Int J Biometeorol (2012) 56:205–207
DOI 10.1007/s00484-011-0406-9

SHORT COMMUNICATION

Modifiers of the temperature–mortality association in Shanghai, China

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Received: 7 August 2010 / Revised: 17 January 2011 / Accepted: 17 January 2011 / Published online: 30 January 2011

Abstract Various factors can modify the health effects of temperature. Prior findings about modifiers are inconsistent, and such studies have been conducted mostly in developed countries. We conducted a time-series analysis to examine the modifying effect of gender, age and education on the association between temperature and daily mortality in Shanghai, China, using 4 years (2001–2004) of daily data. A natural spline model was used to analyze the data. Elderly subjects were found to be more vulnerable to temperature health effects compared with younger people. We observed no significant modifying effect of gender or education level. These findings may provide useful information for local governments seeking to take steps to protect vulnerable sub-populations.

Keywords Temperature · Mortality · Time-series · Modifying effect

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Introduction

Temperature has long been recognized as a physical hazard, and is associated with a wide range of effects on health (Haines and Patz 2004). Global warming and other climate phenomena, such as El Niño, have sparked renewed interest in the weather–health relationship (Haines et al. 2009). The association between temperature and mortality risk has been observed extensively (Basu and Samet 2002).

Recently, interest has focused on possible modifiers of the relationship between temperature and adverse health effects, such as preexisting health status and population demographic characteristics (e.g., gender and age) (Braga et al. 2001; Hajat et al. 2007). It is also hypothesized that the effects of temperature on health are greater in people with lower socioeconomic status (SES) (Gouveia et al. 2003; O'Neill et al. 2003). However, prior findings about the modifying effect of SES remain inconsistent; some studies found evidence of modification (O'Neill et al. 2003), but others not (Gouveia et al. 2003). Moreover, most of these studies were conducted in developed countries, and only a small number of studies have been conducted in China (Huang et al. 2010)—the largest developing country and one of the countries most vulnerable to global climate change. In the current study, we conducted a time-series analysis to examine the modifying effect of gender, age and education on the association between temperature and daily mortality in Shanghai, China.

Methods

We collected daily non-accidental mortality data from 1 January 2001 to 31 December 2004 from Shanghai

Municipal Center of Disease Control and Prevention. We obtained daily average temperature and humidity from Shanghai Meteorological Bureau, and daily air pollution data from Shanghai Environmental Monitoring Center.

We used Poisson multiple regression models with natural spline (ns) smoothers to analyze the daily mortality, temperature, and covariates (including long-term and seasonal trends, day of the week, relative humidity, and air pollutant concentrations). The details of our statistical methods have been reported previously (Kan et al. 2007). Briefly, we first constructed the basic models for daily mortality excluding temperature. Then we used the smoothing function to graphically analyze the relation between temperature and residuals of the basic models. For quantification of temperature effects, we conducted simple linear threshold models that assume a log-linear increase in risk above or below a threshold. We examined the association between temperature and total mortality stratified by age (5–14, 15–24, 25–44, 45–64, and ≥65), gender (female and male) and education level (low: illiterate and primary school; high: middle school and above). 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 percent confidence interval (95% CI) as $(\hat{Q}_1 - \hat{Q}_2) \pm 1.96\sqrt{\left(\hat{SE}_1\right)^2 + \left(\hat{SE}_2\right)^2}$, where $\hat{Q}_1$ and $\hat{Q}_2$ are the estimates for the two categories, and $\hat{SE}_1$ and $\hat{SE}_2$ 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).

Results

From 2001 to 2004 (1,461 days), a total of 173,911 deaths (82,597 females and 91,314 males) were registered in the study population. The mean annual temperature and humidity in 2001–2004 were 17.7°C and 72.9%, reflecting the humid subtropical climate in Shanghai. The mortality risk decreased from the lowest temperature, and increased above a turning point (~18°C), producing a "V" relationship (Fig. 1). The relationship of mortality with temperature seemed fairly linear above and below this turning point.

