Miao *et al. BMC Public Health* (2024) 24:2645
https://doi.org/10.1186/s12889-024-20066-y

BMC Public Health

RESEARCH

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Relationship between temperature and acute myocardial infarction: a time series study in Xuzhou, China, from 2018 to 2020

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Abstract

Background It is widely known that the incidence rate and short-term mortality of acute myocardial infarctions (AMIs) are generally higher during the winter months. The goal of this study was to determine how the temperature of the environment influences fatal acute myocardial infarctions in Xuzhou.

Methods This observational study used the daily meteorological data and the data on the cause of death from acute myocardial infarction in Xuzhou from January 1, 2018, to December 31, 2020. After controlling meteorological variables and pollutants, the distributed nonlinear lag model (DLNM) was used to estimate the correlation between temperature and lethal AMI.

Results A total of 27,712 patients with fatal AMI were enrolled. 82.4% were over the age of 65, and 50.9% were men. Relative to the reference temperature (15 ℃), the 30-day cumulative RRs of the extremely cold temperature (– 2 ℃) for the general population, women, and people aged 65 years and above were 4.66 (95% CI: 1.76, 12.30), 15.29 (95% CI: 3.94, 59.36), and 7.13 (95% CI: 2.50, 20.35), respectively. The 30-day cumulative RRs of the cold temperature (2 ℃) for the general population, women, and people aged 65 years and above were 2.55 (1.37, 4.75), 12.78 (2.24, 5.36), and 3.15 (1.61, 6.16), respectively. No statistically significant association was observed between high temperatures and the risk of fatal AMI. The influence of the cold effect (1st and 10th) was at its peak on that day, and the entire cold effect persisted for 30 days. Temperature extremes had an effect on the lag patterns of distinct age and gender stratifications.

Conclusion According to this study, the risk of fatal AMI increases significantly in cold weather but not in hot weather. Women above the age of 65 are particularly sensitive to severe weather events. The influence of frigid weather on public health should also be considered.

Keywords Acute myocardial infarction, Daily average temperature, Extreme temperature, Xuzhou, Generalized additive model

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Introduction

Due to the widespread use of invasive strategies/thrombolysis, advancements in antiplatelet drugs and anticoagulants, and increased use of statins and other secondary prevention strategies in the last decade, the prognosis of acute myocardial infarction (AMI) has significantly improved. However, it continues to remain the leading cause of global incidence rate and mortality [1]. More and more data point to the possibility that the temperature of the environment has an effect on cardiovascular health [2, 3]. Previous research on the relationship between temperature and AMI was primarily conducted in developed nations, with little in developing nations. According to a recent WHO assessment, the global burden of cardiovascular disease mortality in the future decades is likely to be borne primarily by emerging countries, raising the alarm for developing countries [4]. China, the world's largest developing country, has a dense population, enormous land, and a diversified climate.According to China's cardiovascular health and disease report, it is projected that as high as 330 million people are affected by cardiovascular disease (CVD). At the same time, cardiovascular disease is the leading cause of death in China, accounting for 40% of all deaths, exceeding other diseases such as cancer, and is expected to climb further in the future [5]. As a result, Chinese society urgently needs to implement a comprehensive CVD response and utilize all available resources to reduce the prevalence of CVD or perhaps reverse it [6]. At present, China has carried out several national time series analysis studies covering 184–272 cities and elaborated on the impact of low and high temperatures on AMI from different perspectives such as short-term temperature change [7]and nonoptimal temperature [8, 9]. However, different cities in China may have varied temperature effects on AMI due to different climatic conditions, geographic features, and locations. This is well confirmed in Brazil, which has a long and narrow territory. The expected number of AMI deaths caused by climate, as well as the lowest risk temperature, differ by region [10]. Similarly, the burden of cardiovascular disease (CVD) mortality caused by temperature varies significantly between cities, ranging from 10.1% in Shanghai to 23.7% in Guangzhou [11, 12]. In Xuzhou, a major transportation hub in China, with a population comparable to Austria, a comprehensive disease reporting system has been built. We can acquire health information data using this system. However, research on the association between the death of AMI and the change in temperature has not been conducted in Xuzhou. More importantly, temperature may not only have acute effects on AMI, but the lagged effect of temperature should also be taken seriously in the long term.In fact, relatively little research has been done on AMI deaths in recent years, with the majority of studies focusing on AMI occurrence.

