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RESEARCH ARTICLE

The effects of temperature variability on mortality in patients with chronic obstructive pulmonary disease: a time-series analysis in Hangzhou, China

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Abstract

Chronic obstructive pulmonary disease (COPD) is a leading cause of death in people aged over 60 years old. Research has been reported that ambient temperature and diurnal temperature range (DTR), as representative indices of temperature variability, are contributors to the development and exacerbation of COPD. However, few studies are available in Chinese population. In this study, we aimed to assess the associations of temperature variability on COPD mortality in a fast developing city in China. Using the mortality surveillance system, we obtained a total of 7,863 deaths attributed to COPD from 2014 to 2016. Quasi-Poisson generalized linear regression with distributed lag non-linear model was applied to explore the associations between temperature variability and COPD deaths, after controlling for the potential confounders, including relative humidity, day of week, public holiday, and long-term trend. A J-shaped association of DTR and a reversely J-shaped association of temperature for COPD mortality were observed. Risk estimates showed that the relative risks (RRs) of COPD mortality with extreme high DTR at lag 0 and 0–7 days were 1.045 (95% CI: 0.949–1.151) and 1.460 (95% CI: 1.118–1.908), and the extreme high temperature at lag 0 and 0–7 days were 1.090 (95% CI: 0.945–1.256) and 1.352 (95% CI: 1.163–1.572). Our findings suggest that short-term exposure to extreme temperature was associated with mortality for COPD in Hangzhou. The evidence has implications for policy decision-making and targeted interventions.

Keywords Ambient temperature · Chronic obstructive pulmonary disease · Mortality · Distributed lag non-linear model

Introduction

Chronic obstructive pulmonary disease (COPD) is a progress respiratory disease, characterized by airflow limitation. The onset of COPD has a significant impact on the quality of life and work productivity, which induced substantial economic and social burden (Mannino 2002; Vestbo et al. 2013). COPD is the third leading cause of death, accounting for 3.2 million deaths annually. The prevalence of COPD was reported to be about 300 million in 2017, with the disease burden expected to increase further over the coming decades (GBD Disease Injury Incidence Prevalence Collaborators 2018, WHO 2020). In China, the prevalence of COPD in people over 40 years old was as high as 13.7%, and every year there were over 0.9 million people died prematurely because of COPD (Wang et al. 2018; Zhou et al. 2016). Despite the emergence of worldwide attention and the great burden imposed on population health, the relationships between COPD mortality and environmental risk factors have not been explored adequately.

In recent years, climate change characterized by anthropogenic global warming and increasing episodes of extreme weather has become a major environmental public health concern. Of all the meteorological factors, temperature has been studied most. It is well known that temperature can increase the risk of adverse health outcome, ranging from subclinical status to death, especially

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for those who have already been suffering from respiratory disease (Kim and Lee 2019). It is reported that heat stress could cause inflammation of the bronchial mucosa and increase the risk of acute injury to lung tissue (Monteiro et al. 2013). Hayes et al. (2012) further demonstrated that increasing airway temperature may trigger bronchoconstriction through the cholinergic reflex pathway.

The anticipated effect of climate change also included unstable weather. Defined as difference between maximum and minimum temperature within a day, diurnal temperature range (DTR) is an important indicator for studying temperature variability (Braganza et al. 2004; Jones 1995a, b; Sun et al. 2019). The effects of DTR exposure have been recently identified in a growing number of time-series studies, highlighting its great influence on human health (Lim et al. 2012; Zhang et al. 2018). It is worth noting that the risk estimates of temperature varied greatly by different geographical region, study population, and social environment. Studies with geographical comparisons provided a clear evidence that the health effect of temperature affect different parts of the country in a unique way (Healy 2003; Yang et al. 2019). However, in China, few studies have investigated the impacts of temperature variability on COPD mortality.

