Environmental Research 164 (2018) 669–675

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Diurnal temperature range in relation to death from stroke in China

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ARTICLE INFO

Keywords:
Ambient temperature
Diurnal temperature range
Stroke
Mortality
Temperature variation

ABSTRACT

Background: Stroke is the second leading cause of death in the world. It has multiple risk factors of which some, such as ambient temperature, are less well documented.
Objective: We aimed to examine the association between diurnal temperature range (DTR) and stroke mortality, and to test the possible effect modification of this association according to gender, age and educational level.
Methods: Daily data on weather and stroke mortality from 16 provincial capital cities in China for the years 2007–2013 were obtained, with a total of 788,783 deaths from stroke. A quasi-Poisson generalized linear regression combined with a distributed lag non-linear model was used to examine the city-specific DTR effect on stroke mortality. The pooled effects of DTR on stroke mortality were then obtained using a meta-analysis, which was based on restricted maximum likelihood estimation.
Results: The DTR impacts were generally limited to a period of eight days, while significant effects during lag 0–8 days were only found in the cities of Beijing, Zhengzhou, Nanjing, Hefei, Chongqing and Changsha. The DTR effects were significantly and negatively associated with latitudes at lag 0–10 days ($r_s = -0.640$, $P = 0.008$). An increase of 1 °C in DTR was associated with pooled estimate of 0.66% (95%CI: 0.28–1.05%), 0.12% (−0.26% to 0.51%) and 0.67% (0.26–1.07%) increases in stroke mortality at lag 0–10 days during the total, hot and cold days, respectively. The impact of DTR was much higher in southern China than in northern China [1.02% (0.62% to 1.43%) versus 0.10% (-0.27% to 0.47%)]. For the individual characteristics, only females, the elderly aged ≥ 65 years, and those with lower educational attainment were vulnerable to DTR.
Conclusions: DTR has considerable effects on risk of mortality from stroke in various cities in China, especially among the elderly, females, those with low educational level, and people living in southern China. The results can inform decisions on developing programs to protect vulnerable subpopulations from adverse impacts of DTR.

1. Introduction

Stroke, also known as cerebrovascular disease, including ischemic and haemorrhagic stroke, was the second leading cause of death worldwide (WHO, 2017). According to the Global Burden of Disease, stroke resulted in 6.45 million deaths in 2013, increasing from 4.58 million deaths in 1990 (Wang et al., 2016). In the past few decades, the risk of death from stroke has decreased in many developed countries but rapidly increased in many developing countries (Feigin et al., 2009). Therefore, quantitative assessment of stroke-related risk factors in developing countries is important to inform policymakers and local governments on managing and controlling these fatal events.

Diurnal temperature range (DTR) is the difference between daily maximum and minimum temperature, and is an important

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https://doi.org/10.1016/j.envres.2018.03.036
Received 4 November 2017; Received in revised form 19 March 2018; Accepted 22 March 2018

meteorological index relating to global climate change and weather variation (Braganza et al., 2004; Hansen et al., 1995). Large variation in daily DTR causes additional environmental stress with adverse impact on human health, particularly for those suffering from pre-existing chronic health problem, such as cardiovascular diseases and respiratory diseases (Bhaskaran et al., 2009; Dilaveris et al., 2006; Lim et al., 2012; Yang et al., 2013). As one of the sensitive diseases to weather variability, there are only few single-city studies examining the association between DTR and stroke mortality (Chen et al., 2007; Yang et al., 2013; Zhang et al., 2017), which may limit their applicability to the country level scale.

In this study, we aimed to investigate the association between DTR and mortality from stroke in 16 Chinese capital cities, and to test whether the effect estimates differed by individual characteristics, such as gender, age and educational attainment.

2. Methods

2.1. Study sites

This study included 16 provincial capital cities in China, including eight southern cities (Shanghai, Nanjing, Hefei, Chengdu, Wuhan, Chongqing, Changsha and Guangzhou) and eight northern cities (Harbin, Changchun, Shenyang, Beijing, Tianjin, Yinchuan, Jinan and Zhengzhou). The Qin Mountains and the Huai River near 33° N latitude were used to classify cities as northern or southern (Fig. 1).

2.2. Data collection

Daily counts of stroke mortality during 2007–2013 were collected from the National Center for Chronic and Noncommunicable Disease Control and Prevention , Chinese Center for Disease Control and Prevention. The stroke mortality was coded following the International Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10): I60–I69. In addition, data were further stratified by gender, age group (0–64 and 65+ years) and educational attainment (primary school or lower and secondary school or higher).

Daily weather data were acquired from the National Meteorological Information Center, China Meteorological Administration, comprising daily maximum, mean and minimum temperatures, relative humidity and atmospheric pressure.