We chose to adopt the widely accepted method of researching the temperature effect because AMI is a very significant global major public health problem. We discuss the effect of temperature on the death of AMI in China by limiting the role of various confounding factors. The objectives of this study are as follows: (1) To deeply analyze the impact of short-term and long-term temperature exposure on the risk of lethal AMI; (2) To assess the overall trend of the impact of temperature on the risk of lethal AMI by gender and age; and (3) To evaluate the impact of extreme temperatures on the risk of fatal AMI and investigate the possible susceptible population.

Materials and methods

Study population

From January 1, 2018, to December 31, 2020, this study examined the daily fluctuations in the number of AMI deaths in Xuzhou City in relation to temperature. Xuzhou has a longitude and latitude of 34 ° N and 117 ° E, respectively, and a population of about 8.8 million. It is located in the east of China and the north of Jiangsu Province. The city has a semihumid monsoon climate that is warm and temperate, with four distinct seasons: short spring and autumn, long winter and summer, high temperature and rainy summer, and frequent cold waves in winter. The seasons are divided into spring (March–May), summer (June–August), autumn (September–November), and winter (December–February).

The Environmental Monitoring Center has established eight air quality monitoring stations in Xuzhou, and each monitoring station collects air pollution data every hour. From China's National Urban Air Quality Real time Publishing Platform (https://www.aqithudy.cn/), the meteorological factors (daily average temperature, wind level, and relative humidity) and standard pollutants (i.e. fine particulate matter, nitrogen dioxide, sulfur dioxide, ozone, and carbon monoxide) of daily average concentration were collected.

The research object of this study was the permanent residents of Xuzhou from 2018 to 2020, ensuring that the research object was exposed to the air pollution and meteorological environment of Xuzhou for an extended period of time. The inclusion criteria were lethal AMI, and the basic concept of myocardial infarction served as the foundation for the diagnosis [13]. The medical network of Xuzhou City maintains computerized records of all daily inpatients, outpatients, and emergency patients. Gender, date of birth, diagnosis code at admission, dates of admission and discharge, permanent residence area, and residency area are among the details that have been recorded. The Xuzhou Disease Control and Prevention Center (CDC) is in charge of health information data statistics and analysis, as well as the organization, construction, application, and maintenance of the health network platform, central database, and application system. Diagnostic codes are entered in accordance with the 10 revisions of the International Classification of Diseases (I21, ICD-10). Therefore, the information from the registration database was complete and accurate enough to be used for epidemiological studies. The study was approved by the Ethics Committee of the Affiliated Hospital of Xuzhou Medical University.

Statistical analyses

When the correlation between the two pollutants is very strong, there may be interaction, affecting the stability of the effect estimation and necessitating multivariate regression analysis. Therefore, in this study, if the correlation coefficient r of the two pollutants is greater than 0.8 using Spearman correlation analysis, that is, when the correlation between the two pollutants is very strong, the two pollutants will not be analyzed in the same model. As shown in Fig. 2, the correlation between $PM_{2.5}$ and PM_{10} is 0.864. According to the meta-analysis [14], $PM_{2.5}$, rather than PM^{10}, had a significant impact on the risk ratio of CVD mortality. Therefore, $PM_{2.5}$ was included in the model for this study.

The distribution follows a time series since the AMI daily death data, air pollution data, and meteorological data are matched by date. Changes in the research exposure conditions did not have a major hybrid influence on the health outcomes because the individual features, such as hypertension, of the same study group were largely stable in the short term. The number of deaths from AMI generally followed the Poisson distribution rate, and there was typically a nonlinear correlation between the death rate from AMI and any given variable. As a result, the generalized additive model (GAM) was used in the statistical model, and the Poisson distribution was linked to it. The distributed lag nonlinear model (DLNM) was used to explain the time course of the effect relationship and examine the nonlinear relationship and lag effect between temperature and population [15, 16].

