RESEARCH ARTICLE

The relationship between ambient temperature and acute respiratory and cardiovascular diseases in Shenyang, China

Yang Shen[1] · Xudong Zhang[2] · Cai Chen[3,4] · Qianqian Lin[5] · Xiyuan Li[4] · Wenxiu Qu[6] · Xuejian Liu[7] · Li Zhao[2] · Shijie Chang[1]

Abstract

The purpose of this study was to analyze the acute effect of ambient temperature on hospitalization due to acute exacerbation of chronic obstructive pulmonary disease (AECOPD), stroke, and myocardial infarction (MI) in Shenyang, China. We used the distributed delayed nonlinear model to evaluate the impact of ambient temperature on respiratory and cardiovascular diseases. The study population was divided into four groups: < 65 group and ≥ 65 age groups, female and male groups. The < 65 age group of AECOPD patients was more likely to be affected by high ambient temperature, while the ≥ 65 age group of AECOPD patients was more sensitive to low ambient temperature. The hospitalization risk of MI admission increased in the ≥ 65 age group at 1–8 days delay under low ambient temperature conditions.

Keywords Ambient temperature · Acute hospitalization · Distributed delay nonlinear model · Acute exacerbation of chronic obstructive pulmonary disease

Introduction

Respiratory, cardiovascular, and cerebrovascular diseases are the leading causes of death worldwide (Ryan et al. 2019; Pranata et al. 2020). According to the Global Burden of Disease Study 2015, approximately 3.2 million people have died from chronic obstructive pulmonary disease (COPD). The prevalence of COPD has increased to 44.2% from 11.6% in 1990 (Dang et al. 2019; GBD 2015 Chronic Respiratory Disease Collaborators 2017). Another study indicated that by 2025, approximately 1.5 million individuals in Europe will suffer a stroke and the associated incidences of re-hospitalization, recurrent events, dementia mild cognitive disorder, and depression will increase (Béjot et al. 2016). Myocardial infarction (MI) is a cardiovascular disease that has physiological and psychological effects. Feng et al.'s study showed that the prevalence of depression among patients with MI was 28.70% (Feng et al. 2019). Considering the high incidence of COPD, stroke, and MI, all of which lower a patient's quality of life, there is an urgent need to better understand disease risk factors.

Several studies have demonstrated that ambient temperature may be an important risk factor for COPD, stroke, and MI in China (Chen et al. 2019; Qi et al. 2020). One study

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Yang Shen and Xudong Zhang contributed equally to this work.

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✉ Li Zhao
    lzhaoli@163.com

✉ Shijie Chang
    sjchang@cmu.edu.cn

[1] Division of Biomedical Engineering, China Medical University, Shenyang 110122, Liaoning, China

[2] Department of Pulmonary and Critical Care Medicine, Shengjing Hospital of China Medical University, No. 36 Sanhao Road, Heping District, Shenyang 110000, Liaoning, China

[3] Shandong Institute of Advanced Technology, Chinese Academy of Sciences, Jinan 250000, Shandong, China

[4] Biomedical Engineering Institute, School of Control Science and Engineering, Shandong University, Jinan 250061, Shandong, China

[5] College of Letters and Science, University of California, Berkeley, Berkeley, CA 94720, USA

[6] Parexel China Co., Ltd. Shenyang Branch, Shenyang 110000, China

[7] The First General Internal Medicine, Shengjing Hospital, China Medical University, No.16 Puhe Road, Shenbei New District, Shenyang 110000, Liaoning, China

Fig. 1 The number of stroke patients' hospitalization during the study period
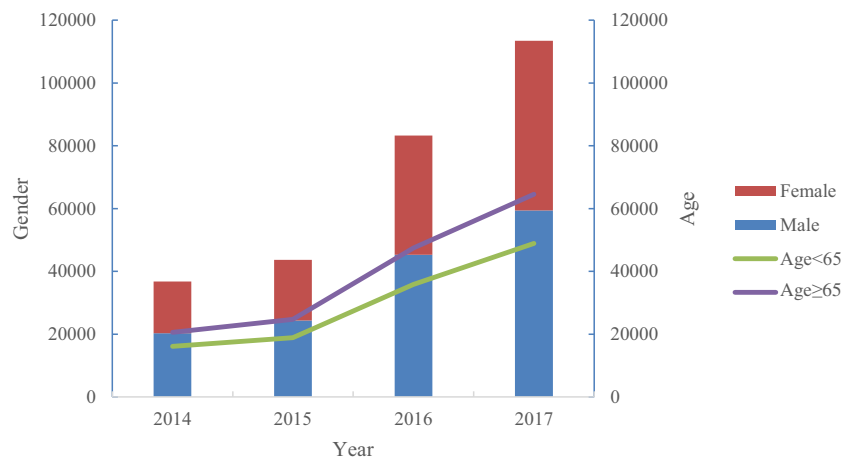
conducted in Changchun, China, that evaluated changes in ambient temperature on consecutive days found that the elderly and females were at a greater risk of acute disease exacerbation (Ma et al. 2020). Lian et al. found that an increase of 1 °C increased stroke risk by 1.13% (0.58–1.68%) and that a decrease of 1 °C increased the risk by 1.2% (0.84–1.57%) (Lian et al. 2015). One survey in the Vietnam North-Central Coast region showed that the risk of MI hospital admission increased by 11% (95% confidence interval (CI): 0.91–1.35) at moderately low temperatures and increased by 25% (95% CI: 1.02–1.55) at extremely low temperatures (Thu Dang et al. 2019). These studies support a link between ambient temperature and acute exacerbation of respiratory and cardiovascular diseases. However, these studies were conducted in different geographical regions with varying climates. The goal of this study was to investigate the association between ambient temperature and acute exacerbation of COPD (AECOPD), stroke, and MI in Shenyang, China.

Methods

The admission records of patients with AECOPD, stroke, and MI were obtained from Shenyang Medical Healthcare

Security Administration. The records included admission date, gender, age, date of discharge, and admission number. Mean temperature (°C) and relative humidity (%) were attained from the Shenyang Meteorological Bureau. We used the distributed delayed non-linear model (DLNM) to determine the association between ambient temperature and disease. The DLNM can be used as an index of the relationship between cumulative hysteresis effect, exposure, and response as shown in equation (1) (Gasparrini et al. 2010; Forbes 2010):

$$\log[E(yt)] = \alpha + \phi_1 Temperature + ns(humidity, df) + s(time, df) + s(pressure, df) + \phi_2 factor(dow) + \phi_3 factor(holidays) \quad (1)$$

where α is the intercept value; φ_1, φ_2, and φ_3 are regression correlations; $E[(yt)]$ is the expected number of daily admissions at day t; df is the degrees of freedom; Temperature is ambient temperature; humidity is the daily relative humidity; pressure is the daily average pressure; dow is a dummy variable for the day of the week; ns represents a smoothed function of time (df = 4), pressure (df = 5), and humidity (df = 3) (Chen et al. 2019; Song et al. 2019; Luo et al. 2018a).