Hangzhou, is a capital city of Zhejiang province located in the Yangtze River Delta region, China. It has a typical subtropical climate with four distinct seasons, characterized by humid, hot summer and dry, chilly winter. By the end of 2019, the city's gross domestic product was RMB 1537.3 billion, and the population of permanent residents was about 10.36 million (Mao et al. 2020). Dramatic economic growth and population explosion have a significant effect on the trends of annual mean and extreme temperature indices (Gu et al. 2011). Research on temperature variability is becoming an imperative task. Hence, the aim of the present study was to investigate the associations between daily average temperature and DTR, as two representative indices of temperature variability, and COPD deaths. Daily meteorological data and mortality data from Hangzhou, China, were used to test the associations in a time-series analysis.

Methods

Mortality data

Daily mortality records for respiratory disease during the study period were retrieved from the mortality surveillance system of Zhejiang Provincial Center for Disease Prevention and Control. Based on the 10th revision of the International Classification of Diseases and Related Health Problems (ICD-10), deaths due to COPD (J40-44) were incorporated. In addition, demographic characteristics such as age, gender, and residence status (local residence or not) were also extracted from the system.

Meteorological and air pollution data

Meteorological data including temperature and relative humidity from January 1, 2014 to December 31, 2016, were obtained from Zhejiang Meteorological Bureau. DTR was calculated by subtracting minimum temperature from maximum temperature for each day. Daily mean temperature was the 24-h average temperature. Over the same period, daily air pollutant data, mainly including $PM_{2.5}$, NO_2, and SO_2, were collected from eight environmental monitoring stations in urban areas. Twenty-four-hour means were applied for air pollutants.

Statistical analysis

First, we provided a descriptive review on the distribution of COPD deaths, meteorological, and pollutant datasets. Data were summarized as mean, percentiles, and standard deviation for continuous variable and absolute and relative frequency for categorical variables. Then, time-series analyses were applied to estimate the associations between temperature exposure and COPD deaths.

Deaths due to COPD are small-probability events, which follow a Poisson distribution; thus, a Poisson time-series generalized linear model (GLM) was applied to estimate the associations between temperature variability and COPD deaths. The distributed lag non-linear model (DLNM) in the natural cubic splines and a maximum lag of 7 days were incorporated into the GLM to account for the contributions of delayed and non-linear effect (Gasparrini et al. 2010; Zhan et al. 2020). Specifically, the cross-basis function was used to present the lag response for temperature at different day. In order to choose the particular degree of the freedom (df) for temperature and DTR, quasi-Akaike's information criterion (QAIC) was used to evaluate the goodness of fit of the models. The lowest QAIC determined the best model. Thereafter, the dfs for temperature and lag were set to 3, as well as the dfs for DTR and lag were set to 3. The df for long-term trend was 2 df per year. Additionally, using the moving average of lag 0–3, relative humidity was included in the adjusted model. Controlling variables included day of week and public holiday were also adjusted, as previous studies reported (Alahmad et al. 2019; Phosri et al. 2020). The model used for this study is as follows:

$$Y_t \sim \text{Poisson}(\mu_t)$$

$$\log\left(\mu_t\right) = \alpha + \beta\left(DTR_t, Lag\right) + \gamma\left(temperature_t, Lag\right) + ns\left(humidity_{03}, df\right) + ns\left(time_t, df\right) + DOW + Holiday$$

where μ_t represents the daily COPD deaths on day t; α is the intercept of the model; β is the is the vector of the coefficient for DTR; and γ is the vector of the coefficient for temperature. The minimum mortality temperature, at which the risk is lowest, was defined as reference value (Gasparrini et al. 2015). The extreme high temperature and extreme DTR were defined as the 99th percentile of the data distribution. Relative risks (RRs) and 95% confidence intervals (CIs) were calculated to evaluate the time-lag and cumulative effects of associations between temperature change and COPD deaths. Stratified analysis with regard to age was conducted to investigate whether there were potential differential associations of the exposure across subgroups (Schenker and Gentleman 2001). Seasonal modification for DTR was also examined. Warm season was defined as from April to September. Cold season was defined as from October to March. The difference of temperature effect on COPD mortality between subgroups was tested by calculating the 95% confidence interval (CI) as $(\hat{Q}_1 - \hat{Q}_2) \pm 1.96\sqrt{\hat{SE}_1^2 + \hat{SE}_2^2}$, where $\hat{Q}_1$ and $\hat{Q}_2$ represent the estimates for the strata, and $\hat{SE}_1$ and $\hat{SE}_2$ are their standard errors (Zeka et al. 2006).

