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# Temperature and daily mortality in Suzhou, China: A time series analysis

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## HIGHLIGHTS

- Current evidence on temperature and mortality is limited in China.
- Both extreme cold and hot temperatures increased the death risk in Suzhou.
- Cold effects persisted for 10 days, while heat effects were more immediate.

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## ABSTRACT

The evidence concerning the association between ambient temperature and mortality is limited in developing countries, especially in China. We assessed the effects of temperature on daily mortality between 2005 and 2008 in Suzhou, China. A Poisson regression model combined with a distributed-lag nonlinear model was used to examine the association between temperature and daily mortality. We investigated effect modification by individual characteristics, including gender, age and educational attainment. We found significant non-linear effects of temperature on total and cardiovascular mortality. Heat effects were immediate and lasted for 1–2 days, whereas cold effects persisted for 10 days. The relative risk of total morality associated with extreme cold temperature (1st percentile of temperature, −0.3 °C) over lags 0–14 days was 1.75 [95% confidence interval (CI): 1.43, 2.14)], compared with the minimum mortality temperature (26 °C). The relative risk associated with extremely hot temperature (99th percentile of temperature, 32.6 °C) over lags 0–3 days was 1.43 (95% CI: 1.31, 1.56). We did not observe significant modifying effect by gender, age or educational level. This study showed that exposure to both hot and cold temperatures was associated with increased mortality in Suzhou. Our findings may have implications for developing intervention strategies for extreme cold and hot temperatures.


## 1. Introduction

In recent years, the impact of climate change has led to an increased frequency and intensity of extreme temperatures. The International Panel on Climate Change projects that global climate change through changing weather patterns will result in an increased risk of temperature-related mortality around the world (IPCC, 2007). Many studies have examined the association of low and high temperatures with daily mortality (Basu and Samet, 2002; Braga et al., 2002; Guo et al., 2011; Stafoggia et al., 2008). For example, in the United States, elevated ambient temperature and heat-waves were associated with excess deaths (Barnett, 2007; Davis et al., 2003; Sheridan et al., 2009). In Europe, low temperature was associated with increased mortality from all causes, ischemic heart disease, cerebrovascular disease, respiratory disease and cardiovascular disease (Hajat and Haines, 2002; Carder et al., 2005).

Current knowledge of the health effects of temperature on mortality is mainly from developed countries, and few studies have been conducted in developing countries. The associations between temperature and mortality vary greatly by climate, geographic regions and populations (Curriero et al., 2002; El-Zein et al., 2004; Revich and Shaposhnikov, 2008; Rocklöv and Forsberg, 2008; Basu, 2009; Yu et al., 2011a, 2012). It is therefore necessary to assess the impacts of temperature in various regions. McMichael et al. reported that developing countries are more sensitive to climate change, as they have poor public health infrastructure and more vulnerable populations (McMichael et al., 2008). China is the largest developing country, yet only a few studies on the temperature–mortality relationship have been conducted in

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Beijing (Liu et al., 2011), Shanghai (Kan et al., 2003) and Tianjin (Guo et al., 2011).

In this study, we investigated the effects of ambient temperature on daily mortality in Suzhou, China. We also sought to examine effect modification by individual characteristics, including gender, age and educational attainment.

## 2. Materials and methods

### 2.1. Data collection

Suzhou, the economic and cultural center of Jiangsu Province, is located 60 km northwest of Shanghai (latitude 31°17′N and longitude 120°35′E), and has a typical subtropical monsoon climate with an annual average temperature of 16.7 °C in 2008. Our study area was restricted to the urban areas of Suzhou due to inadequate numbers of air pollution monitoring stations in the sub-urban districts.

The Suzhou Center for Disease Control and Prevention provided information for 49,984 deaths from January 1, 2005 to December 31, 2008. The underlying cause of death was classified by the Tenth Revision of the International Classification of Disease (ICD-10). We considered total non-accidental mortality (ICD-10: A00-R99), mortality due to cardiovascular disease (I00–I99) and respiratory disease (J00–J99). We also examined the association between temperature and total mortality stratified by gender (female and male), age (0–64 and ≥65 years) and educational attainment (low: illiterate and primary school; high: middle school and above).