Fig. 2 The hospitalization variation of patients with myocardial infarction during research period
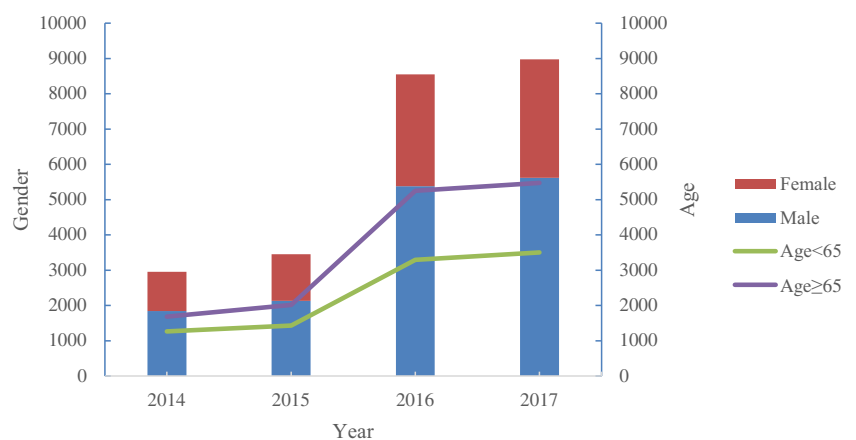
Fig. 3 The variation of admission rate for patients with AECOPD (AECOPD: acute exacerbation of chronic obstructive pulmonary disease)
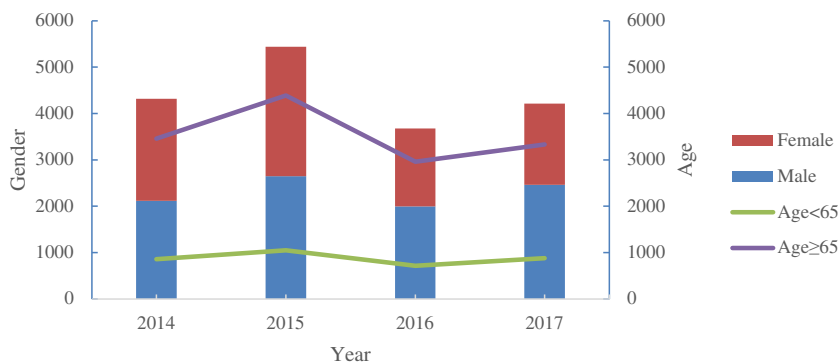
Analysis results are expressed as percent change of the relative risk (RR) of hospitalization and the 95% CI for temperature change. Stratification analysis was used to compare the < 65 age and the ≥ 65 age groups, and the male and female groups. Statistical analysis was conducted using RStudio 4.0.2.

Results

Descriptive results

There were 276,736 stroke cases (149,500 male and 127,236 female); 56.8% was ≥ 65 years old, and 43.2% was < 65 years old. Figure 1 illustrates the trend of stroke morbidity during the study period. The incidence rate of stroke increased over time.

There were 26,235 MI cases (16,408 males and 9,827 females); 55.0% was ≥ 65 years old, and 45.0% was < 65 years old. Figure 2 shows the hospitalization variation of patients with MI. The incidence rate was greater in patients ≥ 65 years old compared to those < 65 years old. Morbidity was higher in males compared to females.

There were 17, 644 cases of AECOPD (9228 males and 8416 females); 80.2% was ≥ 65 years old, and 19.8% was < 65 years old. Figure 3 shows the variation of admission rate for patients with AECOPD. The incidence of AECOPD was more common in patients ≥ 65 years old.

The meteorological factors involved in this study are presented in Table 1. The average ambient temperature, relative humidity, and air pressure were 9 °C, 46%, and 1017 hPa, respectively.

DLNM result for stroke

The maximum RR and 95% CI between ambient temperature and acute admission of stroke under different delay conditions are shown in Table 2. The maximum RRs and 95% CIs in Lag 0-27 were as follows: < 65 age group [1.470 (95% CI: 1.040–2.078)] and ≥ 65 age group [1.487 (95% CI: 1.060–2.085)]; male group [1.567 (95% CI: 1.120–2.193)] and female group [1.395 (95% CI: 0.942–2.063)].

As shown in Fig. 4, there was a nonlinear relationship between ambient temperature and the whole population of acute stroke admission. The risk of admission reached a peak value when the ambient temperature was − 20°C, and the risk persisted for 25 days when the temperature exceeded 20 °C.

The three-dimensional graph and contour map for the risk of male and female stroke admission under different delay days are shown in Fig. 5. The relationship between temperature and admission risk was fairly complex. When the temperature was between 3 °C and 20 °C, there was no impact in the female group. Lower temperatures exacerbated the risk of stroke admission for both the male and female groups, and the risk of stroke admission increased when the temperature was lower than − 11 °C with a delay of 24–27 days. The ambient temperature appeared to have a protective effect in the male population, and the risk of admission was reduced when the temperature ranged between 20 °C and 30 °C with a delay of 0–20 days.

Table 1 Descriptive statistics result for daily meteorological factors

Meteorological factors	$X \pm S$	Min	P_{25}	P_{50}	P_{75}	Max	IQR
Temperature (°C)	9 ± 13	− 25	− 3	11	21	30	24
Relative humidity (%)	46 ± 26	2	17	51	67	98	50
Pressure (hPa)	1017 ± 71	987	1008	1016	1025	1041	17
Wind speed (Km/h)	8 ± 3	2	6	8	10	26	4

Min minimum, *Max* maximum, *IQR* interquartile range, *X* mean value, *S* standard deviation, P_{25} the first quartile, P_{50} the second quartile, P_{75} the third quartile

Table 2 Maximum relative risk (RR) and 95% confidence interval (CIs) under different delay conditions for temperature and acute stroke admission

	Lag$_{0-6}$	Lag$_{0-13}$	Lag$_{0-20}$	Lag$_{0-27}$
Total				
RR	1.186	1.359	1.255	1.470
95%CI	1.044–1.347	1.135–1.627	0.997–1.579	1.040–2.078
Age < 65				
RR	1.118	1.301	1.201	1.458
95%CI	0.975–1.281	1.061–1.595	0.922–1.565	0.981–2.169
Age ≥ 65				
RR	1.210	1.412	1.304	1.487
95%CI	1.048–1.398	1.179–1.690	1.040–1.636	1.060–2.085
Female				
RR	1.304	1.424	1.312	1.567
95%CI	1.141–1.491	1.190–1.705	1.047–1.645	1.120–2.193
Male				
RR	1.093	1.319	1.206	1.395
95%CI	0.953–1.255	1.080–1.612	0.945–1.537	0.942–2.063

The relationship between temperature and the risk of acute stroke hospitalization under different delay days is shown in Fig. 6. Low ambient temperatures increased the possibility of stroke admission in the ≥ 65 age group and the < 65 age group, and the ≥ 65 age group was more susceptible to lower temperatures.

S 1(a) shows the curve variation between temperature and risk of stroke admission in females under different cumulative lag days. Under the conditions of cumulative Lag$_{0-13}$ and Lag$_{0-20}$ days, higher temperatures had a protective effect on the female group and the risk of admission was reduced. The risk of acute stroke admission among the female group decreased at first but then increased at cumulative Lag$_{0-27}$ days. The association between temperature and the risk of acute stroke among the male group under different cumulative lag days is shown in S 1 (b). The shaded part represents the 95% CI. The upper left and right images show a cumulative lag of 6 days and a cumulative lag of 13 days, respectively. The risk of admission of stroke in the male group increased initially, but then decreased with increases in temperature; the bottom right shows the cumulative lag of 27 days. With the increase in temperature, the risk of admission in the male group decreased at first and then increased. The results based on age stratification are shown in S 1(c-d).