Demographic data for each city were collected from China's 2010 population census, including the percentage of those with percentage of those with high school level or above and percentage of those with aged 65 years old or above. City-level economic data, such as gross regional domestic product (GDP), capital and percentage of green space were collected from the Chinese National Bureau of Statistics (http://www.stats.gov.cn/tjsj/ndsj/). The detailed information of city-level variables was presented in Supplementary Table A1.

2.3. Exposure definition

Diurnal temperature range (DTR) was computed as the difference between the daily maximum temperature and daily minimum temperature in one day.

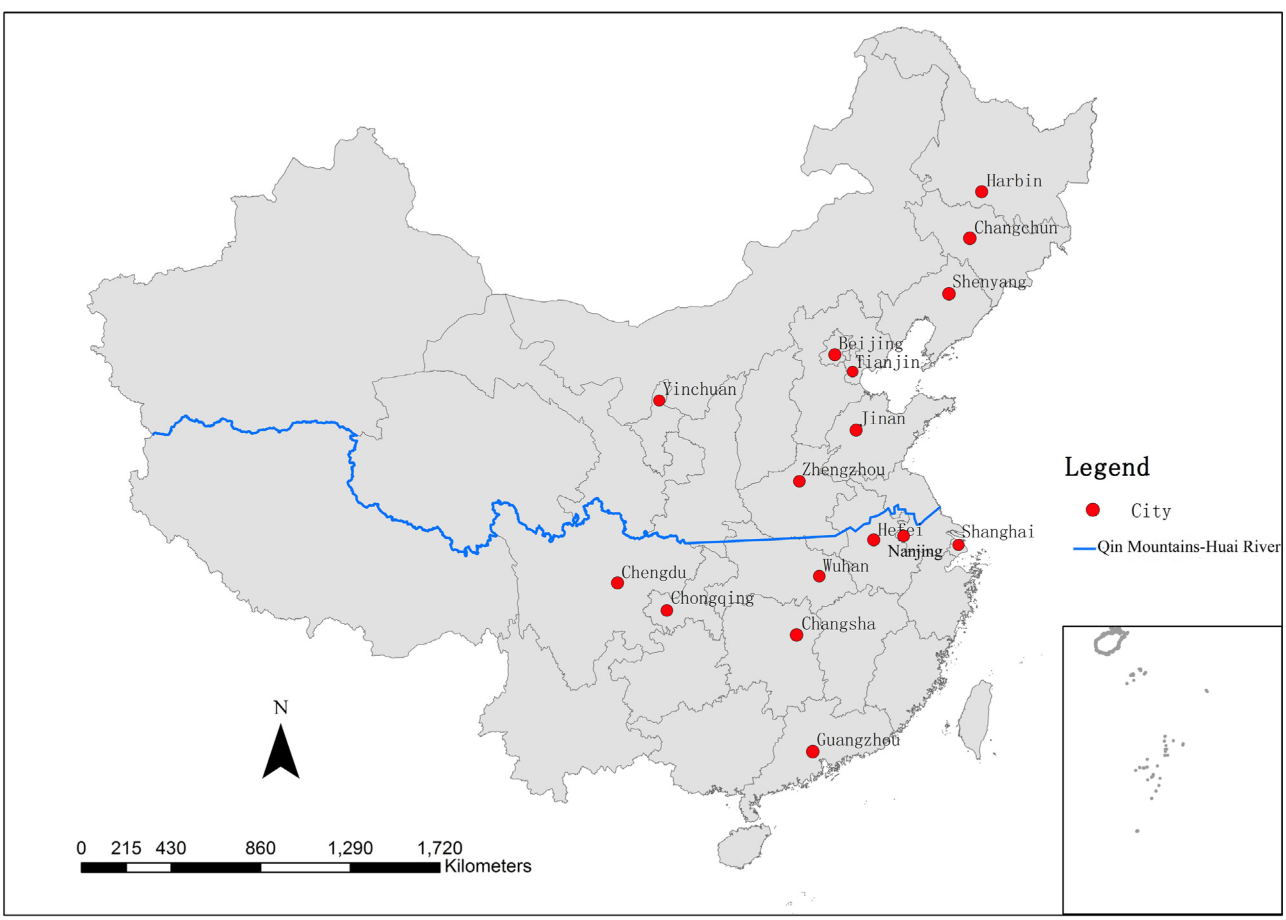

Fig. 1. Locations of the 16 cities in China included in the study. These cities were categorized as northern cities (Harbin, Changchun, Shenyang, Beijing, Tianjin, Yinchuan, Jinan and Zhengzhou) and southern cities (Shanghai, Nanjing, Hefei, Chengdu, Wuhan, Chongqing, Changsha and Guangzhou).