The daily weather conditions (mean temperature and relative humidity) were collected from the Suzhou Meteorological Bureau. There were no missing data for weather data. In order to adjust for the potential confounding effects of air pollution, we collected daily air quality data on particulate matter <10 μm in aerodynamic diameter ($PM_{10}$), sulfur dioxide ($SO_2$), and nitrogen dioxide ($NO_2$); these data were obtained from the Suzhou Environmental Monitoring Centre. These criteria pollutants have been associated with cardiorespiratory mortality (Pope et al., 2002). The daily 24 h-mean concentrations for $PM_{10}$, $SO_2$ and $NO_2$ were averaged from eight fixed-site stations (Zhagangchang, Nanmen, Wuzhongqu, Caixiang, Suzhouxinqu, Suzhougongyeyuanqu, Xiangchengqu, Shangfangshan).

### 2.2. Statistical methods

Mortality risk depends not only on exposure to the current day's temperature, but also on exposure to the temperature of previous days (i.e., lag effect) (Anderson and Bell, 2009). Therefore, the distribution of the temperature effects over days or weeks after exposure is a problem that is often dealt with by establishing distributed-lag models. In addition, the relationship between temperature and mortality has not shown to be linear, but rather J-, V- or U-shaped (Armstrong, 2006; Gasparrini et al., 2010; Martin et al., 2012). Thus, we used a distributed-lag nonlinear model (DLNM) to estimate the non-linear and delayed effects of temperature on daily mortality. The DLNM is developed on the basis of a "cross-basis" function, which allows a simultaneous estimation of the non-linear effect of temperature at each lag and of the non-linear effects across lags. The model can also calculate the cumulative effect of a delayed contribution of temperature on mortality (Gasparrini et al., 2010).

Daily counts of deaths approximately follow a Poisson distribution; we therefore used a Poisson regression model combined with a DLNM to estimate the impact of temperature on mortality (Armstrong, 2006; Gasparrini et al., 2010). We included long-term and seasonal trend of daily mortality using a natural cubic spline of time with 7 degrees of freedom (df) per year (Peng et al., 2006). We examined the non-linear effect of temperature using a natural cubic spline with 5 df and the lagged effect using a natural cubic spline with 5 df (Yang et al., 2012). We controlled for $PM_{10}$, $SO_2$ and $NO_2$ using the polynomial distributed lag model with 3 lag days and 3 df. A natural cubic spline for relative humidity with 3 df was also included in the model (Anderson and Bell, 2009; Stafoggia et al., 2008).

Mean temperature was used as the predictor variable in this analysis, because it is highly correlated with other metrics (minimum, maximum and apparent temperature) and provides more easily interpreted results in a policy context (Hajat and Haines, 2002; Anderson and Bell, 2009; Yu et al., 2010; Yang et al., 2012). We estimated temperature effects over the following lag periods: 0–3, 0–7, 0–21 and 0–28 days. We calculated the relative risk of mortality by comparing the extreme cold (1st percentile of temperature) and extreme hot (99th percentile of temperature) temperatures with the minimum mortality temperature (Curriero et al., 2002).

Analyses by gender, age and educational attainment were conducted for total mortality. We tested the statistical significance of differences between effect estimates of the strata of a potential effect modifier (e.g., the difference between females and males) by calculating the 95% confidence interval (95% CI) as $\left(\widehat{Q}_1\text{-}\widehat{Q}_2\right) \pm 1.96\sqrt{\left(\widehat{SE}_1\right)^2 + \left(\widehat{SE}_2\right)^2}$, where $\widehat{Q}_1$ and $\widehat{Q}_2$ are the estimates for the two categories, and $\widehat{SE}_1$ and $\widehat{SE}_2$ are their respective standard errors (Zeka et al., 2006). Regardless of significance, we considered modification of effect by a factor of two or more to be important and worthy of attention (Zeka et al., 2006).

We conducted several sensitivity analyses to examine the robustness of our findings. First, we examined the effect of extreme temperatures before and after adjustment for air pollution levels. Second, we further examined the additional effects of heat waves and cold spells by including a dummy variable in the regression models. The heat wave was defined as a period of at least 7 consecutive days with daily maximum temperature above 35.0 °C and daily average temperatures above the 97th percentile during the study period; the cold spell was defined as a period of at least 7 consecutive days with daily maximum temperature and daily average temperatures below the 3rd percentile during the study period (Ma et al., 2011).

