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Global climate change: Impact of diurnal temperature range on mortality in Guangzhou, China

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ABSTRACT

Diurnal temperature range (DTR) is an important meteorological indicator associated with global climate change, but little is known about the effects of DTR on mortality. We examined the effects of DTR on cause-/age-/education-specific mortality in Guangzhou, a subtropical city in China during 2003–2010. A quasi-Poisson regression model combined with distributed lag non-linear model was used to examine the effects of DTR, after controlling for daily mean temperature, air pollutants, season and day of the week. A 1 °C increase in DTR at lag 0–4 days was associated with a 0.47% (95% confidence interval: 0.01%–0.93%) increase in non-accidental mortality. Stroke mortality was most sensitive to DTR. Female, the elderly and those with low education were more susceptible to DTR than male, the youth and those with high education, respectively. Our findings suggest that vulnerable subpopulations should pay more attention to protect themselves from unstable daily weather.

1. Introduction

Climate change is associated with an increase in the frequency, intensity and duration of adverse weather events (e.g., heat waves and cold spells), which cause substantial economic and social costs. It is urgent to evaluate the association between climatic factors and human health. The association between daily ambient temperatures and mortality has been demonstrated in various regions and climatic zones worldwide (Barnett, 2007; Basu, 2009; Curriero et al., 2002; Guo et al., 2011a, 2012b; Yang et al., 2012). Previous studies usually used daily mean temperature, maximum temperature, minimum temperature or apparent temperature as indicators of ambient temperatures. However, few studies have assessed the potential effects of intraday variation in temperature (i.e., diurnal temperature range, DTR) on mortality (Cao et al., 2009; Kan et al., 2007; Lim et al., 2011). Also, there is less evidence on lag pattern of DTR effect, especially in Guangzhou, a subtropical city in China. DTR, defined as the difference between daily maximum temperature and minimum temperature, reflects whether the weather is stable or not. It is an important meteorological indicator associated with global climate change (Braganza et al., 2004; Makowski et al., 2008).

Studies have shown that age, gender and socioeconomic factors may modify the effects of ambient temperature on human health, indicating that some subpopulations are more susceptible to ambient temperature than others (Basu, 2009; Gouveia, 2003; Hajat et al., 2006; Schwartz, 2005; Son et al., 2012; Yang et al., 2012). A few studies found significant effects of DTR on mortality due to chronic obstructive pulmonary diseases (Song et al., 2008) and coronary heart diseases (Cao et al., 2009) in Shanghai, Hong Kong (Tam et al., 2009) and Taiwan (Liang et al., 2008). However, none of these studies has examined whether the effects were different by age, gender, and education level. Recently, Lim et al. (2011) analyzed the effect modification of DTR on mortality by individual characteristics and season in Korea. The seasonal characteristic of DTR effect suggests a potential interaction between DTR and temperature.

In this study we aimed to assess the effects of DTR and the interaction effect with daily mean temperature on cause-specific mortality in Guangzhou, China during 2003–2010; and to determine whether the effects were different by individual characteristics (i.e., gender, age group and education level).

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2. Materials and methods

2.1. Data collection

Guangzhou is the largest metropolis in Southern China with the latitude of 23° 7′ N. It has a typical subtropical climate, with an average temperature of 22.9 °C (Table 1). It has 12.7 million populations.

There is policy that every death in Guangzhou should be registered. We collected individual data for all 189 379 registered deaths between 1 January 2003 and 31 December 2010 from Guangzhou Center for Disease Control and Prevention. The causes of mortality were coded according to the International Classification of Diseases, the tenth version (ICD-10). We classified the mortality into non-accidental (ICD-10: A00-R99), cardiovascular (ICD-10: I00-I99) and respiratory (ICD-10: J00-J99), chronic obstructive pulmonary diseases (COPD, J40-47), ischemic heart diseases (IHD, I20-I25) and stroke (I60-I69). In addition, we stratified above cause-specific mortality by gender, age groups (0–64, 65–74, and 75+ years) and education level (no formal education, primary education, and secondary or higher education).

We obtained daily meteorological data from China Meteorological Data Sharing System, including daily mean temperature, minimum and maximum temperature, and relative humidity. Weather data were collected from a single station (Wushan station) in Guangzhou. This station is located at the urban area of Guangzhou city. DTR was calculated by the difference between daily maximum and minimum temperatures. Daily data on particulate matter less than 10 μm in aerodynamic diameter (PM_{10}), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) were obtained from Guangzhou Bureau of Environmental Protection.

The Ethics Committee of Southern Medical University has approved the study proposal.

2.2. Data analysis

A quasi-Poisson regression model combined with distributed lag non-linear model (DLNM) was used to examine the effects of DTR on cause-/age-/education-specific mortality. The DLNM is developed on the basis of "cross-basis" function, which allows to estimate the non-linear effect of exposure at each lag and the cumulative effect across lags at the same time (Gasparrini et al., 2010). This approach has been widely applied for assessing the effects of ambient temperature on mortality (Guo et al., 2011a, 2012b; Martin et al., 2012; Yang et al., 2012). Previous studies have confirmed that the effects of temperature on mortality usually last for several days and might be delayed (Armstrong, 2006; Gasparrini et al., 2010; Guo et al., 2011a, 2012b; Yang et al., 2012). In this study, to completely capture the effects of DTR on mortality, the DLNM was applied for DTR. We controlled for log-term trends and season using a nature cubic spline for time with 7 degree of freedom (df) per year. We controlled for day of the week and holidays as categorical variables. The effects of mean temperature was controlled for using 5 df natural cubic spline for mean temperature and 4 df natural cubic spline for lag up to 20 days. Relative humidity, PM_{10}, SO_2 and NO_2 on the current day were controlled for using 3 df natural cubic spline (Gasparrini et al., 2010; Guo et al., 2011a; Muggeo and Hajat, 2009). The maximum lag days, df for DTR and lags were selected by the minimum value of the sum of the Akaike information criterion for quasi-Poisson (Q-AIC) values for all cause-/age-/education-specific mortality (Gasparrini et al., 2012). Finally, based on the best model fit, we used 10 days as the maximum lag for DTR, and a linear function was used for DTR, while a 3 df natural cubic spline was used for lag.

