Europe, the PHEWE project reported a negative linear association between temperature and mortality for the cold season (October–March) by using daily data from the period 1990–2000, with evidence of an adverse impact of cold on mortality (Analitis et al., 2008). In subtropical climates, the cold effect is more pronounced and durable than the hot effect (Wu et al., 2013; Yi and Chan, 2015). A multi-country study of populations with markedly different characteristics and a wide range of climates also reported most of the temperature-related mortality burden attributable to cold but not heat (Gasparrini et al., 2015).

Although cold temperature is well known to be associated with increased mortality, little is known about some important details of the cold–mortality association (e.g. slope and threshold) (Carder et al., 2005; McMichael et al., 2008). In addition, most previous studies of cold-related mortality were conducted in low-altitude cities, usually with temperate or subtropical climates (Anderson and Bell, 2009; Chung et al., 2015; Gasparrini et al., 2015; Guo et al., 2014; Lin et al., 2013; Ma et al., 2015; Yi and Chan, 2015). Few studies focused on the cold effect on mortality in high-altitude areas of developing countries, with a subtropical plateau

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monsoon climate and thin air (Bai et al., 2014; Ma et al., 2015). The cold–mortality association may vary depending on many factors, such as climate (e.g. temperate, subtropical, tropical, continental, marine, or monsoon climate), geographic features, and population age structure and disease profile. Therefore, details of the association need to be identified for different regions. On the other hand, several epidemiological studies have suggested that the cold–mortality relationship is modified by personal characteristics (e.g. age, gender, race/ethnicity, and occupation) and specific mortality causes (Huang et al., 2015; Medina-Ramon et al., 2006; Qiu et al., 2015; Zanobetti et al., 2013). Identifying factors that confer susceptibility to cold has become an issue of interest and an important step to better protect the vulnerable population.

This study aimed to quantitatively estimate the magnitude of the effect of cold temperature on non-accidental mortality and to identify details of the cold–mortality association in the distinct subtropical plateau monsoon climate of Yuxi, a high plateau region in southwest China. An additional aim was to evaluate the effect modification by several demographic characteristics and mortality causes. A better understanding of how cold affects mortality is of critical importance to local government in dealing with the effect of cold temperature.

2. Materials and methods

2.1. Data collection

Yuxi city is on the western edge of the Yunnan-Guizhou Plateau in southwest China, and has complex geographic features such as plateaus, mountains, hills, valleys, basins, and lakes. Situated in a high-altitude region at about 2000 m, Yuxi has a distinct subtropical plateau monsoon climate with low atmospheric pressure, and dry, thin air, for low seasonal variation in temperature and 4 spring-like seasons year-round. The hottest month of the year is June or July, and the coldest is January or December. In the 2010 national population census, Yuxi had a population of 2,303,511 (1,181,277 males), 202,149 being 65 years of age or older. As an agricultural city, more than 70% people in Yuxi engage in agricultural production. Moreover, Yuxi is a multi-ethnic region and contains about 0.74 million ethnic minority residents, including the Yi, Hani, Dai, Hui, Mongolian, and other ethnic minorities.

Mortality data on every death in Yuxi for the period from January 1, 2009 to December 31, 2014 were obtained from the Yuxi Center for Disease Control and Prevention, including information on date of death, gender, age (age at death), ethnicity, marital status, occupation, and cause of death. Personal history of hypertension was abstracted from the Medical Certificate of Death. We also downloaded daily meteorological data on minimum, maximum, and mean temperature and relative humidity for 2009–2014 from the China Meteorological Data Sharing System.

According to the *Tenth Revision of the International Classification of Diseases*, we classified all deaths as non-accidental deaths (A00–R99). Individual death record data were collapsed into a series of daily counts for the total group, as well as the subgroups specific cause of death (cardiovascular disease [I00–I99] or respiratory disease [J00–J99]), gender (male or female), age (<75 or ≥ 75 years old), marital status (married or unmarried), ethnicity (Han nationality or ethnic minorities), occupation (farmer or non-farmer), and previous history of hypertension (yes or no).

