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Acute effects of diurnal temperature range on mortality in 8 Chinese cities

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ABSTRACT

Diurnal temperature range (DTR) is a meteorological indicator closely associated with global climate change. There have been no multicity studies in China addressing the DTR-related health impact. We hypothesized that an increase of DTR is associated with higher daily mortality with a potential lag of effect, and investigated the acute effects of DTR on total, cardiovascular, and respiratory mortality in 8 large Chinese cities from 2001 to 2010. We first calculated city-specific effect of DTR in the full year, the cool season (November to the next April) and the warm season (May to October) separately using a semi-parametric generalized additive model; then we pooled the city-specific estimates with meta analysis. After adjusting for long-term and seasonal trends, temperature, relative humidity and air pollution levels, we found statistically significant associations between DTR and daily mortality, especially in cool seasons. A 1 °C increment of DTR on lag-day 1 corresponded to a 0.42% (95% CI, 0.14 to 0.70) increase in total non-accidental mortality, 0.45% (95% CI, 0.26 to 0.65) increase in cardiovascular mortality, and a 0.76% (95% CI, 0.24 to 1.29) increase in respiratory mortality in cool seasons. Deaths among females and elderly (≥65 years) were more strongly associated with DTR than among males and younger people (<65 years). Our analysis suggests that DTR is a potential trigger for death in China. Our findings may have important implications for the climate policies in the country.

1. Introduction

Climate change may be the biggest global health threat of the 21st century (Costello et al., 2009). China, the largest developing country, has surpassed the United States as the country emitting the most carbon dioxide (CO_2); China is also a large emitter of methane and black carbon, which both contribute to global warming (Kan et al., 2012). As in other parts of the world, China has experienced noticeable climate change over the past century (Kan, 2011). Annual average air temperature has increased by 0.5–0.8 °C during the past 100 years, which is slightly higher than the average global temperature rise. The Chinese government has paid increasing attention to climate change, but only limited engagement has been given to the health impacts so far. Obviously, optimal adaptation strategies to climate change require a comprehensive and in-depth understanding of the nature of the effect of temperature variation on human health.

Diurnal temperature range (DTR), defined as the difference between maximal and minimal temperatures within one day (midnight to midnight), is a meteorological indicator closely associated with global climate change and urbanization (Braganza, 2004; Easterling et al., 1997). Previously, higher DTR was found to be a potential trigger for daily mortality in some Chinese cities, including Shanghai (Kan et al., 2007), Guangzhou (Luo et al., 2013; Yang et al., 2013), Taiwan (Liang et al., 2009), and Hong Kong (Tam et al., 2009). However, these single-city studies adopted different study designs and model specifications, limiting the ability to compare the results across cities. A multi-city analysis of DTR is needed in China, especially in areas with different climate patterns, latitudes and air pollution levels.

In this study, we hypothesized that an increase of DTR is associated with higher daily mortality with a potential lag of effect. We therefore assessed the relationships between DTR and daily mortality in 8 large Chinese cities, and examined the possible modification of the DTR-mortality associations by individual socio-demographic characteristics (such as gender and age).

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2. Materials and methods

2.1. Data

This study included 8 large cities with general study periods from 2001 to 2010 from northern to southern China: Anshan, Tangshan, Xi'an, Nanjing, Suzhou, Wuhan, Shanghai, and Guangzhou (Fig. 1). Of these cities, Anshan, Tangshan, and Xi'an belong to the warm-temperate zone; and Nanjing, Suzhou, Wuhan, Shanghai, and Guangzhou belong to the subtropical zone. Our analysis was restricted to the urban areas because the Death Registry has not been well established in suburban and rural areas in China.

We obtained daily counts of deaths from the Municipal Center for Disease Control and Prevention (CDC) in each city. The causes of death were coded according to the International Classification of Diseases, Revision 10 (ICD-10). The mortality data were classified as due to causes into total non-accidental causes (ICD-10: A00-R99), cardiovascular disease (ICD-10: I00-I99), and respiratory disease (ICD-10: J00-J98). The data for total mortality were classified by gender (female and male) and age ($<$65 and $\geq$65 years) in half of the eight cities. The quality of mortality data was the responsibility of the Center of Disease Control and Prevention in each city.