To test the robustness of the model, sensitivity analysis was assessed by varying the df of calendar time and relative humidity. Also, we have tried to adjust air pollutants including $PM_{2.5}$, NO_2, and SO_2 in our analysis. All the statistical analyses were performed using R software (4.1.0). p value less than 0.05 was considered statistically significant.

Results

Descriptive analysis

Table 1 summarizes the basic characteristics of study population, meteorological condition, and air pollution from January 1, 2014 to December 31, 2016 (1,096 days). During this period, the records of 7,863 deaths were analyzed with an average of 7.17 cases per day (standard deviation, SD: 3.44). Roughly 98.89% of all deaths were at ages 65 and older. There were more deaths among males (54.38%) than females (45.62%).

The 24-h average mean concentrations for PM_{25}, NO_2, and SO_2 were 56.83 μg/m^3 (range: 8.00 to 228.56 μg/m^3), 47.9 μg/m^3 (range: 10.89 to 118.30 μg/m^3), and 16.29 μg/m^3 (range: 4.33 to 81.20 μg/m^3), respectively. The daily mean temperature, DTR, and relative humidity were 17.77 °C (range: – 5.00 to 34.40 °C), 7.57 °C (range: 0.90 to 18.50 °C), and 74.41% (range: 27.00 to 98.00%).

Table 2 shows the Spearman correlation coefficients between weather condition and air pollutants. Daily mean temperature was slightly correlated with relative humidity and negatively correlated with air pollutants, while DTR was negatively correlated with relative humidity and moderately correlated with air pollutants. Air pollutants were strongly correlated with each other.

Table 1 Summary statistics for daily weather and air pollution variables in Hangzhou during the study period (January 1, 2014 to December 31, 2016)

Variables	*N* (%)	Mean	Standard deviation	Percentile						
				Minimum	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	Maximum
COPD death										
Total	7,863 (100)	7.17	3.44	0.00	3.00	5.00	7.00	9.00	12.00	25.00
Male	4,276 (54.38)	3.90	2.29	0.00	1.00	2.00	4.00	5.00	7.00	15.00
Female	3,587 (45.62)	3.27	2.06	0.00	1.00	2.00	3.00	4.00	6.00	15.00
Old	7,776 (98.89)	7.09	3.41	0.00	3.00	5.00	7.00	9.00	11.00	24.00
Warm	3296 (41.92)	6.00	2.46	0.00	3.00	4.00	6.00	8.00	9.00	14.00
Cold	4567 (58.08)	8.35	3.87	0.00	4.00	6.00	8.00	10.00	14.00	25.00
Air pollution										
PM_{25} (μg/m^3)	–	56.83	31.45	8.00	24.70	34.08	50.20	72.24	97.55	228.56
NO_2 (μg/m^3)	–	47.90	17.63	10.89	27.20	34.76	45.85	58.03	72.40	118.30
SO_2 (μg/m^3)	–	16.29	8.91	4.33	7.60	9.70	14.00	20.10	28.40	81.20
Meteorological data										
Temperature (°C)	–	17.77	8.43	– 5.00	5.85	10.50	19.15	24.43	28.20	34.40
DTR (°C)	–	7.57	3.60	0.90	2.80	4.70	7.50	10.20	12.20	18.50
Relative humidity (%)	–	74.41	13.86	27.00	54.00	65.00	76.00	85.00	93.00	98.00

Table 2 Spearman correlation coefficients between weather conditions in Hangzhou during the study period

	DTR	Relative humidity	PM_{25}	NO_2	SO_2
Mean temperature	0.17*	0.09*	−0.38*	−0.52*	−0.45*
DTR		−0.64*	0.25*	0.13*	0.25*
Relative humidity			−0.23*	−0.07*	−0.49*
PM_{25}				0.70*	0.68*
NO_2					0.64*

*$p < 0.05$

Time-lag and cumulative effects

Figure 1 presents three-dimensional curves for the RRs of COPD deaths along DTR and temperature variability in lags. Overall, the exposure–response relationships for COPD deaths were non-linear. Large increase in both DTR and temperature had delayed adverse effects on COPD deaths.