All statistical tests were two-sided, and values of $p < 0.05$ were considered statistically significant. All of the analyses were performed using R software (version 2.15.1), with its "dlnm" package to create the DLNM.

## 3. Results

### 3.1. Descriptive statistics

During the study period (January 1, 2005–December 31, 2008), there were 49,984 total deaths; 18,530 persons (37.1%) died of cardiovascular

**Table 1**
Descriptive statistics of daily mortality, weather conditions and air pollution in Suzhou, China (2005–2008).

| | Mean | Std | Min | Percentile | | | | | Max |
|---|---|---|---|---|---|---|---|---|---|
| | | | | P1 | P10 | P50 | P90 | P99 | |
| Morality | | | | | | | | | |
| Total non-accidental deaths | 34.2 | 8.8 | 13.0 | 18.0 | 24.0 | 33.0 | 46.0 | 59.0 | 75.0 |
| Cardiovascular deaths | 12.7 | 5.0 | 2.0 | 4.0 | 7.0 | 12.0 | 19.0 | 28.0 | 36.0 |
| Respiratory deaths | 4.6 | 2.6 | 0 | 0 | 2 | 4 | 8 | 12 | 18 |
| Weather conditions | | | | | | | | | |
| Mean temperature (°C) | 17.2 | 9.2 | −2.8 | −0.3 | 4.1 | 18.3 | 29.1 | 32.6 | 33.8 |
| Relative humidity (%) | 77.0 | 12.4 | 34.0 | 46.0 | 60.0 | 78.0 | 93.0 | 100.0 | 100.0 |
| Air pollution | | | | | | | | | |
| $PM_{10}$ (μg/m$^3$) | 89.8 | 48.3 | 10.0 | 22.0 | 40.0 | 80.0 | 147.0 | 248.0 | 428.0 |
| $SO_2$ (μg/m$^3$) | 44.7 | 20.7 | 4.0 | 13.0 | 23.0 | 41.0 | 71.0 | 114.0 | 174.0 |
| $NO_2$ (μg/m$^3$) | 49.1 | 20.7 | 8.0 | 20.0 | 28.0 | 45.0 | 75.0 | 123.0 | 176.0 |

disease and 6760 (13.5%) of respiratory disease (Table 1). An average of 34, 13, and 5 cases per day occurred for non-accidental, cardiovascular and respiratory mortality, respectively. The average daily temperature and relative humidity were 17.2 °C (range: −2.8 °C, 33.8 °C) and 77.0% (range: 34.0%, 100.0%), respectively. The 1st, 10th, 90th and 99th percentiles of temperature were −0.3 °C, 4.1 °C, 29.1 °C and 32.6 °C, respectively. The mean concentrations of daily $PM_{10}$, $SO_2$ and $NO_2$ were 89.8 μg/m$^3$, 44.7 μg/m$^3$ and 49.1 μg/m$^3$, respectively, which were well above the international health-based standards.

Table 2 shows the Pearson correlation coefficients of weather conditions and air pollution. Mean temperature was moderately correlated with air pollutants and relative humidity. $PM_{10}$, $SO_2$ and $NO_2$ were strongly correlated with each other.

### 3.2. Regression results

Fig. 1 shows the estimated cumulative effects of mean temperature on total, cardiovascular and respiratory mortality at lag 0–14 days. The relationships of temperature with total and cardiovascular mortality were non-linear, with higher relative risks at cold and hot temperatures. The temperature with the minimum mortality risk was 26 °C. We did not observe a clear pattern for the relationship between temperature and respiratory mortality.

Fig. 2 shows the estimated risks of daily mortality associated with extreme cold (−0.3 °C) and extreme hot temperatures (32.6 °C) at lags of 0–14 days, compared with the minimum mortality temperature (26 °C). Significant effects of extreme cold temperature were observed after 1–2 days and persisted for 8–10 days, whereas the most significant and strongest effects of extreme hot temperature were observed on the current day and lasted for only 1–2 days. We did not find evidence of mortality displacement due to effects of high temperatures on total and cardiovascular mortality.