To examine the joint effects of DTR and mean temperature on mortality, we used a 6 df natural cubic spline for both DTR and mean temperature. We plotted the 3D graphics to visualize whether there was an interaction between DTR and mean temperature on cause-specific mortality (Guo et al., 2011b).

The effect of DTR was presented as the percent change in mortality associated with a 1 °C increase in DTR. For all statistical tests, two-tailed $P < 0.05$ were considered statistically significant. All data manipulation and statistical analyses were performed using "mgcv" and "dlnm" functions of *R* packages (The *R* Foundation for Statistical Computing, version 2.13.1).

2.3. Sensitivity analysis

To check our main findings, we changed df (6–11 per year) for time to control for season, degrees of freedom (4–7) for air pollutants and relative humidity, the maximum lag from 25 to 30 days for DTR.

3. Results

Table 1 shows the summary statistics of daily deaths, and meteorological measures and air pollutants. Mean temperature was 22.9 °C (range, 5.4–34.2 °C) during 2003–2010 in Guangzhou, China. The mean DTR was 7.6 °C (range, 1.0–16.9 °C). There were a total of 181 912 non-accidental deaths. Cardiovascular and respiratory diseases accounted for 38.3% and 18.8% of all non-accidental deaths, respectively.

Table 2 shows the Spearman's correlation between weather conditions and air pollutants. DTR was positively correlated with three air pollutants, while DTR was negatively correlated with relative humidity. DTR was slightly correlated with mean temperature.

There were linear relationships between DTR and all cause-specific mortality (Supplementary Fig. S1). Fig. 1 shows the estimated effect of DTR on cause-specific mortality along lags of 10 days. Generally, the effect of DTR appeared immediately and lasted for 4 days for all cause-specific deaths.

We presented the cumulative effects of DTR on cause-specific mortality at lag 0, lag 0–4, lag 0–7, and lag 0–10 (Table 3). We observed a 0.47% (95%CI: 0.01%–0.93%) increase in non-accidental mortality at lag 0–4 days associated with an increase of 1 °C in DTR. The magnitude of DTR effects was higher for cardiovascular and respiratory mortality, compared with non-accidental mortality. Particularly, the effect estimate on stroke mortality was the highest.

Table 4 shows the cumulative effect of DTR on cause-specific mortality at lag 0–4 stratified by individual characteristics. Women and the elderly were consistently more sensitive to DTR than men and the youth. In general, people with low education level had higher risk associated with DTR than people with high education level. Similar results were found for lag 0–7 and lag 0–10 (Supplementary Table S1 and S2).

Fig. 2 shows the joint effects of DTR and daily mean temperature on cause-specific mortality at lag 0–4. We found that the higher DTR increased the adverse effects of daily mean temperature on mortality when the mean temperature was less than 22 °C. But, the DTR did not affect mean temperature–mortality relationship when mean temperature was higher than 22 °C. Thus, there were joint effects of DTR and daily mean temperature on mortality when mean temperature was lower than 22 °C. We found similar

Table 1
Summary statistics for daily weather conditions, air pollutants, and mortality in Guangzhou, China from 2003 to 2010.

Variables	Frequency distribution					Mean	SD
	Min	P_{25}	Median	P_{75}	Max		
DTR (°C)	1.0	5.7	7.6	9.3	16.9	7.6	2.8
Mean temperature (°C)	5.4	18.5	24.4	27.9	34.2	22.9	6.2
Relative humidity (%)	20.0	64.0	72.0	81.0	99.0	71.1	13.0
PM_{10} (μg/m^3)	7.0	52.1	80.0	114.6	370.1	88.2	48.5
NO_2 (μg/m$^{/3}$)	24.7	48.0	65.8	89.9	281.3	73.2	34.0
SO_2 (μg/m^3)	6.1	29.3	49.7	80.3	237.3	59.3	39.6
Non-accidental mortality	28	53	60	70	233	62	13.6
Cardiovascular mortality	6	19	23	28	102	24	7.3
Stroke	0	6	8	10	31	8	3.3
IHD	0	5	7	10	27	8	3.4
Respiratory mortality	2	9	11	14	46	12	4.4
COPD	0	4	6	8	27	6	3.1

Note. IHD: ischemic heart disease; COPD: chronic obstructive pulmonary disease; P_{25}: the first quartile; P_{75}: the third quartile.

Table 2
Spearman correlation between daily meteorological and air pollution variables in Guangzhou.

	DTR	Mean temperature	Relative humidity	PM_{10}	SO_2	NO_2
DTR	1	0.032	−0.540[a]	0.343[a]	0.205[a]	0.344[a]
Mean temperature		1	0.092[a]	−0.114[a]	0.152[a]	−0.235[a]
Relative humidity			1	−0.161[a]	0.111[a]	−0.115[a]
PM_{10}				1	0.673[a]	0.864[a]
SO_2					1	0.655[a]

[a]$P < 0.01$.