As interactive health effects between DTR and daily mean temperature were found in our previous study (Yang et al., 2013), we constructed two separate DTR variables: DTR on days with cold temperature (DTR_c) and DTR on days with hot temperature (DTR_h). Cold and hot temperatures were defined as daily mean temperature below or above the minimum mortality temperature (MMT), which was derived from the city-specific overall temperature–mortality association (Supplementary Fig. A1). This method is in concordance with a previous study (Vicedo-Cabrera et al., 2016). The formula is as follows:

$$DTR_{h,t} = Tmax_t - Tmin_t, \text{ if } Tmean_t > \text{MMT}, \text{ else } 0 \tag{1}$$

and

$$DTR_{c,t} = Tmax_t - Tmin_t, \text{ if } Tmean_t < \text{MMT}, \text{ else } 0 \tag{2}$$

where $Tmax_t$, $Tmin_t$ and $Tmean_t$ denote the maximum, minimum and mean temperatures on each day t.

2.4. Statistical analysis

We performed a three-stage analysis to estimate the impact of DTR on stroke mortality in 16 Chinese capital cities, adjusted for daily mean temperature, relative humidity, time trends, public holiday and day of the week. Firstly, the influence of the city-specific socioeconomic and weather factors on the spatial distribution of stroke mortality rate was tested. Then, the effect estimate for each city was calculated. Finally, the city-specific estimates were combined in a random-effect meta-analysis.

2.4.1. First-stage analysis

In the first stage analysis, to identify the potential health effect modifiers, the stratified heterogeneity q statistic test was applied to compare the geographical variation of stroke mortality rate versus the socioeconomic and weather variables in 16 Chinese cities (Wang and Hu, 2012; Wang et al., 2010). Before being introduced into the stratified heterogeneity q statistic test, the city-level variables were converted into the dummy variables by using the corresponding median as reference. The detailed introduction on q statistic test could be found elsewhere (Wang and Hu, 2012; Wang et al., 2010).

2.4.2. Second-stage analysis

In the second stage analysis, the distributed lag non-linear model (DLNM) combined with a quasi-Poisson generalized linear regression, allowing for over-dispersion, was used to examine the effect of DTR on death from stroke (Gasparrini et al., 2010). This strategy follows a standard analytical method for fitting the association between time-varying environmental exposure and time-varying health outcomes (Armstrong, 2006; Francesca et al., 2003). The city-specific model is given as:

$$\begin{aligned} Log\,[E\,(Y_t)] &= \alpha + S\,(Time,\,7{*}7) + S\,(Hum_t,\,3) + \gamma Dow_t + \nu Holiday_t \\ &\quad + \beta_1 Tmean_{t,l} + \beta_2 DTR_{t,l} \\ &= COVs + \beta_2 DTR_{t,l} \end{aligned} \tag{3}$$

and

$$Log\,[E\,(Y_t)] = COVs + \beta_3 DTR_{h,t,l} + \beta_4 DTR_{c,t,l} \tag{4}$$

where Y_t is the observed number of deaths from stroke at day t; α is the intercept; S(.) denotes the natural cubic spline function; 7 degrees of freedom (df) per year for the time variable was used to control for the long-term trend and seasonality, in concordance with previous studies (Yang et al., 2015a, 2012, 2015b); 3 df was selected for relative humidity (Hum_t); $Tmean_{t,l}$, $DTR_{t,l}$, $DTR_{h,t,l}$ and $DTR_{c,t,l}$ are matrices produced by DLNM to separately capture distributed lag effects of daily mean temperature and DTR during total days, hot days and cold days over the current day (lag 0) to lag l days, and β_1, β_2, β_3 and β_4 were the corresponding vectors of coefficients. Specifically, a natural cubic spline with 4 df for mean temperature and a linear function for DTR/DTR_h/DTR_c were based on previous studies (Yang et al., 2013), and both natural cubic splines with 4 df for their lags up to 10 days. COVs denotes all the confounding variables in this model.

2.4.3. Third-stage analysis

In the third stage, we used a meta-analysis to provide the combined effects of DTR on stroke mortality from 16 Chinese cities across different lag days, based on restricted maximum likelihood estimation (Viechtbauer, 2005). To test for effect modification in the DTR-mortality association by regional and individual characteristics, the three-stage analysis was repeated separately by region (the North and the South), gender, age group and educational attainment. The between-city heterogeneity and the percentage of variation due to the true differences between cities was tested by Cochran's Q test and the I^2 statistics, respectively (Huedo-Medina et al., 2006).

For identifying the city-level effect modifiers, the mixed effects model meta-regression analysis was used to test the effect modification of the association between DTR and stroke mortality by the city-level factors that were identified to be significantly associated with the spatial variation of stroke mortality rate (Viechtbauer, 2010).

2.4.4. Sensitivity analysis

In order to test the consistency of our main analysis to model specifications, sensitivity analyses were conducted by changing the maximum lag for temperature-mortality association by 14–21 lag days, 4–6 df for relative humidity and 4–10 df for time trend, respectively.