The natural smooth spline (NS) function is incorporated in the basic GAM model to control the changing trend of fatal AMI on the time axis and season, as well as the nonlinear mixed effect of climatic elements and air pollutants on the research output. The d_f of T_{mean} on the day of admission for AMI was set at 4 [17] based on the previous literature. This study focuses on AMI patients admitted to the emergency department. Because the number of AMI inpatients in a week is unaffected by the day of the week (DOW), it is not included as an indicator variable in the basic model. To decrease the enormous computational burden, the daily average value of the event day was employed for meteorological factors in the basic model, as in most previous research [18, 19].

The temperature of the environment may have a delayed effect on health and cardiovascular disease. In order to explore the impact of temperature on AMI before its occurrence, this study conducted a lag effect analysis. The single-day lag effect and the cumulative lag effect of temperature were studied. The lag impact of the temperature of a single day is the single-day lag effect, whereas the cumulative lag effect is the moving average of the temperature over consecutive days. This study explored the overall trend of the impact of T_{mean} on the risk of lethal AMI and the impact of extreme temperature on the risk of death from AMI. The three-dimensional graph was used to show the impact of different days of delay and different temperature conditions on the risk of lethal AMI. When investigating the impact of extreme temperatures, the percentile of each temperature (1st, 10th, 90th, and 99th) was classified as extremely cold temperature, cold temperature, high temperature, and extremely hot temperature, respectively. Because the effect of low temperature on cardiovascular disease can continue up to 3 weeks [20], the lag days in the general model were set to 30 days, and the cumulative relative risk (CRR) of the effect of temperature on the risk of fatal AMI in the general population was determined. The cumulative effect of extreme temperatures in each subgroup was evaluated by stratification based on gender (men and women) and age (<65 years old, ≥ 65 years old). The number of lethal AMI at different extreme temperatures was compared with the reference temperature (15 ℃) to determine the change in CRR, which was expressed as RRs and a 95% confidence interval (CI).

All analyses were carried out in R (version 4.0.0, R statistical calculation project). The software packages of "mixed GAM calculation vehicle (MGCV)" and "distributed lag nonlinear model" (DLNM) were used to simulate and quantitatively analyze the generalized additive model and distributed lag nonlinear model, respectively. All tests were bilateral, and the alpha value was 0.05.

Results

Descriptive results

From January 1, 2018, to December 31, 2020, 27,712 patients with fatal AMI were initially enrolled in the database, as shown in Fig. 1. The average age of men was 73.5±14.1 years, and the average age of women was 81.0±11.4 years. 82.4% of them were above the age of 65, and 50.9% were men. Women represent a significant proportion of the older population, and winter is the season with the most fatal AMI (Table 1). The average T_{mean} in winter was 3.4±4.1 ℃, the minimum was − 7 ℃, the maximum was 23 ℃, and the median T_{mean} was 3 ℃ (25th, 75th ; 0,6). The average T_{mean} in summer was 26.7±2.7 ℃, the minimum was 17 ℃, the maximum was 33 ℃, and the median T_{mean} was 26 ℃ (25th, 75th