DLNM result for MI

The maximum RRs and their 95% CIs for ambient temperature and acute MI admission under different delay conditions are summarized in Table 3. The maximum RRs and 95% CIs were as follows: entire population [1.600 (95% CI: 0.775–3.302)], < 65 age group [2.132 (95% CI: 0.704–6.460)], and ≥ 65 age group [1.486 (95% CI: 1.042–2.119)]. As shown in Fig. 7, there was no linear association between ambient
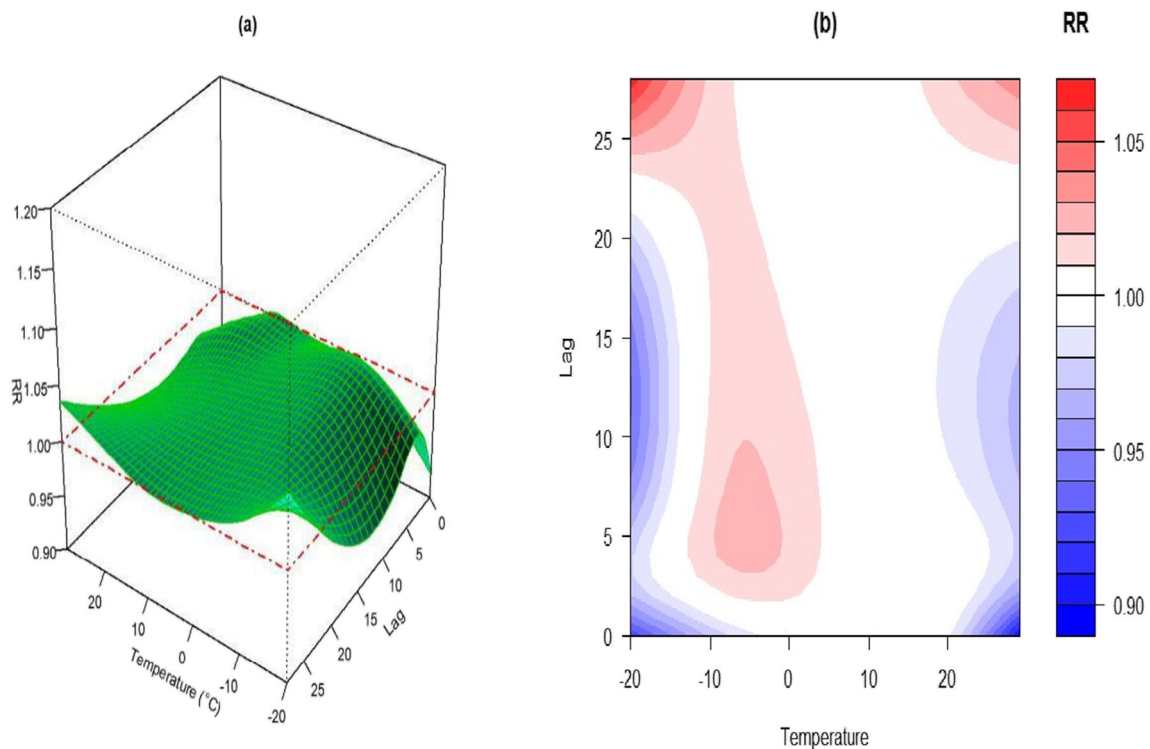
Fig. 4 Relationship between temperature and risk of acute admission of stroke in different delay days
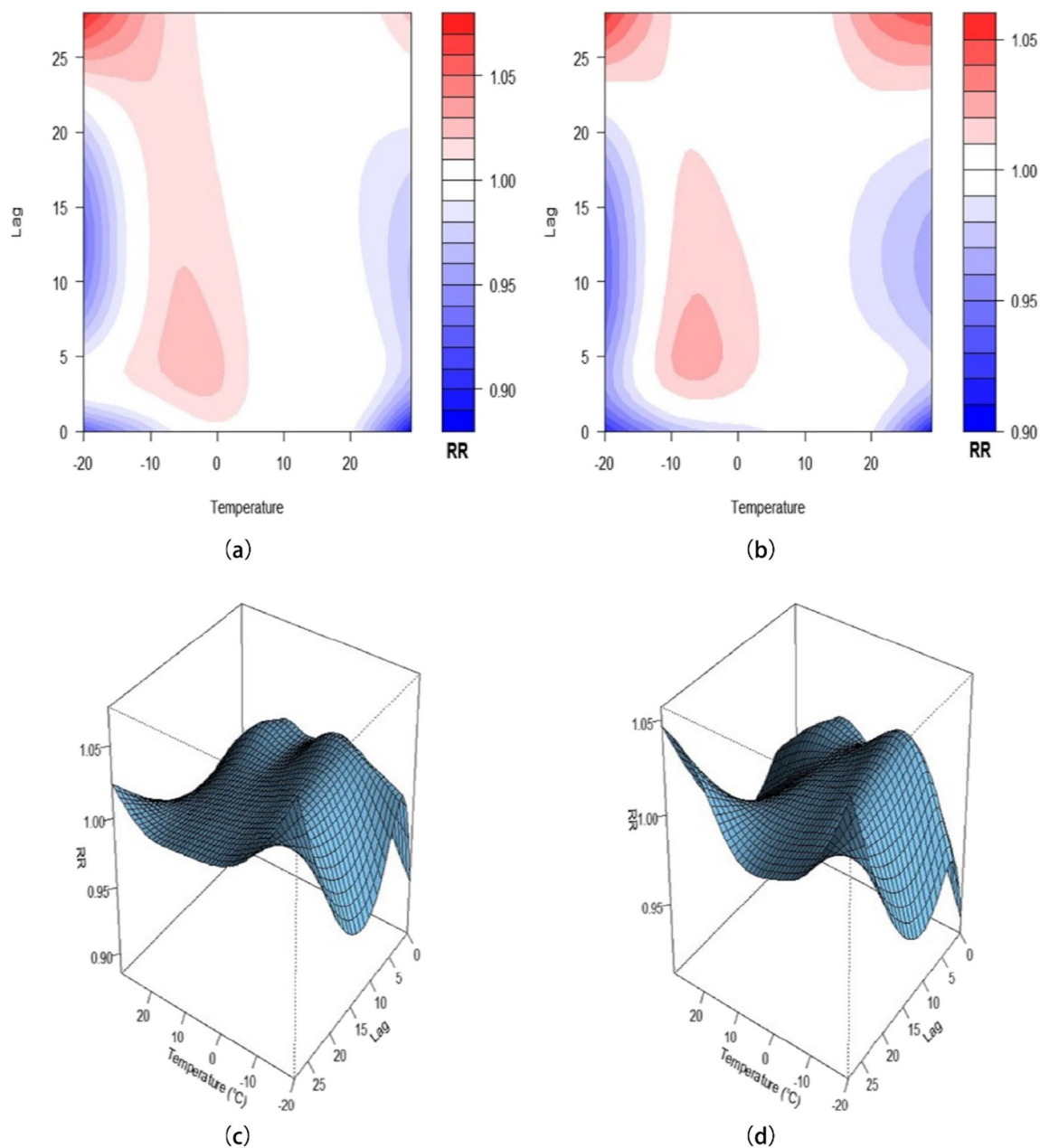
Fig. 5 The influence of ambient temperature on the risk of acute stroke admission based on the gender stratifications (**a** and **c**, female; **b** and **d**, male)

temperature and the entire population of acute MI admission. The data show that lower temperatures are a high-risk factor for MI admission when the delay is 2–8 days. When the temperature was greater than 10 °C, the temperature did not affect the risk of MI, and may actually have been protective.

The RR between temperature and MI hospitalization in the male and female groups under different delay days are shown in Fig. 8. When the delay was 0–6 days, low temperatures increased the RR of MI hospitalization. The effect of ambient temperature on MI in the < 65 age group and ≥ age 65 group is provided in Fig. 9 The risk of MI hospitalization increased in the ≥ 65 age group at 1–8 days delay under low-temperature conditions. The effect of temperature on MI hospitalization

based on gender stratification under different cumulative lag days is shown in S 2(a-b). The analysis based on age stratification and cumulative effect of temperature on MI hospitalization is shown in S 2(c-d).