We calculated the overall effects of temperature on total, cardiovascular and respiratory mortality for lags of 0–3, 0–7, 0–14, 0–21 and 0–28 days (Table 3). Compared with the minimum mortality temperature (26 °C), the relative risks associated with extreme cold temperature (1st percentile of temperature, −0.3 °C) over lags 0–14 days were 1.75 (95% CI: 1.43, 2.14) for total mortality, 1.88 (95% CI: 1.36, 2.61) for cardiovascular morality, and 0.76 (95% CI: 0.41, 1.40) for respiratory mortality, respectively. The relative risks associated with extreme hot temperature (99th percentile of temperature, 32.6 °C) over lags 0–3 days were 1.43 (95% CI: 1.31, 1.56) for total mortality, 1.67 (95% CI: 1.45, 1.92) for cardiovascular mortality, and 1.41 (95% CI: 1.10, 1.81) for respiratory mortality.

The relative risk of total mortality associated with temperature varied by gender, age and educational level (Table 4). The estimated effects of temperature on mortality were significant among both females and males, and the difference across genders was statistically insignificant. We observed significant effects of temperature only among residents ≥65 years of age and residents with low educational attainment; however, the between-age and between-education differences were statistically insignificant.

The sensitivity analyses showed that the effect of extreme temperature did not change much before and after adjustment for air pollution levels (see Table S1 in the online supplement). Also, the additional relative risk of total morality associated with heat wave and cold spell were 1.07 (95%CI: 0.96–1.19) and 1.04 (95%CI: 0.90–1.21). These insignificant estimates suggest that our main effect estimates of extreme temperature were robust against additional effect of heat wave and cold spell.

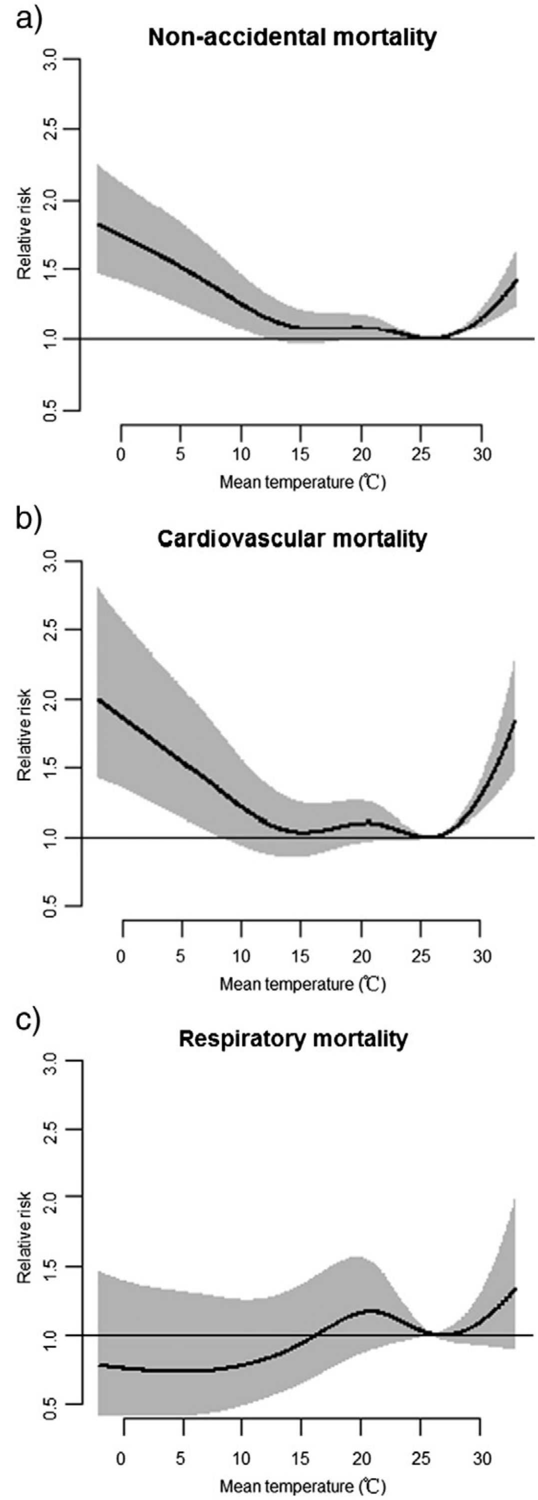


**Fig. 1.** The estimated relative risks of mean temperature (°C) over lags 0–14 days on total non-accidental, cardiovascular, and respiratory mortality. The black lines are the mean relative risks and the gray areas are the 95% CIs of risk estimates.