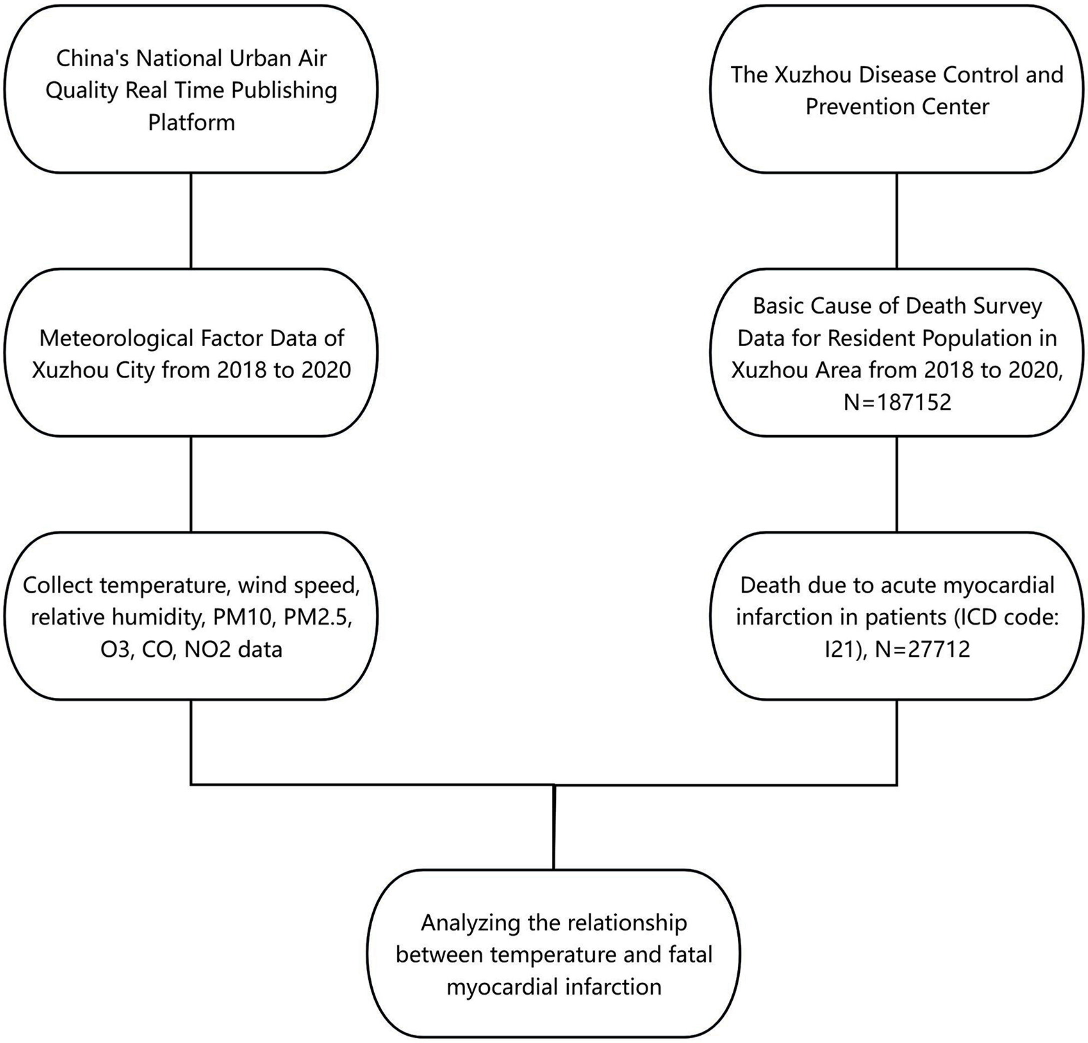

Fig. 1 Flowchart

Table 1 Demographic characteristics of Xuzhou City from 2018 to 2020

Variable	Total	Spring	Summer	Autumn	Winter
Time					
2018	9647	2282	1807	2101	3250
2019	8805	2184	1708	1920	2993
2020	9440	2171	1993	2219	3084
Male	14,110	3329	2960	3239	4582
18-65Y	6693	1661	1565	1551	1916
>65Y	7417	1668	1395	1688	2666
Female	13,602	3394	2341	2999	4868
18-65Y	3367	831	704	760	1072
>65Y	10,235	2563	1637	2239	3796

; 25,29). Extreme cold (−2 °C) and cold temperatures (2 °C) are predominant in winter, whereas extreme hot (31 °C) and high temperatures (27 °C) are prevalent in summer (Table 2).