The estimated effect of DTR was expressed as the percentage change and 95% confidence interval (CI) in stroke mortality with a 1 °C increase in DTR. Spearman's correlation test was used to check the association between the effect estimates of DTR and latitudes. All statistical tests were two-tailed and $P < 0.05$ was considered as statistically significant. All statistical analyses were done with R language (version 2.15.3, R Development Core Team 2013), using the “dlnm” package (Gasparrini, 2011) and “metafor” package (Viechtbauer, 2010).

3. Results

Table 1 shows the descriptive data of weather conditions and daily stroke mortality in the 16 Chinese cities included in the analysis. This study included more than 184.6 million urban inhabitants, with daily mean stroke mortality ranging from 3 to 85 in the 16 cities. Average DTR varied from 6.7 °C (range: 0.86–17.2 °C) in Chongqing to 12.1 °C (1.6–23.8 °C) in Yinchuan.

The influence of city-level socioeconomic variables (such as green rate, capital, elderly rate, air condition and GDP) and weather variables (such as annual mean temperature and relative humidity) on the geographical variation of stroke mortality were non-significant (Supplementary Table A2). Therefore, these factors would not be considered as the effect modifier of DTR-stroke mortality association.

Fig. 2 shows the effects of DTR on stroke deaths across lags 0–10 days. Generally, the DTR impacts were limited to eight lag days, while significant effects during lag 0–8 days were only found in Beijing, Zhengzhou, Nanjing, Hefei, Chongqing and Changsha.

Fig. 3 shows the cumulative effects of DTR on stroke deaths for lag 0, lag 0–4 and lag 0–10 days. There was significant between-city heterogeneity in the association between DTR and stroke mortality (Q = 29.92, I^2 = 53.07%, P = 0.012). The DTR effects were significantly and negatively associated with latitude at lag 0–10 days ($r_s = -0.640$, P = 0.008), indicating that populations in southern cities had a greater stroke mortality risk from DTR than the northern cities (Fig. 4).

Table 2 shows the pooled effects of DTR on stroke deaths at lag 0–10 days, for the two regions, stratified by individual characteristics. An increase of 1 °C in DTR was associated with an increase of 0.66% (95%CI: 0.28% to 1.05%), 0.12% (− 0.26% to 0.51%) and 0.67%

Table 1
Descriptive statistics of daily weather conditions and death from stroke in 16 Chinese cities, during 2007–2013.

City	Daily deaths (Mean ± SD)	Study years	Diurnal temperature range (°C)					Daily mean temperature (°C)				
			Min	Median	Max	Mean	SD	Min	Median	Max	Mean	SD
Harbin	42 ± 10	2008–2013	1.6	9.9	25.0	10.2	3.6	− 28.0	8.0	30.6	5.1	15.6
Changchun	11 ± 4	2008–2011	0.9	9.8	19.9	9.9	3.3	− 27.6	8.7	30.4	6.2	14.5
Shenyang	32 ± 7	2010–2013	1.5	10.9	24.4	11.1	4.2	− 24.0	9.2	28.4	7.6	14.0
Beijing	46 ± 10	2007–2013	1.1	9.7	21.9	9.9	3.5	− 12.5	14.9	34.5	13.2	11.3
Tianjin	42 ± 11	2007–2013	1.2	9.7	22.1	9.9	3.5	− 14.1	14.4	32.4	12.9	11.5
Yinchuan	3 ± 2	2008–2013	1.6	12.2	23.8	12.1	3.9	− 17.7	12.1	30.6	10.3	11.8
Jinan	22 ± 7	2011–2013	0.8	8.7	18.0	8.8	3.0	− 9.4	16.3	33.0	14.4	11.0
Zhengzhou	15 ± 6	2011–2013	0.8	9.3	23.1	9.5	4.0	− 4.4	17.4	34.2	15.6	10.6
Shanghai	25 ± 7	2007–2012	0.6	6.2	17.2	6.7	3.2	− 3.4	18.3	35.7	17.4	9.1
Nanjing	23 ± 7	2007–2013	1.0	8.0	22.6	8.3	3.6	− 4.5	17.8	34.6	16.5	9.6
Hefei	21 ± 7	2011–2013	1.2	8.4	21.4	8.5	3.7	− 2.9	18.4	34.4	16.6	9.9
Chengdu	33 ± 9	2008–2013	0.7	7.2	20.6	7.5	3.7	− 0.5	17.4	29.3	16.3	7.5
Wuhan	7 ± 3	2009–2012	0.9	8.3	19.5	8.4	3.9	− 2.9	18.1	35.3	16.8	9.6
Chongqing	85 ± 25	2011–2013	0.8	6.2	18.7	6.7	3.7	3.0	19.1	36.7	19	8.2
Changsha	16 ± 6	2007–2013	0.4	7.2	19.2	7.1	3.5	− 3.0	19.1	35.8	18.4	9.3
Guangzhou	18 ± 6	2011–2013	1.4	8.0	17.6	8.0	3.0	5.1	23.0	30.8	21.6	6.3

Note: SD, standard deviation; Min, minimum; Max, maximum.