DLNM result for AECOPD

The maximum RRs and 95% CIs for temperature on AECOPD under different delay conditions are shown in Table 4. The maximum RRs and 95% CIs under the condition of lag$_{0-27}$ were as follows: entire population [2.061 (95% CI: 0.772–5.500)], < 65 age group [1.972 (95% CI: 0.910–4.270)], and ≥ 65 age group [1.972 (95% CI: 0.910–4.270)].
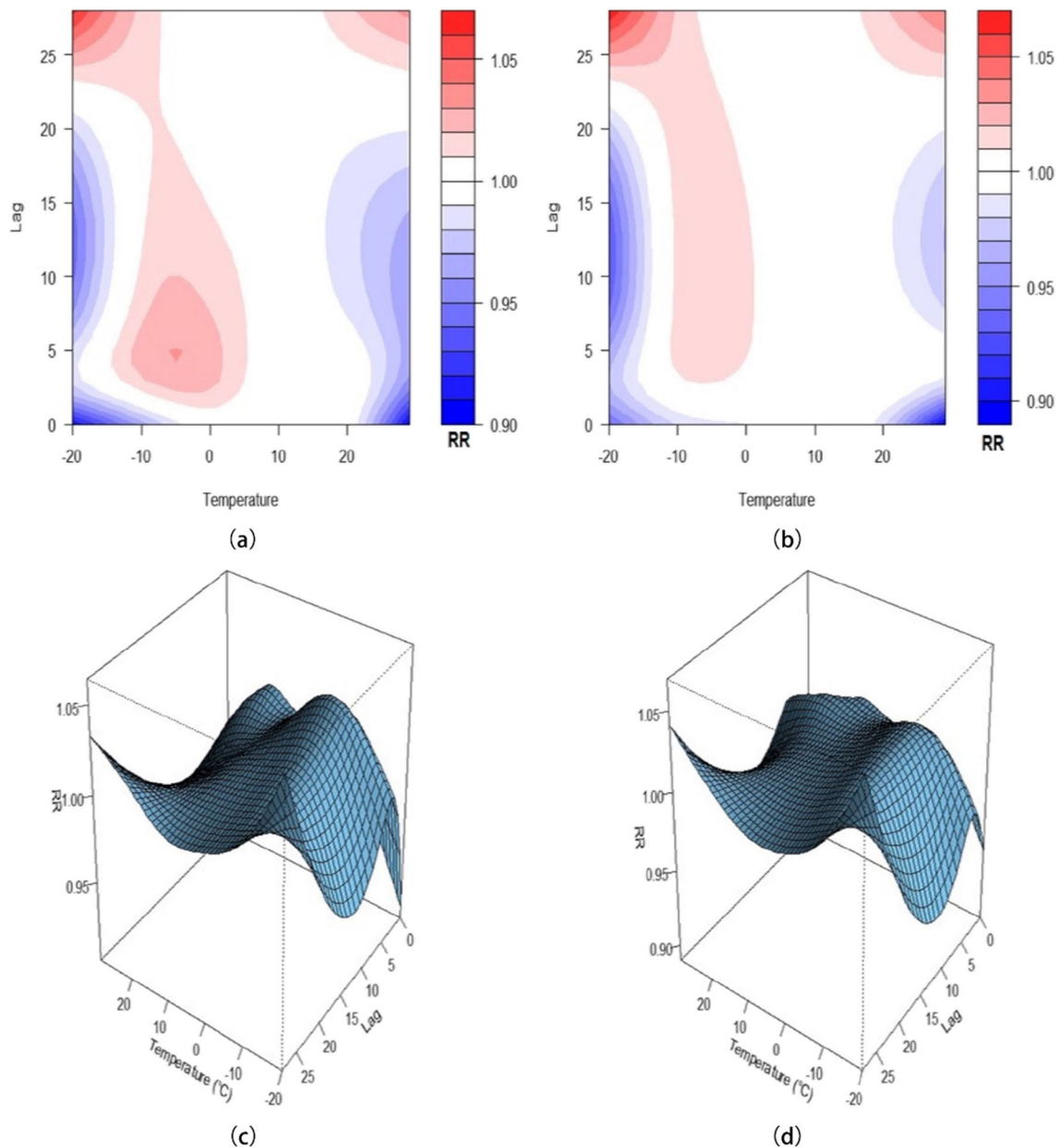
Fig. 6 The influence of ambient temperature on the risk of acute stroke admission based on the age stratifications (**a** and **c**, age ≥ 65 group; **b** and **d**, age < 65 group)

Figure 10 shows that the relationship between ambient temperatures on AECOPD hospitalization was non-linear. As temperature increased, the AECOPD hospitalization risk increased initially, decreased, and then increased again. Temperature had little effect on AECOPD hospitalization in the range of 5 °C to 10 °C.

The risks of ambient temperature for AECOPD in the < 65 age group and ≥ 65 age group are shown in Fig. 11. The < 65 age group was more likely to be affected by high temperature, while the ≥ 65 age group was more sensitive to low temperature. The cumulative effect of temperature on the < 65 and ≥ 65 age group is presented in S 3(a–b). As temperature increased, the hospitalization

risk in the ≥ 65 age group was stable after initially decreasing; when the temperature was greater than – 10 °C, there was a protective effect. S 3(b) shows that high temperatures increased the risk of AECOPD hospitalization in the < 65 age group.

Stratification based on gender is shown in Fig. 12. Temperature had a persistent delayed effect in both the male and female groups. The cumulative lag effect in the male and female groups is shown in S 3(c-d). When the temperature was lower than – 10 °C, the RR of admission increased in the female group. High temperatures reduced the RR of AECOPD hospitalization in the male group.

Table 3 Maximum relative risk (RR) and 95% confidence interval (CIs) under different delay conditions for temperature and acute MI admission

|	Lag$_{0-06}$	Lag$_{0-13}$	Lag$_{0-20}$	Lag$_{0-27}$
Total				
RR	1.208	1.383	1.141	1.600
95%CI	1.004–1.455	1.051–1.819	0.786–1.657	0.775–3.302
Age < 65				
RR	1.203	1.244	1.285	2.132
95%CI	0.739–1.958	0.829–1.867	0.556–2.972	0.704–6.460
Age ≥ 65				
RR	1.245	1.486	1.103	1.297
95%CI	0.982–1.578	1.042–2.119	0.681–1.788	0.513–3.279
Female				
RR	1.213	1.439	0.925	1.449
95%CI	0.910–1.618	0.940–2.202	0.5115–1.663	0.472–4.449
Male				
RR	1.207	1.352	1.293	1.684
95%CI	0.961–1.516	0.968–1.887	0.821–2.035	0.693–4.096

Discussion

The purpose of this study was to evaluate the effect of ambient temperature on AECOPD, stroke, and MI hospitalization rates in Shenyang, China, using the DLNM. Some studies have shown that the coronavirus outbreaks in 2003 and 2019 were closely related to environmental factors, such as temperature (Sehra et al. 2020; Sajadi et al. 2020; Auler et al. 2020). This led us to consider the link between environmental temperature and disease. This study was therefore designed to explore the relationship between respiratory and cardiovascular diseases, particularly COPD, one common underlying respiratory disease that is has been under investigated in the literature. Our study is of great significance for informing COPD patients, as well as stroke and MI patients, of the influence of temperature change on their risk of hospitalization.