**Table 2**
Pearson correlation coefficients of weather conditions and air pollution in Suzhou, China (2005 to 2008)*.

| | $PM_{10}$ | $SO_2$ | $NO_2$ | Humidity |
|---|---|---|---|---|
| Mean temperature | −0.12 | −0.32 | −0.34 | 0.08 |
| $PM_{10}$ | | 0.48 | 0.55 | −0.24 |
| $SO_2$ | | | 0.53 | −0.27 |
| $NO_2$ | | | | −0.11 |

* $p < 0.05$ for all correlation coefficients.

## 4. Discussion

In this study, we examined the effects of temperature on cause-specific mortality in Suzhou, China from 2005 to 2008. We found

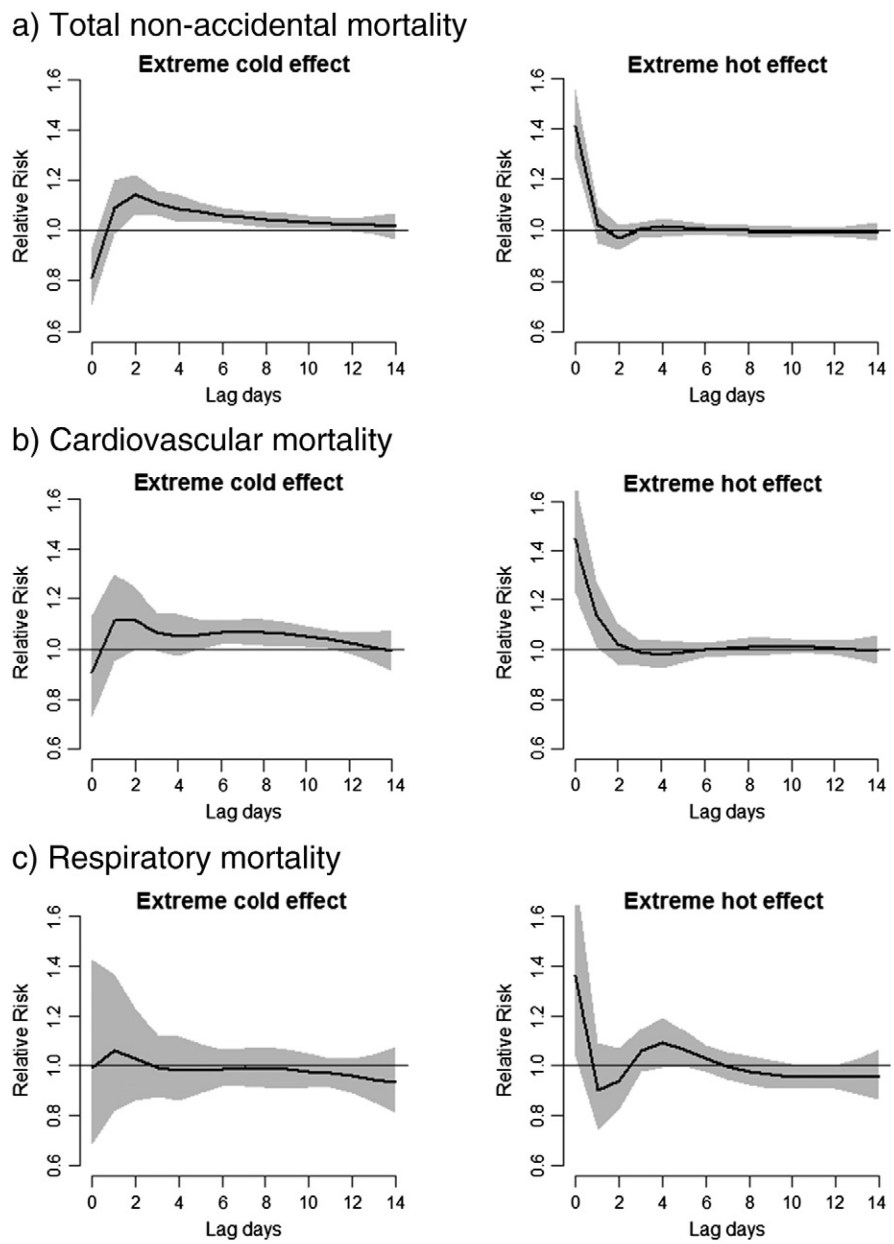


**Fig. 2.** The estimated relative risks of extreme cold and extreme hot temperatures over lags 0–14 days on total non-accidental, cardiovascular, and respiratory mortality, compared with the minimum mortality temperature. The black lines are the mean relative risks and the gray areas are the 95% CIs of risk estimates. [a]Extreme cold temperature: 1st percentile of temperature, −0.3 °C; extreme hot temperature: 99th percentile of temperature, 32.6 °C; minimum mortality temperature: 26 °C.

significant impacts of hot and cold temperatures on mortality. Hot temperatures had a short-term effect, while the effect of cold temperatures appeared after 1–2 days and lasted for 8–10 days. Similar lag structures with characteristics of long duration for cold effects and short duration for heat effects were observed in Beijing (Tian et al., 2012), Tianjin (Guo et al., 2011), Brisbane (Yu et al., 2011b), and Montreal (Goldberg et al., 2011).

Many studies have shown that the magnitude of temperature effects varies greatly by climate, geography and population (Curriero et al., 2002; El-Zein et al., 2004; Revich and Shaposhnikov, 2008; Rocklöv and Forsberg, 2008; Basu, 2009; Yu et al., 2011a, 2012). Notably, we found a significant heat effect associated with a 43% (31%–56%) increase in total mortality risk when comparing the 99th percentile of temperature (32.6 °C) to the threshold temperature (26 °C). An analysis in Beijing reported a similar heat effect with a 38% (20%–60%) increase in total mortality for the 99th percentile of temperature (30.5 °C) relative to the 90th percentile of temperature (27.0 °C) (Tian et al., 