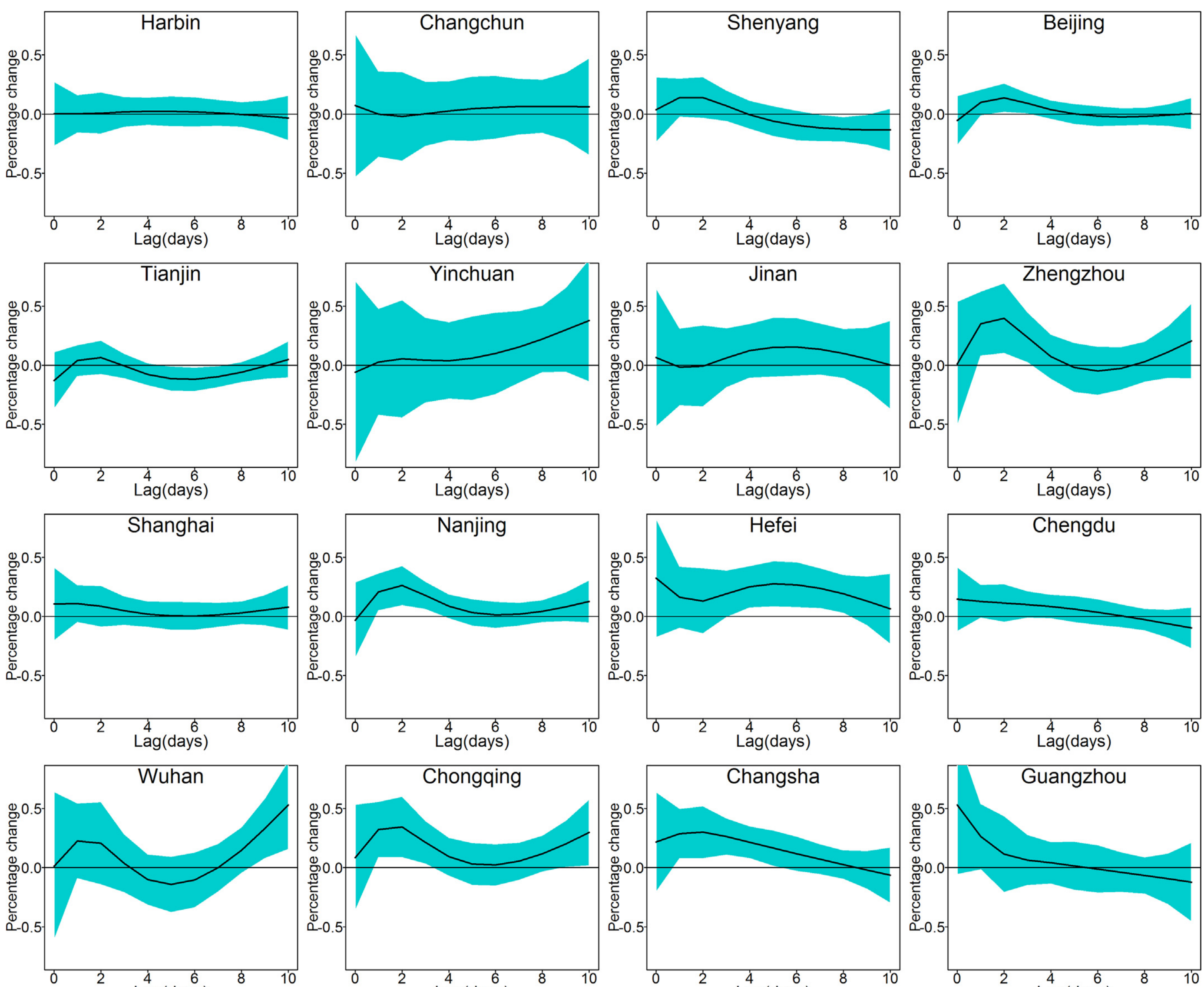

Fig. 2. Percentage change in death from stroke by 1 °C increase in diurnal temperature range along lag 0–10 days in 16 Chinese capital cities.