Figure 2 shows the correlation between six major air pollutants and meteorological factors in Xuzhou City, of which $PM_{2.5}$ and PM_{10} had the strongest correlation (r=0.864). The atmospheric pollutants SO_2, NO_2, $PM_{2.5}$, PM_{10}, and T_{mean} were all moderately correlated. The correlation between CO, RH, and wind level and $PM_{2.5}$, PM_{l0}, SO_2, and NO_2 was found to be weak. O_3 had a negative correlation with other atmospheric pollutants but a substantial correlation with T_{mean} (r=0.708).

The relationship between temperature and the onset of fatal AMI

The correlation between meteorological factors was significant, as shown in Fig. 2. The broken line chart (Fig. 3) shows that the number of lethal AMI in Xuzhou City from 2018 to 2020 fluctuated with months, increasing in the winter and decreasing in the summer. The changing trend of $PM_{2.5}$, PM_{10}, $S0_2$, $N0_2$, and CO concentrations with time is roughly the same, with higher concentrations

Table 2 Statistics of extreme temperature in Xuzhou from 2018 to 2020

Variable	Total	Spring	Summer	Autumn	Winter
DAT(Mean ± SD), ℃	15.4 ± 9.6	15.8 ± 5.9	26.7 ± 2.7	16.0 ± 6.1	3.4 ± 4.1
DAT(Min, Max), ℃	-7, 33	4, 29	17, 33	2, 28	-7, 23
Quartile of DAT(Q1, Q2, Q3), ℃	15(6, 24)	16(11, 20)	26(25, 29)	15(12, 22)	3(0, 6)
Extreme cold weather, day	21	0	0	0	21
Cold weather, day	120	0	0	1	119
High temperature weather,day	132	2	124	6	0
Extreme hot weather,day	23	0	23	0	.0