2012). However, our results were higher than those from the study in Chiang Mai city, indicating that heat-related mortality risk increased by 18% (9%–27%) when comparing the 99th percentile of temperature (31.7 °C) to the 75th percentile of temperature (28 °C) (Guo et al., 2012). Consistent with a study in Thailand (Guo et al., 2012), we did not observe significant cold effects of temperature on respiratory mortality. The relatively small number of deaths due to respiratory diseases may have limited our ability to detect a tenuous temperature association.

Substantive evidence has shown a delay between changes in daily temperature and changes in mortality, though the lengths of the lag periods are not consistent. Previous studies usually estimated the effects for a single lag (Curriero et al., 2002; Bell et al., 2008), and some studies chose a lag period and assessed a cumulative effect (Braga et al., 2002; Hajat et al., 2005). To date, there is lack of a criterion for selecting an optimal lag. Exploring the lag distribution of effects may provide information for selecting an appropriate time frame when assessing temperature effects. Guo et al. stated that the use of short lags might

**Table 3**
Relative risk of extreme cold and extreme hot temperatures on daily mortality, compared with the minimum mortality temperature[a].

| | Lag | Total morality | Cardiovascular mortality | Respiratory mortality |
|---|---|---|---|---|
| Extreme cold | 0–3 | 1.34 (1.17, 1.55)* | 1.44 (1.15, 1.81)* | 1.08 (0.73, 1.58) |
| | 0–7 | 1.58 (1.34, 1.86)* | 1.80 (1.39, 2.35)* | 0.98 (0.61, 1.55) |
| | 0–14 | 1.75 (1.43, 2.14)* | 1.88 (1.36, 2.61)* | 0.76 (0.41, 1.40) |
| | 0–21 | 2.01 (1.57, 2.58)* | 2.38 (1.59, 3.55)* | 2.20 (1.01, 4.79)* |
| | 0–28 | 2.06 (1.53, 2.78)* | 2.67 (1.64, 4.33)* | 2.24 (0.85, 5.89) |
| Extreme hot | 0–3 | 1.43 (1.31, 1.56)* | 1.67 (1.45, 1.92)* | 1.41 (1.10, 1.81)* |
| | 0–7 | 1.49 (1.34, 1.66)* | 1.82 (1.53, 2.16)* | 1.40 (1.03, 1.90)* |
| | 0–14 | 1.40 (1.22, 1.57)* | 1.75 (1.42, 2.16)* | 1.30 (0.89, 1.88) |
| | 0–21 | 1.33 (1.14, 1.55)* | 1.60 (1.25, 2.06)* | 1.24 (0.78, 1.96) |
| | 0–28 | 1.40 (1.17, 1.68)* | 1.62 (1.21, 2.17)* | 1.47 (0.84, 2.59) |