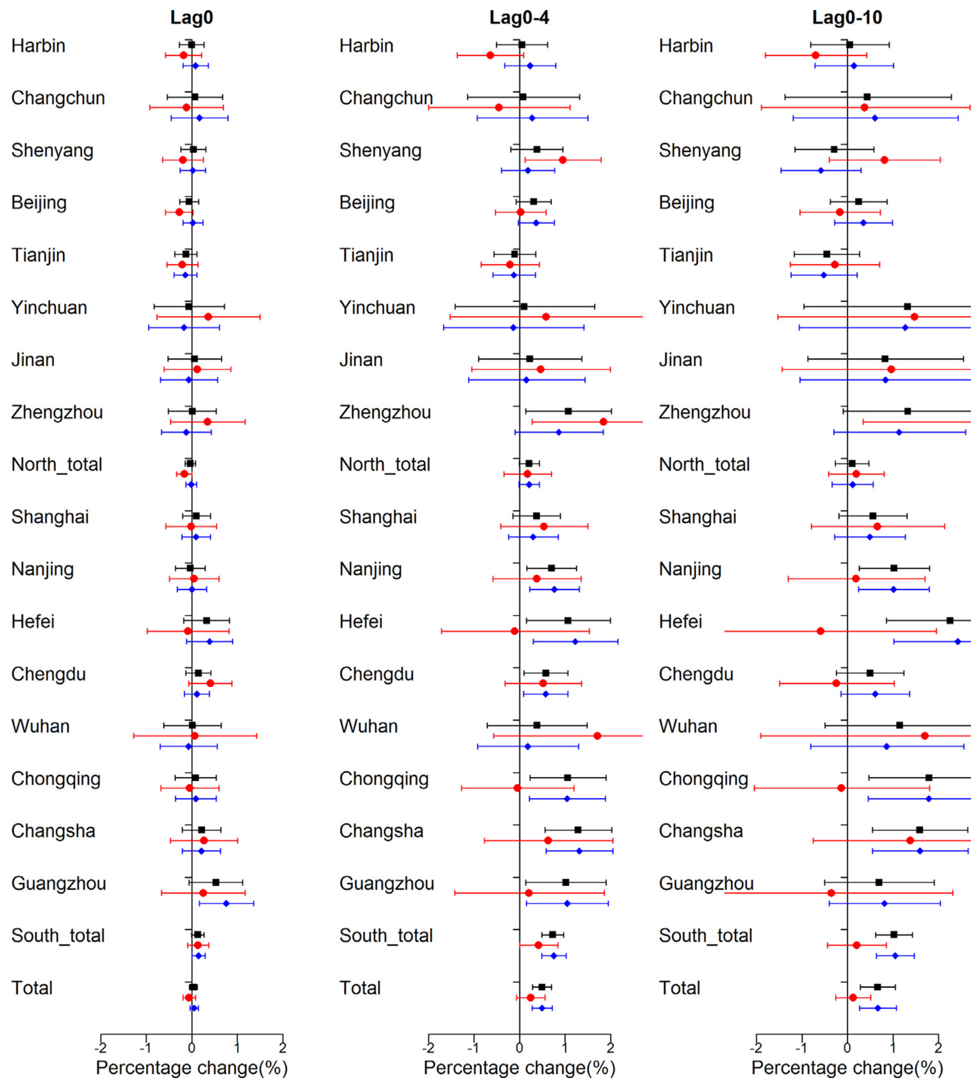

Fig. 3. The cumulative effects of diurnal temperature range on death from stroke along different lag days in 16 Chinese cities. Lines in black, red and blue represent DTR effects in total days, days with hot temperature and days with cold temperature, respectively.