We obtained data on minimal, mean, and maximum temperatures, and relative humidity from the Meteorological Bureau in each city. DTR was calculated as the difference between maximal and minimal temperatures within one day. To control for potential confounding from outdoor air pollution, we also obtained daily data of air pollution from the National Air Pollution Monitoring System which is certified by the Ministry of Environmental Protection of China. Three air pollutants were included: particulate matter less than 10 μm in aerodynamic diameter (PM_{10}), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). The Chinese government has mandated detailed quality assurance and quality control programs at each monitoring station providing air pollution data. In each city, there were from 2 to approximately 10 monitoring stations (Table 1), and the daily air pollutant concentrations, temperatures, and relative humidity were averaged from the available monitoring results.

2.2. Data analysis

First of all, we investigated the correlations between all air pollutants and all meteorological variables used for each city with Pearson correlation test, in case variables with high correlations were included in the model at the same time.

Then we applied two-stage statistical models to estimate city-specific and multi-city average associations of DTR with daily mortality from all causes, cardiovascular mortality and respiratory mortality separately.

For the city-specific analyses, we used a generalized additive model (Ishigami et al., 2008) to analyze the daily mortality, DTR, and covariate data (Zeger et al., 2006). The core analysis was a GAM with log link and Poisson error that accounted for smooth fluctuations in daily mortality. We incorporated several covariates in the GAM: (1) a natural cubic smooth function of calendar time with 6 degrees of freedom (Fakheri and Goldfarb, 2011) per year to exclude unmeasured long-term and seasonal trends in daily mortality; (2) PM_{10} (representing air pollutants), mean temperature and relative humidity, and (3) indicator variables for “day of the week (DOW)” and holiday. Residuals of each model were examined to check whether there were discernible patterns and autocorrelation by means of residual plots and partial autocorrelation function (PACF) plots.

At the second stage, we used meta analysis to obtain the multi-city average estimates of the association of DTR with mortality. Homogeneity test of the estimates among cities was also done. All pooled outcome measures were determined using random-effects models (DerSimonian and Laird, 1986).

We considered several model fitting tests. First, we examined the effects of DTR with single-day lag models (from lag 0 to lag 5). A lag of 0 day (lag 0) corresponds to the current-day DTR, and a lag of 1 day (lag 1) refers to the previous-day DTR. Second, to test the stability of the associations, we compared the effect of DTR with and without adjustment for covariates (e.g. weather, air pollution levels) on the concurrent day (lag 0). Third, we conducted stratified analyses by gender and age for total mortality. We also 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 $\left(\hat{Q}_1-\hat{Q}_2\right) \pm 1.96\sqrt{S\hat{E}_1^{\,2} + S\hat{E}_2^{\,2}}$, where $\hat{Q}_1$ and $\hat{Q}_2$ are the estimates for the two categories, and $S\hat{E}_1$ and $S\hat{E}_2$ are their respective standard errors (Zeka et al., 2006). Fourth, we altered the degrees of freedom for trend as well as tried different lags for temperature as sensitivity analyses.

Both two-stage statistic models and model fitting tests were done in the full year and in separate seasons. A whole year period was divided

Fig. 1. The map of cities in this study.*. *Subtropical cites: Nanjing, Suzhou, Wuhan, Shanghai, and Guangzhou; warm-temperate cities: Anshan, Tangshan, and Xi'an.

Table 1
Descriptive data on study period, population, mean daily death number, mean temperature, diurnal temperature range, and mean PM_{10} levels in eight Chinese Cities.