Figure 2 depicts the overall cumulative effect (7 days) of both DTR and temperature on COPD deaths. The pooled curves found to be J-shaped or reverse J-shaped with no clear threshold effect. We first set median as the reference and found that the minimum mortality temperature for DTR and temperature were 6.5 °C and 23.0 °C, respectively. Then we used 6.5 °C and 23.0 °C as the final reference. We found that the magnitude of associations between COPD deaths and extreme DTR (99th percentile: 16.0 °C) rose steadily towards the end of the lag days. Significant association was observed in lag 0–7 day (RR = 1.460, 95% CI: 1.118, 1.908). While for temperature (99th percentile: 33.0 °C), the greatest RR

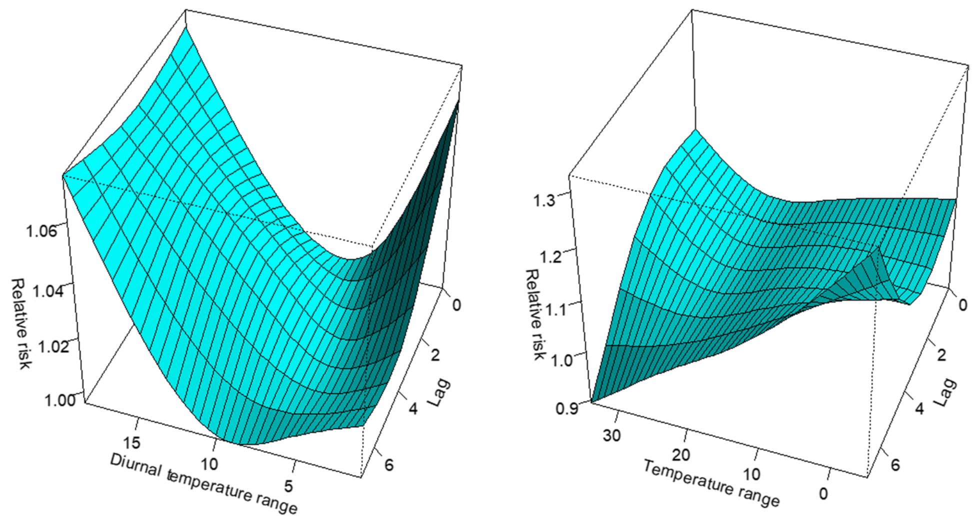

Fig. 1 Relative risk of COPD death with DTR, temperature and lags (lag 0 to lag 7 days)