It is reported that stroke morbidity in Shenyang is increasing, which is particularly alarming for both developing and developed countries. Previous research showed that stroke is connected to astogeny (Béjot et al. 2016), which is consistent with our findings in this study. Kes et al. also reported that acute hospital admissions are higher among males compared to females (Kes et al. 2016).

The findings of this study confirmed the previous research that ambient temperature adversely affects an individual's health. A study that included 4310 hemorrhagic or ischemic stroke patients in Japan demonstrated that when the mean temperature on the onset day was 1 °C lower than that of the previous week, the number of patient hospitalizations increased (Gomes et al. 2015). Alina Vodonos' study showed
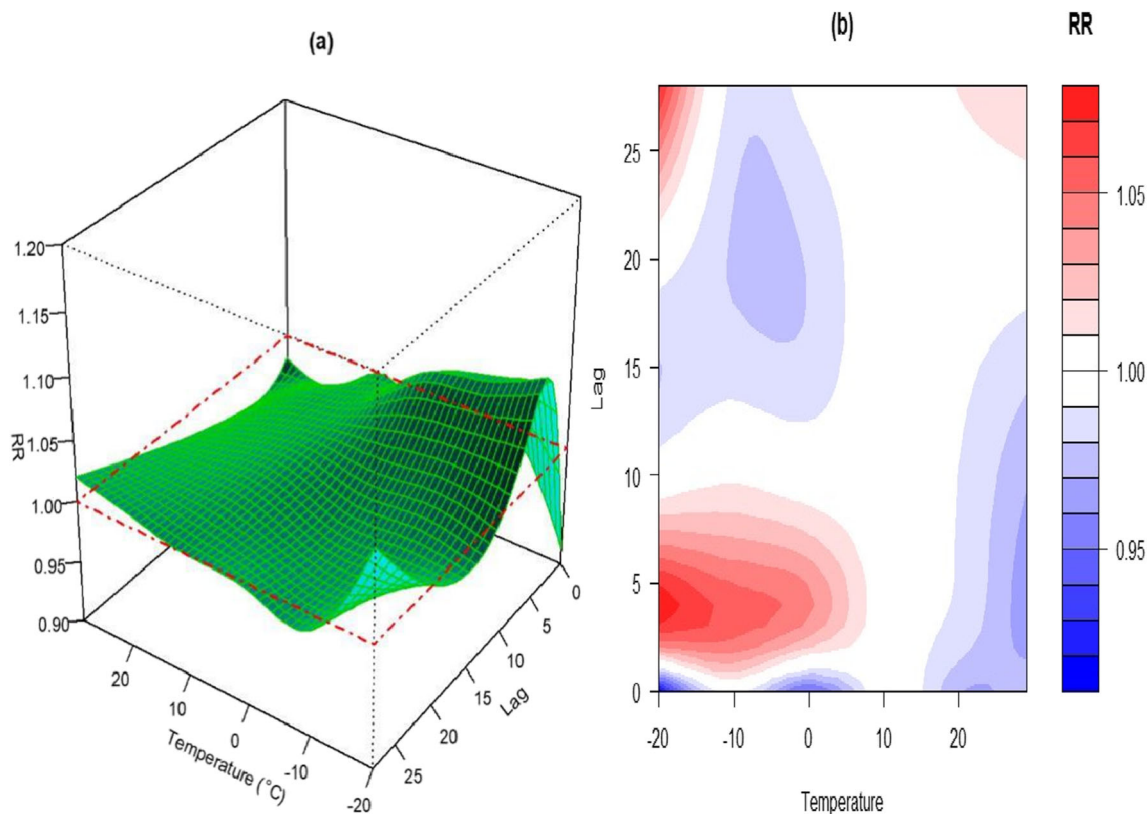
Fig. 7 Relationship between temperature and risk degree of acute admission of myocardial infarction patients in different delay days
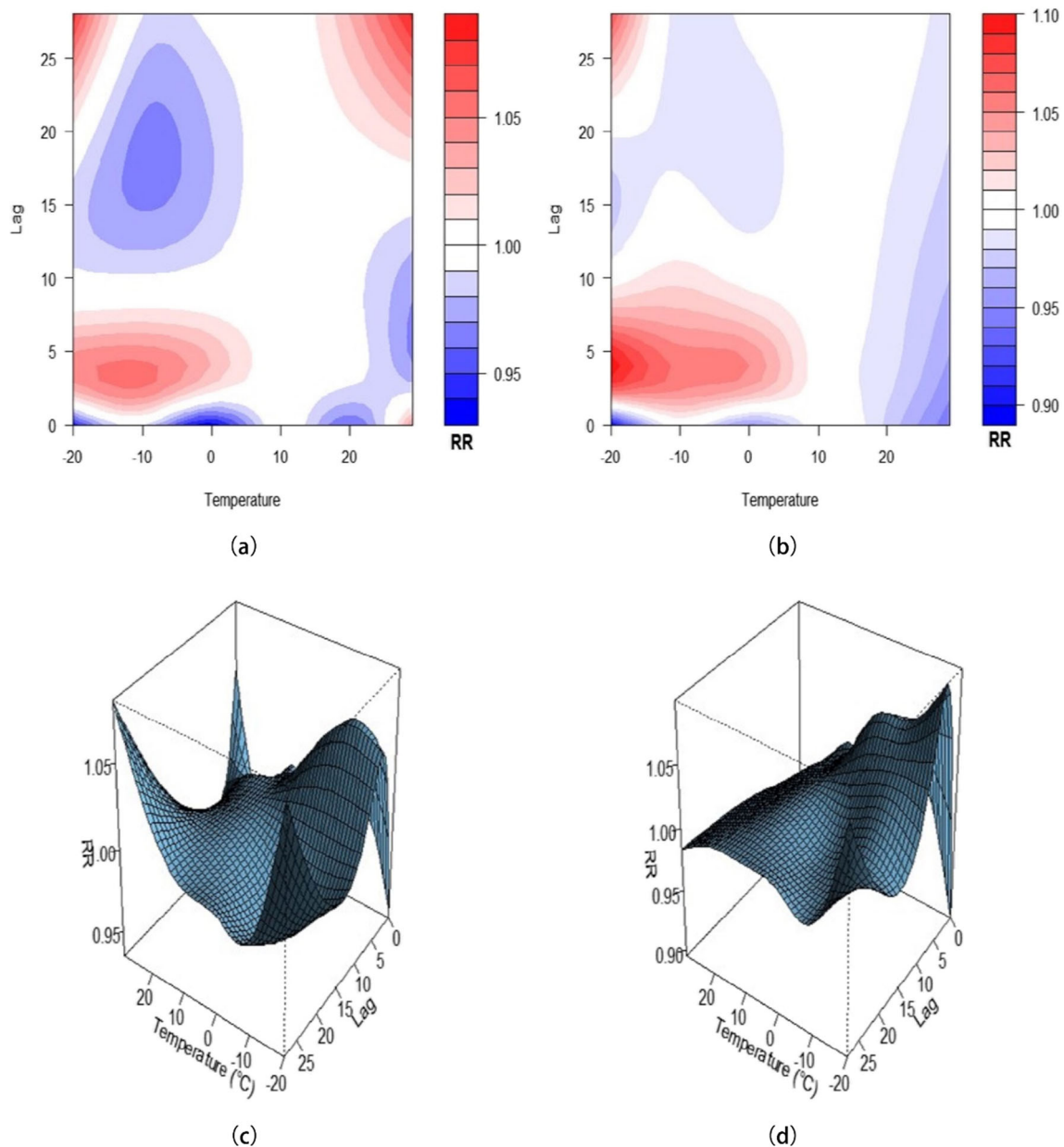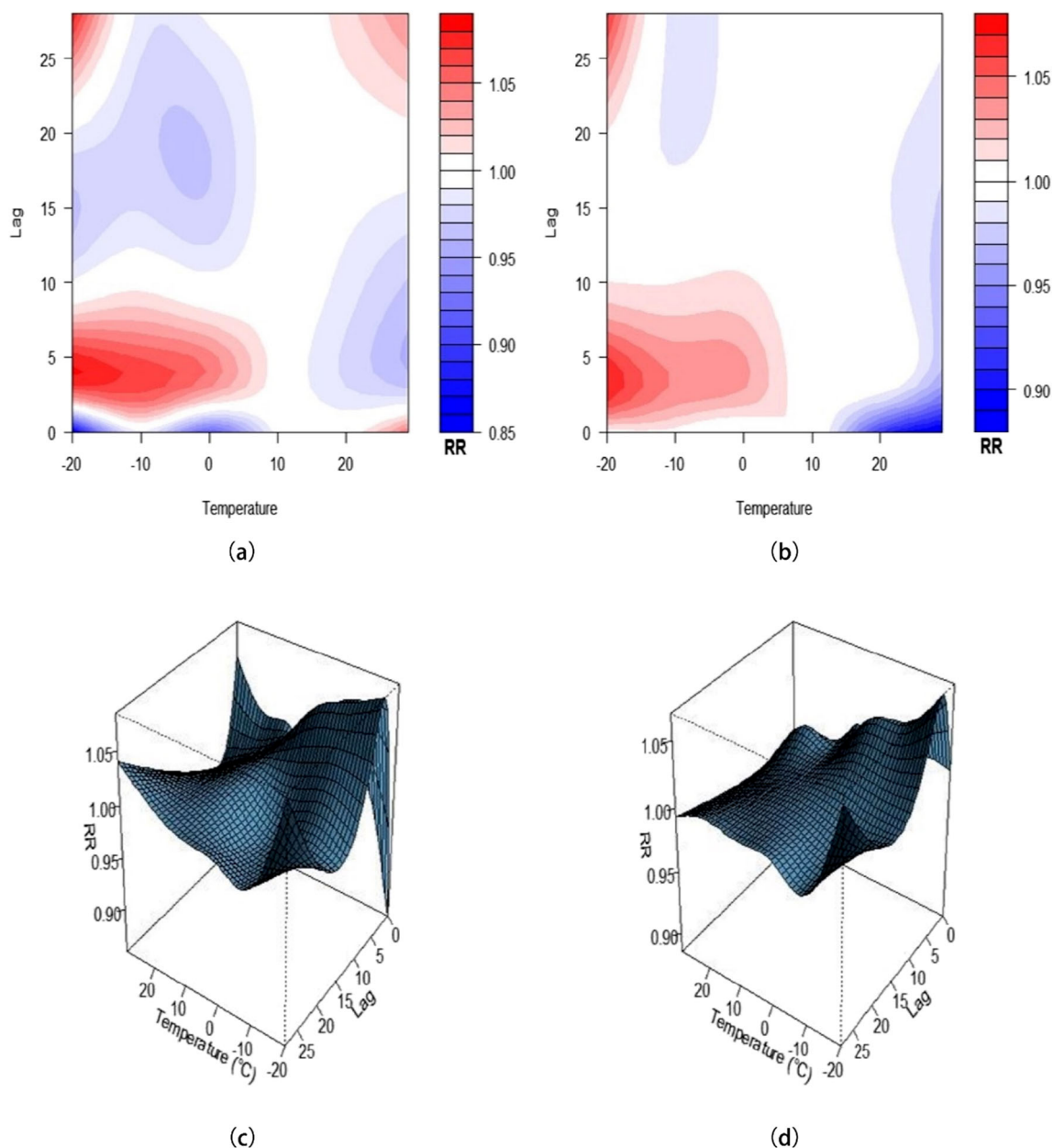
Fig. 8 The influence of ambient temperature on the risk of acute myocardial infarction admission based on the gender stratifications (**a** and **c,** female; **b** and **d**, male)