2.2. Statistical analysis

The daily death counts followed a Poisson distribution, and we assumed that the total variance was proportional to the number of daily counts, estimating the overdispersion constant by quasi-likelihood (Goldberg et al., 2011). The temperature–mortality association is inherently non-linear, and mortality risk depends on exposure to the current day's temperature and also on the exposure experienced during the previous several days, even weeks (so-called lag effects) (Gasparrini et al., 2015). Recently, the family of distributed lag non-linear models (DLNMs), which can simultaneously represent non-linear and lag effects, has been proposed to assess the exposure–response association; the methodology is based on the definition of a "cross-basis", a bi-dimensional space of functions describing the associations along the spaces of predictor and lag dimensions, and each dimension function can be independently chosen among a set of possible options such as piecewise functions, polynomials, or splines (Gasparrini and Armstrong, 2013; Gasparrini et al., 2010). In the present study, we used a two-stage approach to analyze the data.

In the first stage, we used a quasi-Poisson generalized linear regression model combined with a "natural cubic spline–natural cubic spline" DLNM to estimate the temperature–mortality relationship (Guo et al., 2011). We incorporated temperature as a "cross-basis" function in the model to flexibly account for the potential lag and non-linear effects of temperature on mortality (Gasparrini and Armstrong, 2013; Gasparrini et al., 2010). The daily mean temperature that may best reflect daily thermal stress was chosen as the exposure index, providing the best fit in our preliminary exploratory analyses of total non-accidental mortality. We used a natural cubic spline with 7 degrees of freedom (*df*) per year for time to control for the seasonal patterns and long-term trends. The moving average of lag 0–1 days for relative humidity (RH_{0-1}), air pressure (AP_{0-1}), and wind speed (WS_{0-1}) were controlled by the use of a natural cubic spline with 3 *df* at equally spaced quantiles (Bhaskaran et al., 2013; Gasparrini et al., 2010). We also controlled for day of the week (*DOW*) and public holidays (e.g. the Spring Festival, Mid-Autumn Festival, and National Day) as categorical variables in the core model. Therefore, the regression model in each group could be described as follows Eq. (1):

$$\begin{aligned} Y_t = Poisson(\mu_t) Log\ (\mu_t) &= \alpha + \beta\ Temp_{t,l} + S(Time_t, 6 \times 7) \\ &+ S(RH_{0-1\ t}, 3) + S(AP_{0-1\ t}, 3) \\ &+ S(WS_{0-1\ t}, 3) + \lambda\ DOW_t + \gamma Holiday_t \\ &= \alpha + \beta\ Temp_{t,l} + COVs \end{aligned} \tag{1}$$

where Y_t is the number of observed deaths on day t; α is the intercept; $Temp_{t,\,l}$ is a matrix obtained by applying the DLNM to model the non-linear and distributed lag effects of mean temperature over a lag of 0–l days, with the vector of coefficients of β; *S(.)* is the natural cubic spline; and *COVs* are all potential confounders in the model. Although hot effect is limited within the first several days, cold effect on mortality may last for weeks (Guo et al., 2011), so we used a maximum lag of 21 days because our analysis found the effect of temperature on mortality changed little for lags >3 weeks, which is consistent with previous studies (Gasparrini and Armstrong, 2013; Guo et al., 2014; Ma et al., 2015). We used the Akaike information criterion (AIC) for quasi-Poisson models to choose the *df* for mean temperature and lag (Gasparrini, 2014). The natural cubic splines with 5 *df* for temperature (knots at equally spaced values) and 4 *df* for lag space (knots at equally spaced log-values) were finally used in the core model by the lowest AIC value.

We plotted the relative risks (RRs) against temperature and lag to show the entire temperature–mortality association in a 3-D graph, then reduced the association to the overall cumulative association, summing the lag-specific contributions (Gasparrini and Armstrong, 2013). To quantitatively estimate the overall effect of relative temperature changes, we calculated the RRs with their 95% confidence intervals (CIs) for mortality for lag 0–3, 0–14, and