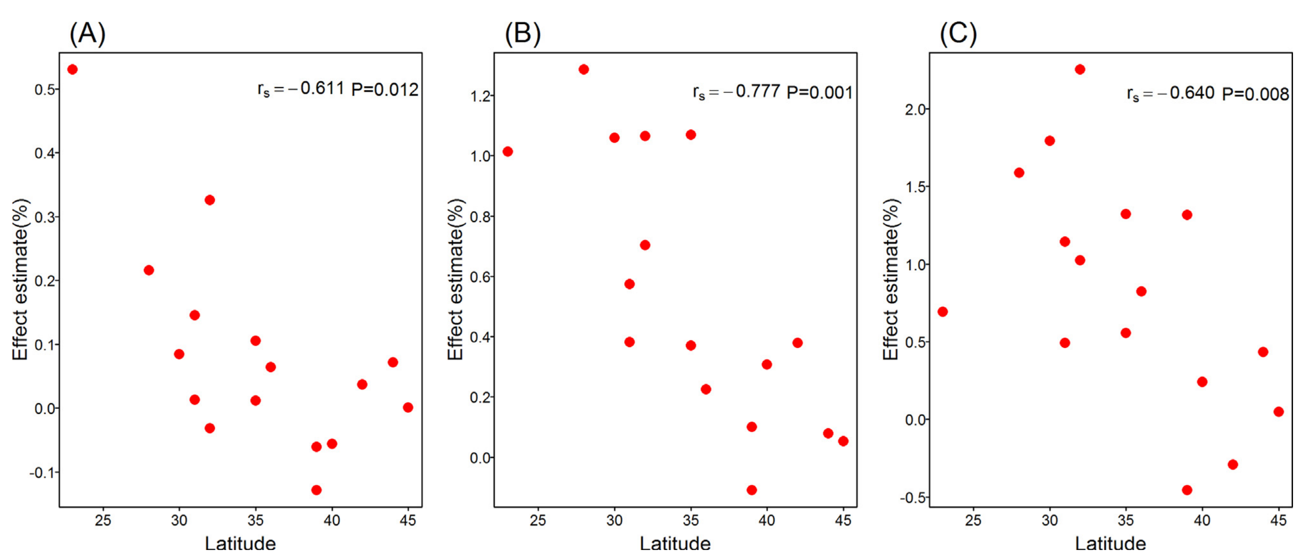

Fig. 4. The correlations between effects of diurnal temperature range on death from stroke in 16 Chinese cities at lag 0 day (A), at lag 0–4 days (B) and at lag 0–10 days (C), respectively. Spearman's correlation coefficients (r_s) and significant test results (*P*-value) were presented.

Table 2
The effect of diurnal temperature range on death from stroke across lag 0–10 days, stratified by gender, age and educational level, for the north and south of China.

Variables	North	South	Total
Total	0.10 (− 0.27, 0.47)	1.02 (0.62, 1.43)	0.66 (0.28, 1.05)
Gender			
Male	0.03 (− 0.40, 0.46)	0.59 (− 0.04, 1.22)	0.29 (− 0.07, 0.65)
Female	0.24 (− 0.36, 0.85)	1.63 (1.13, 2.14)	1.09 (0.52, 1.66)
Age, years			
0–64	− 0.54 (− 1.20, 0.13)	0.61 (− 0.33, 1.56)	0.01 (− 0.63, 0.62)
65+	0.33 (− 0.08, 0.73)	1.07 (0.68, 1.45)	0.81 (0.43, 1.18)
Educational level			
Primary school or lower	0.17 (− 0.29, 0.62)	2.16 (1.40, 2.92)	1.28 (0.63, 1.94)
Secondary or higher	0.01 (− 0.53, 0.53)	− 0.80 (− 1.71, 0.12)	− 0.35 (− 0.90, 0.20)

(0.26% to 1.07%) in stroke deaths at lag 0–10 days for all days, hot days, and cold days, respectively. The impact of DTR was much higher in the South than in the North, with an increase in stroke deaths of 1.02% (0.62–1.43%) and 0.10% (− 0.27% to 0.47%), respectively. For the individual characteristics, only females, the elderly aged 65 years and older, and those with lower educational attainment were more vulnerable to DTR.

Generally, the effect estimates were much greater in the South than the North during cold as well as hot days, while the between-region differences were much smaller during hot days. For the DTR on cold days, adverse and significant effects were observed with increasing DTR in most subgroups except in people aged 0–64 years and those with higher educational level in the South, while non-significant effect estimates were observed in the North (Supplementary Table A3). However, DTR on hot days was only significantly associated with adverse effects among those with lower educational level in the South (Supplementary Table A4).

Sensitivity analyses were conducted to test the robustness of our main findings. The pooled effect estimates relating to DTR were broadly similar when we used 10–21 maximum lag days for the temperature-mortality association, 4–6 df for relative humidity and 4–10 df for time trend, respectively (Supplementary Table A5).

4. Discussion

In the present study, we estimated the impact of DTR on stroke mortality in 16 cities in China and explored the effect modification of risk for stroke mortality by region and individual characteristics. We found that increasing DTR was linked to stroke mortality, with higher DTR impact in the cold season. The DTR-stroke mortality association varied between cities, with higher DTR impact in the southern region of China. Females, the elderly and people with low educational attainment were vulnerable to DTR.

We observed a combined estimate of 0.66% increase in stroke mortality for an increase of 1 °C in DTR at lag days 0–10 days, which is a much greater effect than in previous multi-city studies that used total cardiovascular disease mortality as outcome measure. For example, a pooled estimate from 95 large communities in the United States found an increment of 0.35% (0.31–0.40%) in cardiovascular mortality with an increase of 1 °C in DTR (Lim et al., 2015). A similar study conducted in eight Chinese cities reported an estimate of 0.25% (0.11–0.39%) (Zhou et al., 2014).