The percent increase in total mortality associated with temperature varied by gender, age group and education level (Table 1). The estimated effects of temperature on mortality were significant among both females and males, and there was no significant difference between the genders. Deaths under age 5 were too few, and were therefore excluded from our analysis. We observed no significant effect

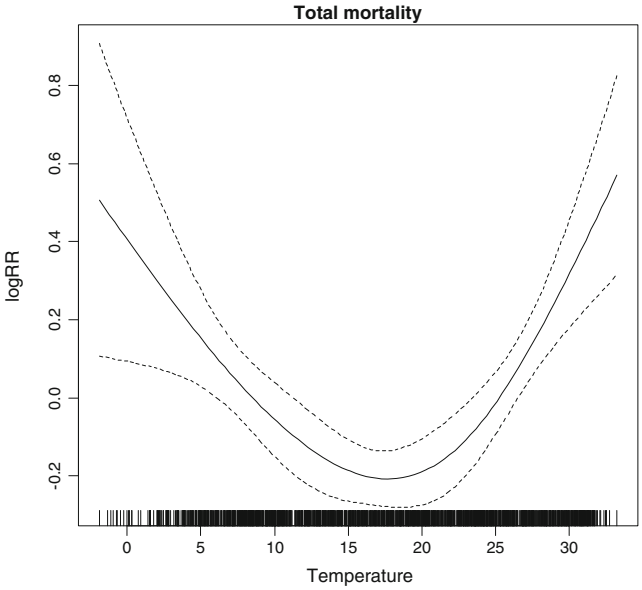

Fig. 1 Smoothing plots of temperature against mortality risk. *x-axis* 2-day average (lags 0–1), *solid lines* estimated mean percentage of change in daily mortality, *dotted lines* twice the standard error

of temperature in residents aged 5–64 years. Among the elderly over 65 years, the estimated effects of temperature on total mortality were significant both below and above the turning point, and were substantially higher than among people aged 5–64. The between-age differences were significant between the 5–44 and ≥65 groups. Stratified by education level, the estimated effects of temperature were significant in both education groups. The estimated effects of temperature were 1–2 times

Table 1 Gender-, age- and education-specific percent increase of total non-accidental mortality of Shanghai residents associated with 1°C increase/decrease in temperature. Values are mean (95%CI)[a]

	≦18°C	>18°C
Gender		
Female	3.61 (1.76,5.46)*	4.37 (2.47,6.27)*
Male	2.86 (1.03,4.70)*	4.67 (2.64,6.71)*
Age		
5-14	0.16 (-1.36,1.68)	0.14 (-1.12,1.40)
15-24	0.20 (-1.20,1.60)	0.21 (-1.64,2.06)
25-44	0.18 (-1.75,2.11)	0.29 (-1.61,2.19)
45-64	1.32 (-0.37,3.00)	0.90 (-0.96,2.76)
>=65	3.33 (1.33,5.34)*	4.38 (2.32,6.44)*
Educational attainment [a]		
Low	3.68 (1.80,5.56)*	4.38 (2.36,6.39)*
High	2.09 (0.35,3.83)*	3.31 (1.35,5.27)*

* $P<0.05$

[a] Low: low educational attainment including illiterate and primary school; high: high educational attainment including middle school and above.

larger among those with low versus high education, but the differences were not significant.

Discussion

Although an association between temperature and daily mortality is well established, the answers to questions regarding potential modifiers remain inconclusive. It is important to understand the characteristics of individuals who are vulnerable to temperature variation. Our results show that age, but not gender or education level, may modify the health effects of temperature in Shanghai. Our findings may provide useful information for local governments seeking to take steps to protect vulnerable sub-populations.

Two age groups, the elderly and the very young, are presumed to be at greater risk of temperature-related effects (Basu and Samet 2002). We observed no significant effects of temperature in residents aged below 65. Like a few other studies (O'Neill et al. 2003; Hajat et al. 2007), we found the elderly to be most vulnerable to the effects of temperature. For the elderly, the ability to regulate body temperature is reduced, and sweating thresholds are generally elevated in comparison with younger people (Foster et al. 1976). In such cases, the cardiorespiratory system cannot adjust well to outside temperature changes, especially for those persons with preexisting diseases.

We found no significant difference in the temperature–mortality association with gender. This finding is consistent with previous studies showing no differences in temperature health effects across genders (O'Neill et al. 2003). Also, our study, with individual-level education as a measure of SES, found no significant modifying effect of educational level, although residents with low educational attainment had slightly higher temperature health effects. More studies are warranted to identify possible modifying factors for temperature health effects.

In summary, our results suggest that age can modify the acute health effects of temperature in Shanghai. The identified susceptible subpopulations signify the need for targeted temperature-mortality prevention efforts.

Acknowledgments H.K. was supported by the National Basic Research Program (973 program) of China (2011CB503802) and Gong-Yi Program of China Ministry of Environmental Protection (200809109). J.T. was supported by the Gong-Yi Program of China Meteorological Administration (GY200706019). W.S. was supported by the 863 Program of China (2007AA06Z409).

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