Abbreviation DAT: daily average temperature; SD: standard deviation

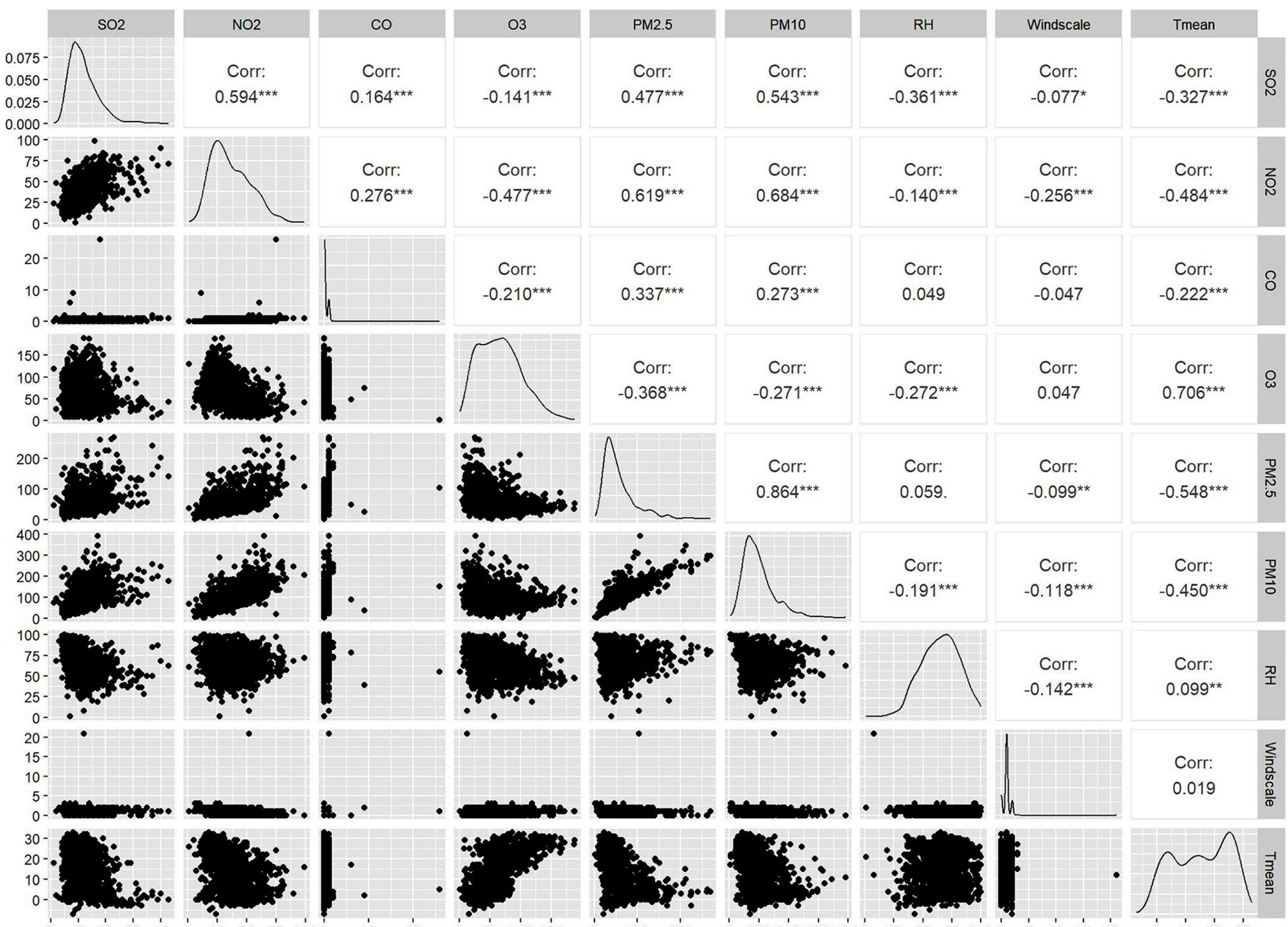

Fig. 2 Correlation between meteorological factors. Note*: $p < 0.05$;**: $p < 0.01$;***:$p < 0.001$

in cold months and lower concentrations in hot months, while the changing trend of 03 concentration with time is different, with higher concentrations in hot months and lower concentrations in cold months.

As shown in Fig. 4, we observed that the CRR increased monotonously with the decrease in temperature, while the CRR increased first and then decreased with the increase in temperature. At about 24 ℃, the RR reached the peak value of 1.26 (0.80–1.97), and at 29 ℃, the RR value was <1 (Fig. 4A). The exposure response relationship and cumulative lag pattern changed depending on age and gender. Each subgroup's low-temperature pattern was identical to the overall pattern. The cumulative effect of hypothermia on patients > 65 years old was significantly higher than on patients ≤ 65 years old. The cumulative lag effect of men at low temperatures was negligible and insignificant in comparison to women. There was no effect of high temperatures on patients ≤ 65 years. High temperatures have an impact on lethal AMI in general and in various subgroup analyses, but it has no practical significance.