The underlying mechanism of DTR on cardiovascular mortality is not well elucidated. With a sudden temperature variation beyond the limits that people could easily bear, the automatic thermoregulation system might not well adapt to such environmental change in a short time period, particularly for people with pre-existing cardiovascular diseases (Zanobetti et al., 2012), who may experience a quick progression from compensated to decompensated status. In addition, sudden temperature change was found to be related to increased serum cholesterol levels, blood pressure, heart rate, platelet aggregation, hemoconcentration, peripheral vasoconstriction and plasma fibrinogen concentrations (Kawahara et al., 1989; Keatinge et al., 1986; Lian et al., 2015). Dehydration, salt depletion, hypotension, and increased surface blood circulation (Bouchama and Knochel, 2002) may also be potential mechanisms. These physiological changes may induce an additional burden to the cardiovascular and cerebrovascular system, and may ultimately trigger the occurrence of lethal events, such as myocardial infarction and stroke (Lian et al., 2015).

In our study, the detrimental health effect of DTR differed greatly by season and region. The impact of DTR on mortality was mainly driven by the temperature change on days with cold temperature, with an estimate of 0.67% (0.26–1.07%), compared with an estimate of 0.12% (− 0.26% to 0.51%) on days with hot temperature. This finding is in agreement with previous studies (Song et al., 2008; Tam et al., 2009; Yang et al., 2013). Furthermore, the effect of DTR was found to be negatively correlated with the latitude, in accordance with the previously reported negative association between health impact of cold temperature and latitude (Xiao et al., 2014; Yang et al., 2016). The cold-induced vulnerability of people living in low latitude areas may be explained by physiological, behavioral and technological adaptations to the local climate (Hondula et al., 2015; Keim, 2008). For example, people residing in the low latitude areas are more likely to take measures to respond to hot weather conditions by using air-conditioning, ventilation and drinking plenty of fluids, while they may not be well prepared for large temperature variations during cold days. Furthermore, central heating policy in China does not target warm climate southern regions and people would therefore have no access to central heating during cold days and days with large temperature variability during winter (Yang et al., 2016).

Our study found that individual characteristics can modify the association between DTR and mortality. The elderly are known to be more susceptible to the adverse impacts of DTR (Cheng et al., 2014; Lim et al., 2012; Yang et al., 2013). In comparison with the youth, the elderly have limited ability to regulate and balance their body core temperature under changing ambient temperature (Van Someren, 2007). Furthermore, with the higher prevalence of chronic diseases, rapid change of daily temperature may cause additional stress on the cardiovascular system of the elderly, which may trigger fatal cardiovascular events, such as myocardial infarction and stroke. Educational level is an important factor reflecting one's socio-economic status. Our study confirmed that people with lower educational attainment were more vulnerable to DTR (Cheng et al., 2014; Ding et al., 2016; Yang et al., 2012). Low socio-economic status may result in poor access to medical care, heating and cooling systems. Our results show higher risk of DTR for women, confirming results from previous studies (Lim et al., 2012; Yang et al., 2013).

Stroke is a leading cause of death and disability-adjusted life years (DALY) lost in many countries, particularly in developing regions (Murray et al., 2012). Our findings underscore the importance to improve public awareness on health hazards of DTR. An early warning system, particularly during the days with cold weather, is recommended and could inform and alert residents, especially the elderly and those living the southern regions, about upcoming adverse impact of rapid temperature change. Hospital emergency departments and medical centers should be prepared for morbidity associated with rapid temperature change.

Some limitations of this study should be noted. Firstly, the present study was mainly focused on populations from urban regions and caution should be taken when the findings are extrapolated to the rural areas, where the socioeconomic status and medical resources are different from that in urban areas. Secondly, similar to previous time-series studies, we collected data on exposure (ie, temperature) from weather monitoring stations rather than using individual exposure to temperature. This may underestimate the DTR effects due to the fact that people may stay more time indoor during days with extreme temperature change. Finally, air pollutants were not controlled for in our study due to the unavailability of air pollution data, although no study has reported that air pollutants are confounders or effect modifiers of the relationship between DTR and mortality.

5. Conclusions

We conclude that diurnal temperature range has considerable effects on stroke mortality in 16 large cities in China, and that especially the elderly, females, those with low educational attainment, and people living in southern China were susceptible to DTR. As climate change increases the intensity, frequency and duration of extreme temperatures, such as heat waves and cold spells, the public health adaptation policies should focus on the impacts from both temperature rise and also the increased weather variability.

Acknowledgements

The study was supported by the National Key Research and Development Program of China (Nos. 2016YFC1200802, 2017FY101202) and the National Basic Research Program of China (973 Program) (No. 2012CB955504).

Competing interests

The authors declare no competing interests.

Author contributions

J.Y., Q.L. and T.K. initiated the study. M.Z., P.Y., J.Y. and Q.L. collected the data. J.Y. and Y.L. cleaned the data. J.Y. and M.L. performed statistical analysis. J.Y. and M.L. drafted the manuscript. B.W., E.P., T.K., W.H., L.A. and Q.L. revised the manuscript. All authors read and approved the final manuscript.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2018.03.036.

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