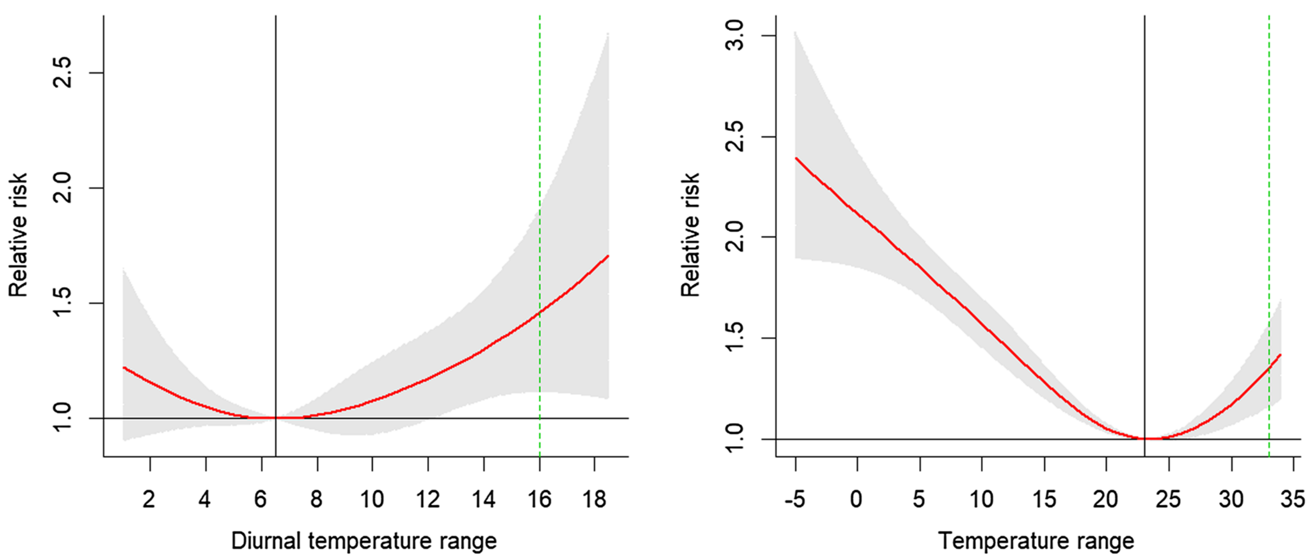

Fig. 2 Cumulative effects of DTR and temperature at lag 0–7 on COPD death

was found at lag 0–4 day. The associations of extremely high temperature on COPD mortality were significantly showed in lags of 0–2, 0–4, and 0–7 days (RR = 1.320, 95% CI: 1.071, 1.627; RR = 1.533, 95% CI: 1.236, 1.902; RR = 1.352, 95% CI: 1.163, 1.572, respectively). The cumulative effects of extremely high DTR and temperature over 7 days were presented in Fig. 3.

Table 3 shows the overall cumulative associations according to sex-specific subgroups. When comparing the associations of extremely high DTR and mean temperature on COPD deaths between males and females, no differences between them were seen. In addition, we have also tried to examine the associations of extremely high DTR on COPD deaths according to season. Seasonal effects of extremely high DTR on COPD mortality in various lag structures were presented in supplementary Table S1. We observed that the associations were more pronounced in cold season in lag 0–4 and lag 0–7, although the difference did not reach the statistical significance.

Sensitivity analysis

When varying the number of df for time period and relative humidity in sensitivity analysis, the estimation value changed little for the number of df we specified (Table 4 and supplementary Table S2). Furthermore, we performed sensitivity analysis by introducing other air pollutants. Although these results were slightly attenuated, the incorporation of $PM_{2.5}$, NO_2, and SO_2 into the base model did not substantially affect the risk estimate of DTR and temperature on COPD deaths (Table 5 and supplementary Table S2). The above results indicated that the relative robustness of the model specification applied in our study.