City	Anshan	Guangzhou	Nanjing	Shanghai	Suzhou	Tangshan	Wuhan	Xi'an
Study period	2004–2006	2007–2008	2007–2010	2001–2004	2005–2008	2006–2008	2003–2005	2004–2008
Population (millions)	2.4	6.5	7.5	8.5	4.1	1.9	4.5	3.4
Mean number of deaths per day								
Total	27.6 ± 6.1	79.5 ± 16.9	34.2 ± 5.9	119.0 ± 22.5	34.0 ± 9.0	18.9 ± 12.4	57.5 ± 21.2	26.1 ± 9.4
% male	/	55.8	/	52.5	58.8	/	/	71.2
% elderly	/	76.5	/	83.7	82.4	/	/	65.1
Cardiovascular	14.1 ± 4.3	29.4 ± 8.8	22.9 ± 3.9	44.2 ± 11.0	13.0 ± 5.0	8.3 ± 6.6	32.7 ± 13.7	12.1 ± 5.7
Respiratory	1.9 ± 1.5	15.0 ± 5.4	7.4 ± 2.9	14.3 ± 6.4	5.0 ± 2.6	2.9 ± 2.7	6.9 ± 6.1	7.2 ± 3.8
Temperature (°C)	8.7 ± 13.3	22.8 ± 6.3	16.6 ± 9.4	17.7 ± 8.5	17.2 ± 9.2	12.6 ± 11.1	17.9 ± 9.4	13.4 ± 9.8
Relative humidity	55.2 ± 16.0	71.0 ± 13.3	71.6 ± 13.9	72.9 ± 11.4	77.0 ± 12.4	60.5 ± 18.5	71.1 ± 12.6	66.5 ± 16.7
Diurnal temperature range (°C)								
Full year	11.0 ± 3.8	8.4 ± 3.0	9.4 ± 3.8	6.8 ± 2.9	7.1 ± 3.0	10.8 ± 3.5	8.1 ± 3.1	10.9 ± 4.6
Cold seasons	11.4 ± 3.6	8.6 ± 3.7	9.9 ± 4.2	7.1 ± 3.3	7.3 ± 3.5	11.1 ± 3.6	8.2 ± 3.5	11.5 ± 4.6
Warm seasons	10.6 ± 3.9	8.2 ± 2.1	8.8 ± 3.2	6.4 ± 2.5	6.8 ± 2.5	10.5 ± 3.4	8.1 ± 2.6	10.4 ± 4.4
P value[a] (between seasons)	0.001	0.036	<0.001	<0.001	0.004	0.002	0.674	<0.001
No. of air monitors	2	9	9	9	8	6	10	7
PM_{10} (μg/m^3)	110.9 ± 60.2	73.8 ± 40.2	104.8 ± 63.4	102.0 ± 64.8	89.8 ± 48.3	98 ± 46.5	129.8 ± 56.4	129.9 ± 53.2
SO_2 (μg/m^3)	59.0 ± 74.3	50.0 ± 33.0	48.3 ± 25.1	44.7 ± 24.2	44.7 ± 20.7	84.3 ± 59.6	51.6 ± 28.9	47.5 ± 26.1
NO_2 (μg/m^3)	25.5 ± 16.3	65.9 ± 31.7	51.1 ± 20.0	66.6 ± 24.9	49.1 ± 20.7	41 ± 17.9	52.7 ± 19.5	38.1 ± 14.8

/: Data not available.
[a] $P < 0.05$, the difference between cold and warm seasons is statistically significant.

into two seasons, May to October as the warm season and the rest as the cool season.

All analyses were carried out in S-PLUS 8.0 software (Seattle, WA) using the convergence criteria recommended by Dominici et al. (2002). An extended GAM function was used to estimate the exact standard errors of the regression coefficients (Dominici et al., 2004). The statistical tests were two-sided, and effects of $P < 0.05$ were considered statistically significant.

3. Results

Table 1 summarizes the population, mortality, DTR, temperature, and PM_{10} data in the 8 Chinese cities. The daily mean numbers of total, cardiovascular and respiratory deaths varied according to the size of the city and ranged from 19 to 119, 8 to 44, and 2 to15, respectively. The annual mean temperature ranged from 8.7 °C in Anshan to 23.0 °C in Guangzhou, which may have fully captured the temperature variations in China. The averaged DTR levels were highest in Anshan and Xi'an, and were lowest in Shanghai. There were no missing data in our dataset. We investigated DTR variations in cool and warm seasons as well. Significant difference in DTR was found between seasons in most of the cities.

Pearson correlation coefficients between all air pollutants and meteorological variables in eight cities are shown in Table S1. As the correlation between DTR and mean temperature was low ($r < 0.2$), it was used as a confounder in the model. Also, SO_2 and NO_2 were highly correlated

Table 2
Percent increase of daily mortality associated with 1 °C increase of DTR (lag 1), Model covariates include particulate matter less than 10 μm in aerodynamic diameter, day of the week, day of study, holiday, relative humidity lag 0, and mean temperature lag 0.