that ischemic stroke was associated with temperature; the odds ratio (OR) for an increase of 5 °C was 3.10 (95% CI, 1.45–6.61) during the summer and 1.86 (95% CI, 1.15–2.99) in the autumn (Vodonos et al. 2017). A case-crossover study in Maputo illustrated that a first stroke occurrence declined with minimum temperature changes between consecutive days of the preceding week (Gomes et al. 2015).

The present study found that lower temperatures increase the risk of stroke hospitalization. The pathogenesis of stroke induced by low ambient temperature may involve blood pressure fluctuations. Temperature drops enhance blood pressure by activating the sympathetic nervous system (SNS) and increasing the activity of the renin angiotensin system (RAS). In cold conditions, extracellular calcium ions enter the cells through L-type calcium channels, causing an increase in calcium concentration, initiating the excitation-contraction coupling mechanism of smooth muscle cells, inducing vasoconstriction (ZHU et al. 2002; Duncker et al. 1996). Previous studies have confirmed that hypertension is the most important cause of stroke. Vascular hypertension mainly manifests as abnormal arterial wall morphology, and the main pathological basis is hyaline degeneration of small arteries. Chronically uncontrolled hypertension can lead to atherosclerosis, which leads to narrowing or occlusion of the arteries, and ultimately stroke (Lawes et al. 2004;

Fig. 9 The influence of ambient temperature on the risk of acute myocardial infarction admission based on the age stratifications (**a** and **c**, age ≥ 65 group; **b** and **d**, age < 65 group)

Gosmanova et al. 2016). Fluctuations in blood pressure can also cause stroke. Analysis of blood pressure monitoring in 1526 elderly males showed that blood pressure fluctuation was closely related to stroke, and the incidence of stroke increased by 2% for every 1 mmHg increase in systolic blood pressure variation (Mena et al. 2017).

Our analysis showed that when the temperature ranged from 3 °C to 20 °C, there was no impact on stroke hospitalization risk, and in fact, this temperature range conferred some protection. This supported Ganeshan's research, which showed that a comfortable temperature for humans ranges 20 °C–22 °C (Ganeshan and Chawla 2017). One meta-analysis involving 476,511 patients

illustrated that older patients were more vulnerable to lower temperatures (Wang et al. 2016), which is consistent with our findings. Our finding that the impact of ambient temperature on stroke admissions was greater in the Males group contradicts a previous study by Luo et al. (Luo et al. 2018b). These discrepancies could be attributed to the fact that males in Shenyang may have an unhealthier lifestyle that involves alcohol consumption and smoking. Some surveys showed that alcohol is closely related to stroke occurrence (Larsson et al. 2016; Bardach et al. 2017). Another possible reason is that males are more likely to work outdoor jobs, which leads to more exposure to ambient air pollution. It has been

Table 4 Maximum relative risk (RR) and 95% confidence interval (CIs) under different delay conditions for temperature and acute COPD admission

	Lag$_{0-06}$	Lag$_{0-13}$	Lag$_{0-20}$	Lag$_{0-27}$
Total				
RR	1.336	1.253	1.311	2.061
95%CI	1.115–1.601	0.935–1.680	0.894–1.921	0.772–5.500
Age < 65				
RR	1.865	1.707	1.756	1.972
95%CI	1.092–3.185	0.757–3.847	0.865–3.561	0.910–4.270
Age ≥ 65				
RR	1.253	1.164	1.209	1.799
95%CI	1.048–1.498	0.857–1.580	0.794–1.839	0.619–5.225
Female				
RR	1.292	1.315	1.237	2.903
95%CI	1.010–1.654	0.909–1.900	0.829–1.845	0.844–9.990
Male				
RR	1.420	1.206	1.422	1.603
95%CI	1.119–1.802	0.849–1.713	0.835–2.422	0.683–3.766

shown that exposure to air pollution can increase the risk of stroke hospitalization (Chen et al. 2020; Shah et al. 2015). We did not address air pollution in our analysis, which is one limitation of our study.