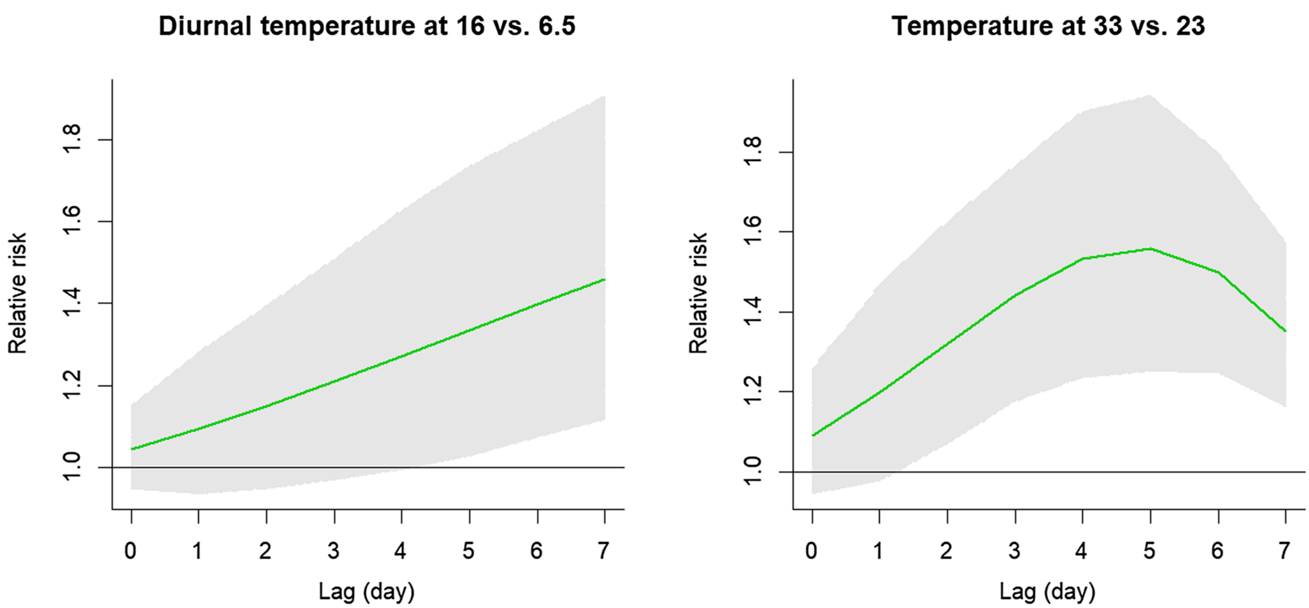

Fig. 3 Cumulative effects of extremely high DTR and temperature over 7 days on COPD death

Table 3 Cumulative effect of extremely high DTR and temperature (99th percentile) on COPD deaths by different gender in various lag structures

Variables	Characteristics	Lag 0	Lag 0–2	Lag 0–4	Lag 0–7	*p* value
DTR	Total	1.045 (0.949–1.151)	1.150 (0.949–1.395)	1.273 (0.995–1.627)	1.460 (1.118–1.908)	
	Male	1.073 (0.941–1.223)	1.237 (0.953–1.605)	1.394 (0.998–1.947)	1.453 (1.009–2.092)	0.992
	Female	1.012 (0.878–1.167)	1.053 (0.793–1.398)	1.136 (0.794–1.626)	1.457 (0.989–2.146)	Ref
Temperature	Total	1.090 (0.945–1.256)	1.320 (1.071–1.627)	1.533 (1.236–1.902)	1.352 (1.163–1.572)	
	Male	1.116 (0.919–1.356)	1.277 (0.959–1.701)	1.334 (0.993–1.793)	1.310 (1.066–1.610)	0.661
	Female	1.057 (0.860–1.299)	1.369 (1.012–1.853)	1.805 (1.323–2.463)	1.401 (1.126–1.743)	Ref

Table 4 Sensitivity analysis using different df for long-term trend and relative humidity

Variables	Characteristics	Basic model	Adjusting df of long-term and seasonal trend		Adjusting df of relative humidity			
			1	3	4	5	6	7
DTR	Total	1.460 (1.118–1.908)	1.491 (1.143–1.946)	1.426 (1.084–1.876)	1.456 (1.114–1.904)	1.435 (1.096–1.878)	1.427 (1.090–1.868)	1.425 (1.088–1.867)
	Male	1.453 (1.009–2.092)	1.501 (1.044–2.158)	1.451 (0.997–2.111)	1.437 (0.997–2.073)	1.428 (0.989–2.063)	1.422 (0.984–2.055)	1.422 (0.983–2.056)
	Female	1.457 (0.989–2.146)	1.466 (0.997–2.156)	1.385 (0.930–2.061)	1.464 (0.993–2.160)	1.428 (0.967–2.109)	1.419 (0.960–2.097)	1.415 (0.957–2.092)
Temperature	Total	1.352 (1.163–1.572)	1.369 (1.178–1.591)	1.351 (1.162–1.570)	1.349 (1.160–1.570)	1.343 (1.154–1.563)	1.340 (1.152–1.559)	1.340 (1.152–1.560)
	Male	1.310 (1.066–1.610)	1.335 (1.087–1.640)	1.309 (1.065–1.610)	1.303 (1.059–1.602)	1.299 (1.056–1.599)	1.297 (1.054–1.596)	1.298 (1.054–1.597)
	Female	1.401 (1.126–1.743)	1.407 (1.132–1.748)	1.399 (1.125–1.740)	1.405 (1.129–1.749)	1.395 (1.120–1.736)	1.391 (1.117–1.732)	1.391 (1.117–1.732)

Discussions

In this study, we examined the impact of temperature change between neighboring days on COPD-related mortality in a southeastern city, China. The results showed that both high DTR and temperature were significantly associated with an increased risk of COPD deaths. Then we illustrated the lag-effects pattern in these relationships and found that high DTR cumulated the risk over the lag period. Meanwhile, the cumulative effect of hot temperature was limited between 0 and 4 lag days. In addition, the results did not appear to be any difference in different sex groups. Air quality data, including $PM_{2.5}$, NO_2, and SO_2, did not confound the associations.