	City	Study period		
		Full year	Cold seasons	Warm seasons
Total mortality	Anshan	0.10 (−0.29, 0.48)	0.46 (−0.09, 1.00)	−0.30 (−0.89, 0.28)
	Guangzhou	0.40 (−0.03, 0.83)	0.66 (0.13, 1.19)[a]	−0.01 (−0.85, 0.83)
	Nanjing	0.29 (0.04, 0.54)[a]	0.51 (0.21, 0.80)[a]	−0.05 (−0.52, 0.41)
	Shanghai	0.35 (0.12, 0.58)[a]	0.40 (0.10, 0.70)[a]	0.17 (−0.21, 0.55)
	Suzhou	0.13 (−0.03, 0.29)	0.74 (0.27, 1.21)[a]	0.56 (−0.09, 1.22)
	Tangshan	0.62 (0.00, 1.24)[a]	1.56 (0.55, 2.58)[a]	0.29 (−0.81, 1.39)
	Wuhan	−0.27 (−0.76, 0.21)	−0.18 (−0.82, 0.46)	−0.51 (−1.27, 0.26)
	Xi'an	−0.04 (−0.36, 0.29)	−0.24 (−0.67, 0.19)	0.38 (−0.14, 0.91)
	Overall	0.18 (0.09, 0.28)[a]	0.42 (0.14, .70)[a]	0.09 (−0.12, 0.29)
Cardiovascular mortality	Anshan	0.08 (−0.45, 0.61)	0.42 (−0.32, 1.15)	−0.42 (−1.25, 0.41)
	Guangzhou	0.66 (0.01, 1.31)[a]	0.80 (0.00, 1.59)[a]	0.30 (−1.25, 1.60)
	Nanjing	0.22 (−0.05, 0.49)	0.44 (0.13, 0.76)[a]	−0.05 (−0.53, 0.44)
	Shanghai	0.41 (0.07, 0.75)[a]	0.44 (0.01, 0.88)[a]	0.07 (−0.51, 0.66)
	Suzhou	0.11 (−0.17, 0.38)	0.60 (−0.11, 1.31)	0.56 (–0.56, 1.69)
	Tangshan	0.89 (0.11, 1.67)[a]	1.91 (0.80, 3.02)[a]	0.69 (−0.58, 1.96)
	Wuhan	−0.11 (−0.68, 0.46)	0.12 (−0.56, 0.79)	−0.72 (−1.71, 0.26)
	Xi'an	0.37 (−0.08, 0.82)	0.10 (−0.50, 0.69)	1.04 (0.32, 1.76)[a]
	Overall	0.25 (0.11, 0.39)[a]	0.45 (0.26, 0.65)[a]	0.12 (−0.15,0.40)
Respiratory mortality	Anshan	0.08 (−1.24, 1.40)	0.70 (−1.15,2.54)	−0.34 (−2.42, 1.74)
	Guangzhou	0.57 (−0.30, 1.45)	0.96 (−0.05, 1.97)	−0.25 (−2.06, 1.56)
	Nanjing	0.60 (0.00, 1.20)[a]	0.73 (0.04, 1.42)[a]	0.26 (−0.89, 1.41)
	Shanghai	0.22 (−0.36, 0.79)	0.22 (−0.49, 0.93)	0.15 (−0.91, 1.21)
	Suzhou	0.38 (0.01, 0.74)	1.45 (0.33, 2.57)[a]	0.80 (−1.01, 2.61)
	Tangshan	0.45 (−0.94, 1.84)	3.78 (1.60, 5.96)[a]	−0.03 (−2.09, 2.02)
	Wuhan	−1.16 (−2.66, 0.35)	−0.23 (−2.14, 1.68)	−2.11 (−4.39, 0.17)
	Xi'an	0.49 (−0.07, 1.05)	0.28 (−0.46, 1.03)	1.25 (0.36, 2.14)[a]
	Overall	0.38 (0.15, 0.60)[a]	0.76 (0.24, 1.29)[a]	0.38 (−0.11, 0.87)

[a] The association was significant ($P < 0.05$).

(r > 0.6) in most of the cities, therefore, they could not be included in the model at the same time.