The findings of this study confirm the previous studies showing that ambient temperature is associated with MI mortality and morbidity. Sun et al. found that cold exposure, heat exposure, and exposure to heat waves were associated with an increased risk of MI (Sun et al. 2018). Similarly, according to Wasserman et al.'s research, there is an association between decreased root mean square successive difference (RMSSD) and increasing temperature in the summer and decreasing temperature in the winter. In a panel of cardiac rehabilitation patients, changes in ambient temperature were associated with decreases in biomarkers of heart rate variability and baroreflex sensitivity (Wasserman et al. 2014). Other reports suggested that variations in temperature trigger vasoconstriction, elevated blood pressure, and capillary contraction, which could explain the link between ambient temperature and MI morbidity (Mackay et al. 2019; Chang et al. 2004). The ability of changes in ambient temperatures to trigger MI could be explained as follows. First, increases in hemodynamic factors, such as blood viscosity, plasma cholesterol, vascular resistance, heart rate, and blood pressure, might lead to MI in colder weather (Giles et al. 2018; Lin et al. 2019). Moreover, temperature changes may impact immunity. Temperature changes can alter body fluids and cellular immunity, resulting in decreased immunity, decreased resistance, and increased risk of MI (Ji et al. 2020). One
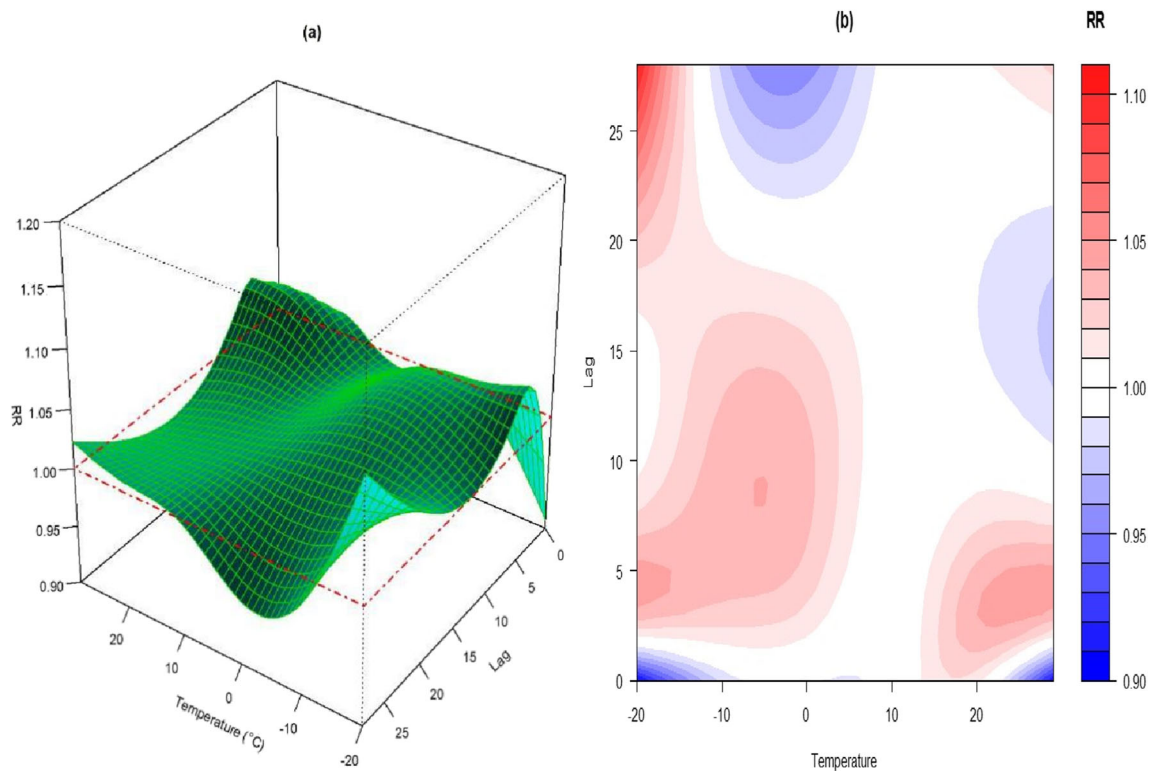
Fig. 10 Relationship between temperature and total admission in patients with AECOPD under different lag days (**a** three-dimension map, **b** contour map; AECOPD, acute exacerbation of chronic obstructive pulmonary disease)
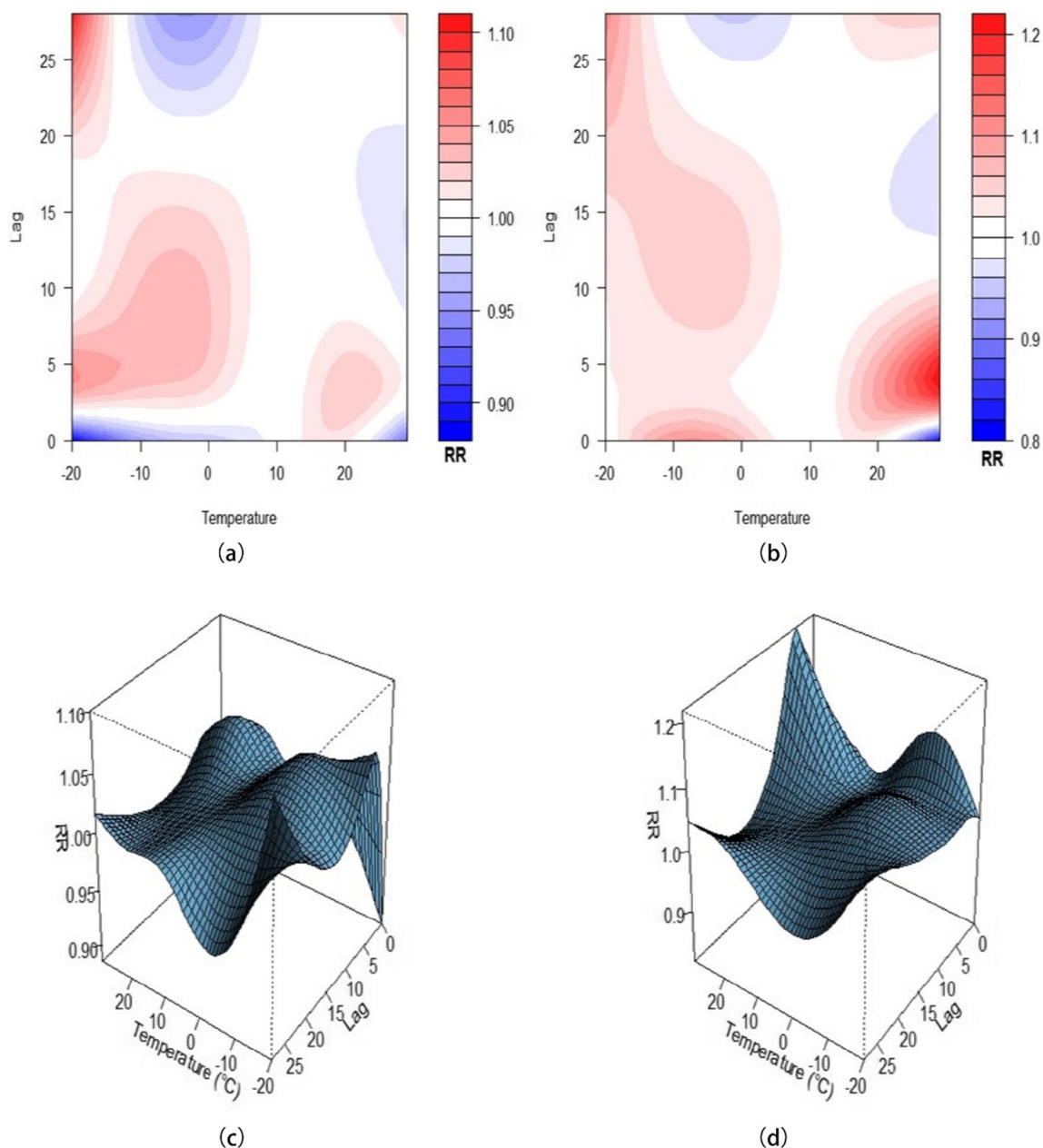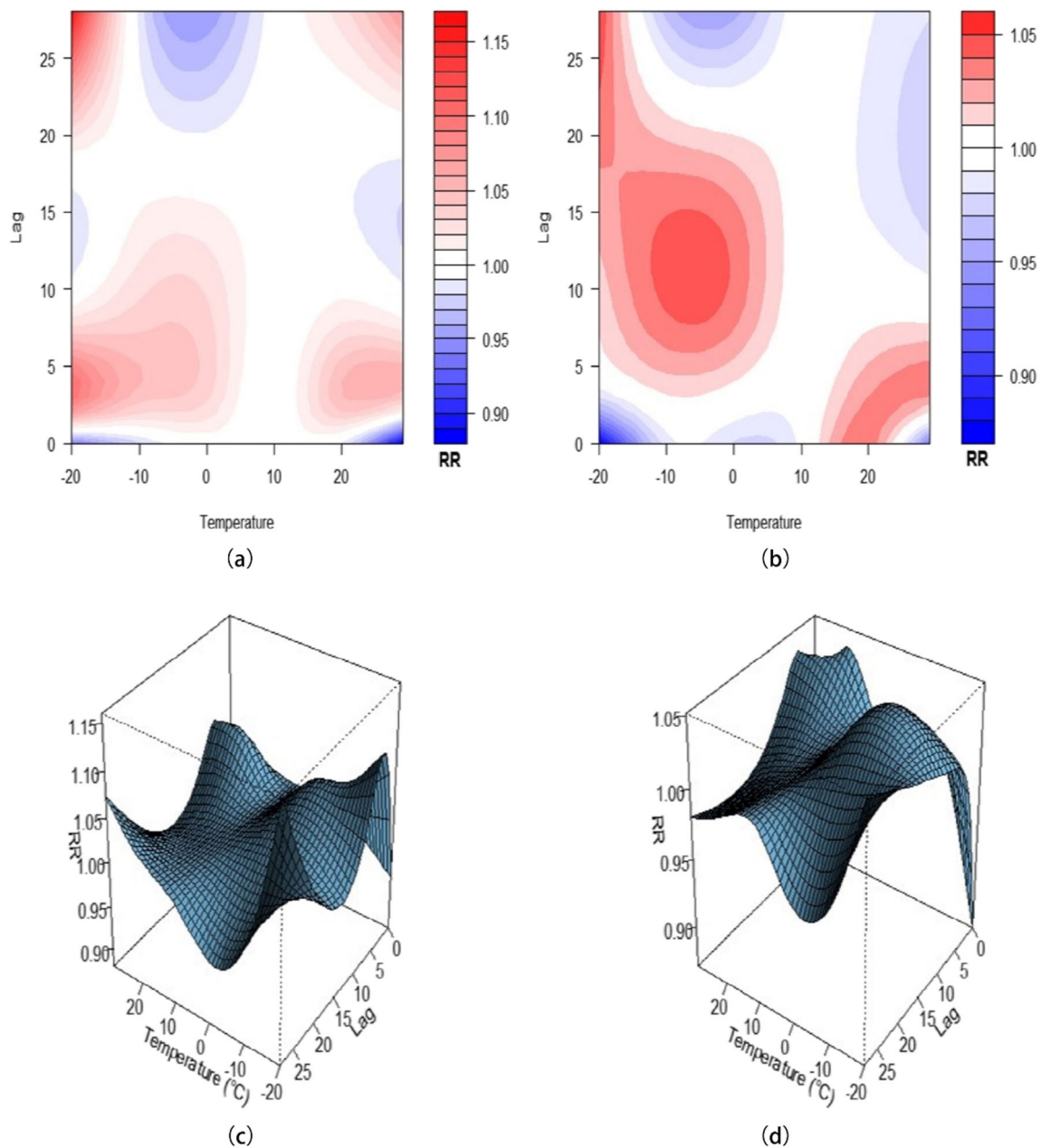
Fig. 11 The influence of ambient temperature on the risk of AECOPD admission based on the gender stratifications (**a** and **c,** female; **b** and **d**, male)