Up to now, relatively few epidemiologic studies focused on identifying specific mortality causes that particularly susceptible to DTR. One key finding of our study is that we depicted a non-linear J-shaped association between DTR and COPD deaths, where the cumulative effect was highest at the stratum of extremely high DTR. Our results were inconsistent with the previous study conducted in Shanghai (Kan et al. 2007). They reported that there was a significant association between DTR and daily COPD mortality with a linear pattern. Despite study concerning COPD-related mortality is limited, some recent studies have attempted to identify the association of DTR on respiratory disease mortalities, but the conclusions were still not coherent. In agreement with our results, studies conducted across different regions of China, including Hefei (Tang et al. 2018), Shenzhen (Xiao et al. 2021), and Yuxi (Ding et al. 2015), have demonstrated a J-shaped DTR-mortality association for respiratory disease, although their cumulative risk estimates of DTR on the mortality were slightly higher. In addition, Sharafkhani et al. (2017) and Lee et al. (2018) conducted studies to assess the association of DTR on deaths in Iran and Japan. The analyses strengthened the non-linear DTR-mortality associations, but it is almost an immediate effect at extremely high DTR and the risk estimate declined sharply as the lag days increased. Minor differences among the above studies might largely depend on the study method and geographical location (Bao et al. 2016; Zhang et al. 2020).

We identified that the associations between temperature and COPD mortality to be reversely J shaped. Low temperature could exert effects last more than a week, while high temperature may have an almost immediate effect, persisted about 4 days, which is consistent with the majority of previous multicity evidences (Guo et al. 2014; Ma et al. 2014, 2015). In fact, as compared with other climate changes, ambient mean temperature was explored most in previous studies. It is well known that extreme temperature is associated with excess mortality. For example, a national study

Table 5 The cumulative effect of extremely high DTR and temperature after controlling air pollution factors

Variables	Characteristics	Basic model	Introducing other air pollution factors		
			$PM_{2.5}$	NO_2	SO_2
DTR	Total	1.460 (1.118–1.908)	1.346 (1.026–1.766)	1.462 (1.111–1.922)	1.376 (1.031–1.836)
	Male	1.453 (1.009–2.092)	1.419 (0.978–2.057)	1.425 (0.979–2.074)	1.347 (0.907–2.000)
	Female	1.457 (0.989–2.146)	1.259 (0.845–1.875)	1.494 (1.002–2.228)	1.400 (0.919–2.132)
Temperature	Total	1.352 (1.163–1.572)	1.300 (1.104–1.531)	1.349 (1.133–1.606)	1.351 (1.148–1.589)
	Male	1.310 (1.066–1.610)	1.285 (1.025–1.612)	1.291 (1.016–1.641)	1.334 (1.067–1.667)
	Female	1.401 (1.126–1.743)	1.317 (1.039–1.671)	1.421 (1.104–1.831)	1.370 (1.081–1.735)

in New Zealand (Davie et al. 2007) detected that mortality rate was 18% higher in cold days. And mortality caused by respiratory diseases accounted for 31% of all excess deaths. Studies in Europe and North America demonstrated that, as a predictor of mortality, increases in temperature could be associated with the risk of lung function decline and exacerbations among those with COPD (Donaldson et al. 1999; Lepeule et al. 2018). Although the exact mechanism explaining the temperature-mortality relationship is not yet clearly established, our findings is biologically plausible. Population mortality rate typically displays a low level in optimal temperature zone. And the mortality rate has been found to be increased substantially as temperature outside this comfort zone (McMichael et al. 2006). Human have a highly efficient thermoregulatory system that elicit response to thermal stress. However, after a certain threshold, the system could not maintain the thermal comfort inside. Therefore, extreme temperature, such as heat waves and cold snaps, have been most frequently studied.