The GAM splines of daily mortality against DTR presented a linear relationship in most of the cities after controlling for confounding factors (data not shown). The associations of DTR with daily mortality varied by cities, causes of deaths, and seasons (Table 2). We observed statistically significant associations of DTR with total, cardiovascular and respiratory mortality in most of the cities in the full year and in cool seasons. Few significant results were found in warm seasons. Test for heterogeneity did not show significant results. An increase of 0.42% (95% CI, 0.14 to 0.70) of total mortality, 0.45% (95% CI, 0.26 to 0.65) of cardiovascular mortality, and 0.76% (95% CI, 0.24 to 1.29) of respiratory mortality were associated with 1 °C increase of DTR (lag 1) in cool seasons. The estimates of DTR associated with daily mortality in the full year were approximately half of those in cool seasons.

DTR showed similar lag patterns for its association on total and cardiovascular mortality (Fig. 2) in the same season, but presented different patterns through different seasons. In the full year and cool seasons, the risks of total and cardiovascular mortality decreased slowly from lag 0 to lag 5, with lag 0 and lag 1 nearly flat. The lag patterns of DTR with respiratory mortality is more complicated, and varied between seasons. In a trial analysis, we found the relations between mortality and confounders (temperature, humidity, air pollutants) were strongest on the concurrent day, so we adjusted them using lag 0.

Table 3 shows the comparison of regression results of the single-variable model, which only considers DTR, and multiple-variable model in cool seasons, which includes covariates such as temperature, humidity and air pollutant concentrations (PM_{10}, SO_2 and NO_2). Results of the full year and warm seasons are shown in Table S2. The effect of DTR on total, cardiovascular and respiratory mortality remained

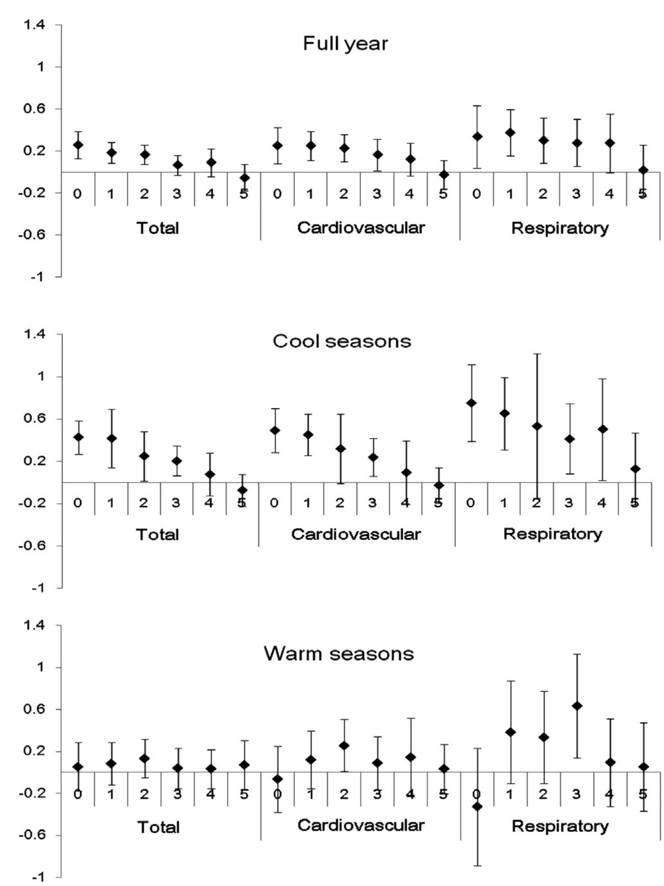

Fig. 2. Percent increase (mean and 95% confidence intervals) of daily mortality associated with 1 °C increase of DTR in different seasons, using different lag structures of DTR, in eight Chinese cities.

statistically significant before and after adjustment for the covariates, although the estimated effect decreased. For example, 1 °C increase of DTR was associated with 0.45% (95% CI, 0.16 to 0.74) increase of total mortality in the single-variable models, whereas the effect decreased to 0.42% (95% CI, 0.10 to 0.73) after adjustment for all covariates.

The results of gender- and age- specific results between DTR are shown in Table 4. We did not observe significant association of DTR among males or younger people (1–64 years). The effect estimate of DTR among females and elderly residents (≥65 years) was approximately 2 times higher than among males and people aged 1–64. While in warm seasons, no significant associations were found in any of the subgroups. No significant difference was found between the two gender and age groups in any of the seasons.