[a] Extreme cold temperature: 1st percentile of temperature, −0.3 °C; extreme hot temperature: 99th percentile of temperature, 32.6 °C; minimum mortality temperature: 26 °C; air pollution levels were adjusted.
* $p < 0.05$.

underestimate cold effects and overestimate hot effects (Guo et al., 2011). In the present study, we chose a lag of 0–14 days because the cold effects would occur until 15 days later if the lag were defined at 0–21 and 0–28 days (data not shown), which would have been unreasonable in spite of the existence of cold effects.

When analyzing the effect of temperature on mortality by cause of death, effect estimates were markedly higher for cardiovascular deaths than for total and respiratory deaths. Since cardiovascular disease was the leading cause of death in Suzhou, our findings may have an important significance from a public health point of view.

The temperature–mortality relationship and the vulnerability to temperature effects may vary by population and region. We did not observe significant modifying effect by gender, age or educational level. Our gender-specific results were consistent with previous studies in Shanghai (Ma et al., 2012) and California (Basu and Ostro, 2008) showing no significant modifying effect of gender. Some studies have found that the elderly were at higher risk of mortality due to cold (Son et al., 2011; Ma et al., 2012) or hot temperatures (Bell et al., 2008; Son et al., 2011, 2012; Ma et al., 2012). Our findings confirmed the vulnerability of the elderly, although the between-age differences of the two groups were insignificant. We found some evidence that the Suzhou residents with lower educational levels were particularly vulnerable to temperature-related mortality. Education may be an indicator of socioeconomic status, which could be related to poor baseline status, limited access to health care and housing conditions. Previous studies have also reported that residents with no or less education were at higher risk of temperature-related mortality (O'Neill et al., 2003; Son et al., 2011, 2012). However, we found no significant modifying effect of education, which was consistent with previous studies in other cities (Basu and Ostro, 2008; Yu et al., 2010; Ma et al., 2012).

**Table 4**
Gender, age, and education-specific effects of extreme cold and extreme hot temperatures on total non-accidental mortality, compared with the minimum mortality temperature[a].

| | Extreme cold temperature | Extreme hot temperature |
|---|---|---|
| Gender | | |
| Female | 1.74 (1.32, 2.29)* | 1.39 (1.17, 1.64)* |
| Male | 1.63 (1.26, 2.10)* | 1.33 (1.14, 1.56)* |
| Age | | |
| 0–64 | 1.34 (0.90, 1.99) | 1.29 (0.99, 1.64) |
| ≥65 | 1.80 (1.45, 2.24)* | 1.38 (1.21, 1.58)* |
| Educational attainment | | |
| Low | 1.75 (1.40, 2.18)* | 1.39 (1.21, 1.60)* |
| high | 1.37 (0.89, 2.11) | 1.27 (0.97, 1.66) |

[a] Extreme cold temperature: 1st percentile of temperature, −0.3 °C; extreme hot temperature: 99th percentile of temperature, 32.6 °C; minimum mortality temperature: 26 °C; air pollution levels were adjusted.
* $p < 0.05$.

Some limitations should be mentioned. First, the data were only from one city, so it was difficult to generalize our results to rural areas or to other cities. Second, we did not control for barometric pressure, wind direction, wind speed and ozone, as these data were not available. Some studies found a potential interaction between temperature and ozone (Ren et al., 2008). Further studies need to be conducted to address this issue. Third, instead of individual exposure, we used the exposure data of air pollution from fixed monitoring sites and temperature from only one site; therefore, there might exist some inevitable assessment error.

In summary, our results confirmed that both cold and hot temperatures were associated with increased risk of mortality in Suzhou. These findings may have implications for developing intervention strategies to reduce temperature-related mortality and provide useful information for local government to protect vulnerable subgroups when encountering extreme cold and hot temperatures.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2013.08.011.

## Conflict of interest

The authors declare they have no competing financial interests.

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