We found that season might be an effect modifier of DTR. This kind of seasonal effect was evidenced in previous studies. Several studies (Ding et al. 2015; Qiu et al. 2013; Zhou et al. 2014) reported the same seasonal pattern as ours: the association of high DTR was more evident in cold season. Increases in admissions with respiratory disease and COPD in cold season have been widely reported (Huang et al. 2015; Ou et al. 2013). Joint effect of DTR and temperature on COPD mortality might exist in our study.

It is worth noting that the potential effect modification in terms of the demographical characteristics could play a role in the temperature-related mortality associations (Goggins et al. 2013). More specifically, an increased vulnerability to mortality in the elderly and males has been reported (Ding et al. 2015; Tang et al. 2018). However, we could not identify significant discrepancies in exposure–response relationships between males and females, as well as between elderly and young adults, although the risk estimates were slightly attenuated. This might be partly explained by the sample size, climate condition, and social behaviors. Moreover, increased urbanization rates correspond to a greater exposure to heat, which is so-called the heat island effect (Medina-Ramon and Schwartz 2007). Thus, for a highly urbanized and densely populated city, such as Hangzhou, local residents are likely to be more exposed to heat wave and suffer worse outcome compared with those living in rural area. Further efforts in this field should focus on what makes the discrepancy and give a more comprehensive understanding of the relative contribution for these potential modifiers.

There is strong evidence that air pollutants could act as a confounder affecting the association of temperature variability on mortalities (Katsouyanni et al. 1993; Mo et al. 2018; Ren et al. 2008). Thus, we integrated air pollutant exposure, including $PM_{2.5}$, NO_2, and SO_2 in this study, but the results were similar with the base models. The risk estimates were only slightly and insignificantly attenuated. We concluded that ambient air pollution was not found to be a major confounder for the associations between temperature variability and COPD mortality.

There are several limitations in this study. First, the study design is an ecological study. Due to lack of temperature exposure at individual level, measurement bias might be existed, which limits the explanatory power of the study. Second, it is widely accepted that attributable risk for temperature is varied by geographic situation. The investigation includes population from one single city. It means that the findings might be hard to interpret to other areas. But we believed that these experiences are helpful for cities in the process of urbanization. Third, the sample size is insufficient to explore the subgroup analysis. Last, previous studies have shown that clinical characteristics such as occupation, socioeconomic status, and behavior pattern might confound the relationships between temperature-related mortality (Basu and Samet, 2002, Berko et al. 2014). However, due to the availability of the data, these factors were not account in this study. Therefore, further studies with diversity population and more detailed information were warrant to validate the above findings and elucidate the underlying mechanism. Moreover, personal measurements using portable monitoring devices with time-location information rather than data from environment monitoring station would be helpful to improve the amount and quality of the exposures.

Conclusions

Our study supported the hypothesis that both extremely high DTR and temperature were associated with an increased risk for COPD-related mortality in Hangzhou, China. Male and female, as well as young people and the elderly, did not differ in the risk estimates. This is a promising initial work in Hangzhou and may also provide instructive clues for other Asian cities, especially for those in the period of rapid urbanization. There is a need for effective action to mitigate and adapt to climate change. More risk-based assessments and managements were encouraged to provide information for decision-makers to address the immense challenges of climate change.

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Author contribution Simeng Gu: methodology, formal analysis, writing—original draft. Xiaofeng Wang: conceptualization, supervision, writing—review and editing. Guangming Mao: project administration. Xuemin Huang: project administration. Yuanyang Wang: project administration. Peiwei Xu: data curation. Lizhi Wu: data curation. Xiaoming Lou: funding acquisition, supervision. Zhijian Chen: methodology, supervision. Zhe Mo: conceptualization, methodology, formal analysis, visualization, writing—review and editing.

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Data availability The dataset is available from the corresponding author on reasonable request.

Declarations

Ethics approval Ethical approval was not required for no patient involved in this study. Personal information is anonymous.

Consent to participate Not applicable.

Consent for publication All authors consent to publish this article in *Environmental Science and Pollution Research*.

Competing interests The authors declare no competing interests.

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