Within the range of 4–8, the change of df/year for time trend did not substantially affect the association of DTR with mortality (data not shown), suggesting that our findings are relatively robust in this aspect. Also, our results did not change substantially when adjusting for mean temperatures with multiple lags, including current-day lag, moving average lags of 0 and 1 day, and moving average lags of 0 and 3 days (data not shown).

4. Discussion

Using a common research protocol, we found significant association between DTR and daily mortality from all causes and from cardiovascular and respiratory causes in 8 Chinese cities in cool seasons. After adjustment for temperature, relative humidity, and air pollution levels, this association remained significant. Our analysis also provided evidence that females and older people might be more susceptible to DTR than males and younger people. Our findings were generally insensitive to alternative model specifications, such as lag structures of DTR and *df* for time trend. To our knowledge, this is the largest epidemiologic study to date in China to examine the association of DTR with daily mortality.

The global mean surface air temperature has risen about 0.5 °C during the past century. This rise has resulted, in part, from the daily minimum temperature increasing at a faster rate or decreasing at a slower rate than the daily maximum, resulting in a decrease in the DTR for many parts of the world (Easterling et al., 1997). However, the pattern of DTR change is complicated and varies across different parts of the world. For example, although in some urban regions of both developed and developing countries, decrease in DTR has been identified, the DTR in India, Russia and part of northern China has increased as a result of a decrease in the minimum temperature. Another analysis in southern China has also found DTR increase from 1984 to 2005 (Li and Chen, 2009). Currently, DTR is assumed to be affected by both large-scale climate effects (e.g. increases in cloud cover, surface evaporative cooling from precipitation, greenhouse gases, and tropospheric aerosols) and local effects such as urban growth, irrigation, desertification, and variations in local land use (Kan et al., 2007). Although it remains uncertain that DTR could serve as a stable indicator of long-term climate change, our results showed that a short-term increase of DTR was still a useful environmental parameter that may affect human health. Therefore, future research on DTR and health is warranted given the complicated trend of DTR change across the world.

In our study, the increased risk of mortality from total, cardiovascular diseases and respiratory diseases in a full year attributable to a 1 °C increase in DTR (lag1) were 0.18%, 0.25% and 0.38%, respectively. Generally, the magnitudes of our estimates for DTR are lower than previous single-city analyses in China. For example, in Guangzhou, an increase of 1 °C of 5-day moving average of DTR corresponds to 0.47%, 0.75% and 0.76% increase in total, cardiovascular and respiratory mortality, respectively (Yang et al., 2013). In Shanghai, a 1 °C increment of DTR (lag 02) corresponded to a 1.37% increase in total mortality, a 1.86% increase in cardiovascular mortality, and a 1.29% increase in respiratory mortality (Kan et al., 2007). Also, a multicity study in Korea found the

Table 3
Percent increase of daily mortality associated with 1 °C increase of DTR (lag 1) in cold seasons, before and after adjustment for covariates.

	Covariates	Total	Cardiovascular	Respiratory
Single-variable model	–	0.45 (0.16, 0.74)	0.48 (0.23, 0.73)	0.84 (0.55, 1.13)
Multi-variable model	Temperature	0.56 (0.24, 0.87)	0.68 (0.36, 1.00)	0.97 (0.43, 1.52)
	RH	0.44 (0.16, 0.72)	0.43 (0.25, 0.60)	0.86 (0.54, 1.17)
	Temperature, RH	0.51 (0.21, 0.80)	0.58 (0.29, 0.87)	0.90 (0.36, 1.44)
	Temperature, RH and PM_{10}	0.42 (0.14, 0.70)	0.45 (0.26, 0.65)	0.76 (0.24, 1.29)
	Temperature, RH, PM_{10} and SO_2	0.42 (0.10, 0.73)	0.46 (0.18, 0.75)	0.81 (0.21, 1.41)

pooled effect of DTR (lag 04) on all-cause mortality was 0.5% with an increment of 1 °C (Lim et al., 2012). The consistency in the literature suggests that the association of DTR with mortality are not likely to be substantially changed by characteristics of geography, climate, and population, and by publication bias and model specifications.