contradictory point is that the lowest risk of ambient temperature in our study was 10 °C, while in a Brazilian study, it ranged between 22 °C and 28 °C (Ferreira et al. 2019). We speculate that latitude difference could account for this difference.

The results of this study provide evidence that ambient temperature affects hospitalization of AECOPD based on DLNM, which support previous studies. Zhao et al.'s research suggested that the OR of hospitalization was 1.05 (95% CI 1.04–1.06) for each 5 °C increase in daily mean temperature at the national level (Zhao et al. 2019). Another study showed that with every degree Celsius decrease in mean weekly temperature, hospital admissions

increased by 5.04%. After accounting for adjustment factors, mean temperatures retained a statistical significance, with a mean increase of 4.7% in weekly admissions for each degree Celsius of temperature (Almagro et al. 2015). Extreme changes in temperature of cold and hot affect one's health. When external conditions change severely, the threshold value exceeds the body's ability to adapt, which can cause a variety of complex emergency responses in the body of the relevant population, and will have adverse effects on the physical and mental health of the population, as well as increase the occurrence or deterioration of corresponding weather-sensitive diseases such AECOPD. Thus, the respiratory system is more

Fig. 12 The influence of ambient temperature on the risk of AECOPD admission based on the age stratifications (**a** and **c**, age ≥ 65 group; **b** and **d**, age < 65 group)

sensitive to outside temperature changes, especially for those > 65 years old with COPD.

Authors' contributions The contribution list is shown in the following form. Guarantor of integrity of entire study: Li Zhao. Study concepts: Cai Chen and Shijie Chang. Study design: Shijie Chang and Li Zhao. Literature research: Cai Chen and Yang Shen. Data acquisition: Xudong Zhang and Yang Shen. Data analysis/interpretation: Yang Shen and Xudong Zhang. Statistical analysis: Yang Shen and Wenxiu Qu. Manuscript preparation: Yang Shen, Cai Chen, and Xuejian Liu. Manuscript definition of intellectual content: Yang Shen, Cai Chen, and Xudong Zhang. Manuscript editing: Xiyuan Li and Qianqian Lin. Manuscript revision/review: Cai Chen and Yang Shen.

Data availability The data was obtained from the supplements.

Compliance with ethical standards

Conflict of interest The authors declare they have no conflict of interest.

Ethical approval This study needs not ethical approval for that no patient participated in this study, and the personal information about patients were fully protected, because the information collected in this study contains admission date, gender, age, date of discharge, place of residence, admission number, and did not include patient's name and ID number.

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

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