It is well-known that ambient temperature can have some influences on human health. Most previous studies have addressed the short-term health effects of day-to-day variations in mean, maximum and minimum temperatures (Yu et al., 2011), but the evidence of within-day variation in diurnal temperature was quite limited. As is shown in Table S1, within-day variation of temperature may be independent from day-to-day variation. Thus, DTR may be an indicator of within-day temperature variations, regardless of it being sudden or slow. Corresponding to the widespread health studies on day-to-day temperature variations, this study contributed to the limited knowledge that temperature variation even within a day could also affect human health.

The underlying mechanisms are not very clear, but some have been proposed to be responsible for the observed adverse health effects of DTR. Previous studies have shown that sudden temperature change might increase cardiorespiratory workload and induce the onset of cardiorespiratory event (Imai et al., 1998; Luurila, 1980). Wide DTR might be a source of additional environmental stress, and stress on the cardiorespiratory systems increases during periods of high temperature change. For example, sudden temperature change of inhaled air has been associated with the release of inflammatory mediators associated with mast cells in a human study (Togias et al., 1985). We also noted that DTR only had statistically significant effect on people older than 65. In this age group, the ability to regulate body temperature is reduced, and sweating thresholds are generally elevated in comparison with those of younger people (Foster et al., 1976; Kenney and Hodgson, 1987). In that case, the cardiorespiratory system could not adjust well to the outside temperature change, especially for those persons with preexisting cardiorespiratory diseases. A panel study among elderly people in Seoul, Korea showed that the heart rate increased with increments of DTR, and large DTR reduced time domain heart rate variability (SDNN and RMSSD) after controlling for individual characteristics and environmental variables, suggesting that DTR might affect the cardiovascular system through alterations in autonomic nervous functions (Lim et al., 2013). However, it should be noted that since most deaths occur over age 65, there is much great power to find associations in this age group.

In the present study, we did observe some differences across city specific analyses (Table 2). The DTR-related health effects were inconsistent even for cities with similar DTR distributions, such as Tangshan and Wuhan. Explaining these differences was not easy. These differences may be in part due to different characteristics of the study sites that may affect the DTR-mortality association, such as demographical constitution, climatic adaptation, housing types, building thermal isolation, and use of cooling and heating equipment. Previous studies reported that these characteristics accounted for some city-specific differences in the associations between temperature and other outcomes such as total mortality and hospitalizations (Basu and Samet, 2002). Different research periods in the eight cities may also contribute to the difference in estimates.

Our analysis had strengths and limitations. The impact of DTR on health might be easier to be identified in developing countries where air conditioning is less used. Further, our analysis included 8 large cities in China, lending sufficient statistical power to investigate the relationship between DTR and daily mortality. Moreover, these cities cover large geographic regions in China (Fig. 1) and thus allowed our examination across diverse climatic environments. Several limitations of our study should also be mentioned. Limited by the data availability, the study periods varied across our cities, which might lead to additional heterogeneity to our results. Also, as in other studies in this field, we used available outdoor monitoring data to represent the population exposure to DTR and other covariates. Measurement error may have substantial implications for interpreting epidemiologic studies on DTR, particularly for the time-series design (Zeger et al., 2006). Also, as in any study using registry-based mortality data, coding errors may occur. Finally, this study was inherently an ecological analysis and thus potential confounding from individual-level risk factors could not be fully excluded.

In conclusion, we found independent association between DTR and mortality in 8 Chinese cities. Females and older people appeared to be more susceptible to the fluctuation of temperature within one day. Because temperature changes (e.g. DTR) and associated adverse effects are potentially modifiable for example via lifestyle changes, our findings may have important implications for public health in China.

Table 4
Gender- and age- specific percentage increase in total mortality associated with a 1 °C increase of DTR (lag1).

	Full year	Cold seasons	Warm seasons
Gender			
Male	0.14 (−0.01, 0.29)	0.21 (−0.18, 0.61)	−0.11 (−0.45, 0.24)
Female	**0.26 (0.10, 0.42)**[a]	**0.51 (0.27, 0.76)**[a]	0.23 (−0.14, 0.60)
Age (years)			
1–64	0.14 (−0.06, 0.35)	0.10 (−0.30, 0.50)	−0.17 (−0.57, 0.23)
≥65	**0.20 (0.07, 0.34)**[a]	**0.46 (0.22, 0.71)**[a]	0.19 (−0.10, 0.47)

[a] The association was significant ($P < 0.05$).

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The authors declare they have no competing financial interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2014.05.116.

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