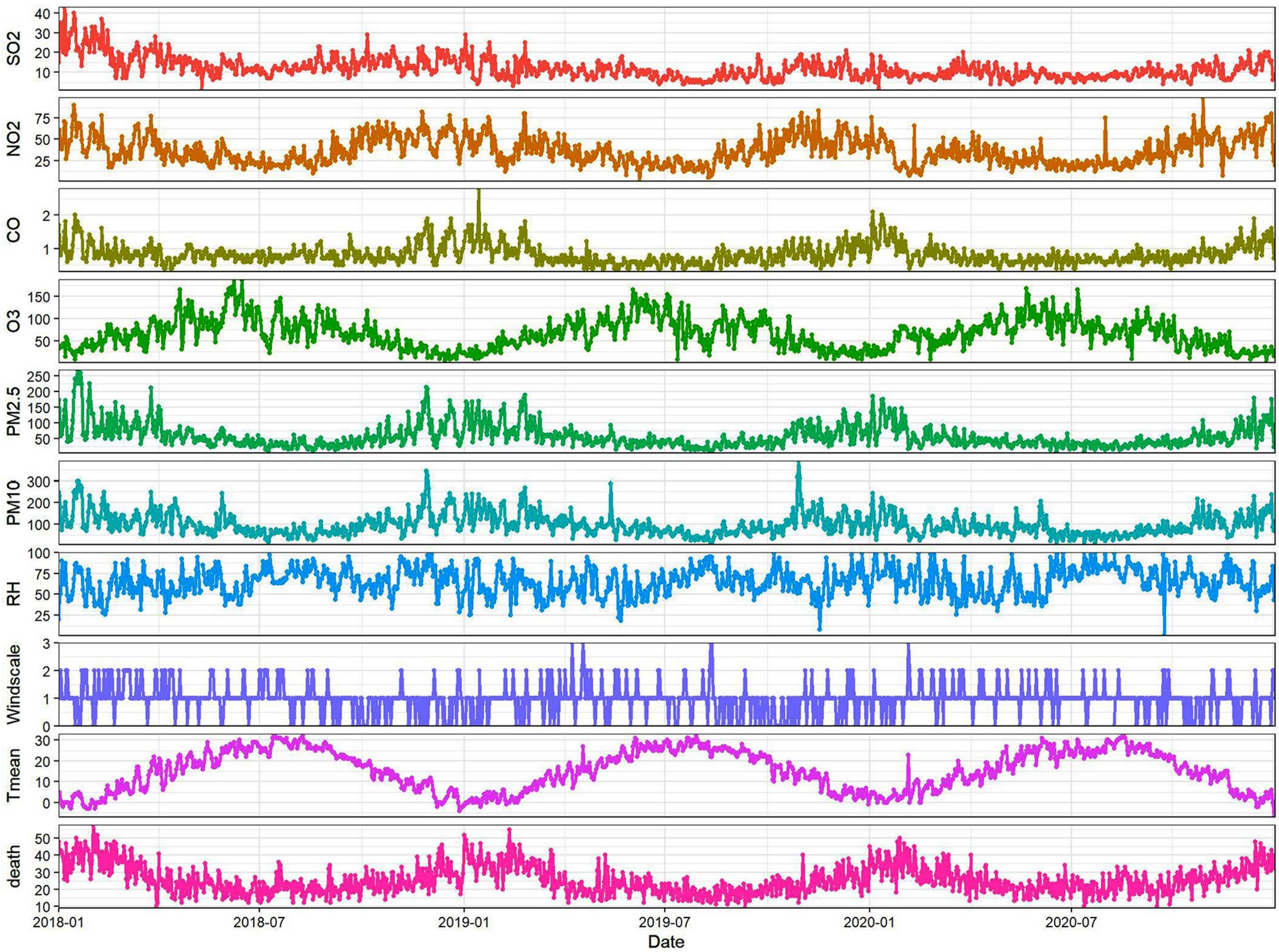

Fig. 3 The actual daily changes of various meteorological factors in Xuzhou from 2018 to 2020

Figure 5 depicts a three-dimensional plot of the relative risk (RR) vs. temperature and hysteresis, with the 15℃ serving as the reference value. Figure a depicts a very strong and direct cooling effect, while Figure b depicts a more delayed effect caused by extremely cold temperatures. On that specific day, the low temperature had the maximum effect. In the long lag check diagram, it can be observed that the effect of extremely cold temperatures increased again. The effect of high temperatures was not clear, and its maximum effect was reached within a few days after the onset. The population under 65 years old displayed an inverted U shape, and the effects of cold and heat on men were less pronounced than on women, according to subgroup analyses. The population over 65 years old and different genders were similar to the total population.

When T_{mean} is taken as a fixed temperature value in the 1st, 10th, 90th, and 99th percentiles, the cumulative RR of lethal AMI in lag0–30 days is shown in Table 3. Relative to the reference temperature (15 ℃), the extremely cold temperature (−2 ℃) had an impact on the 30-day cumulative CRRs for the general population, women, and people aged 65 years and above, which are 4.66 (95% CI: 1.76, 12.30), 15.29 (95% CI: 3.94, 59.36), and 7.13 (95% CI: 2.50, 20.35), respectively. The cold temperature (2 ℃) had an impact on the 30-day cumulative CRRs for the general population, women, and people aged 65 years and above, which are 2.55 (1.37, 4.75), 12.78 (2.24, 5.36), and 3.15 (1.61, 6.16), respectively. There was no association found between high temperatures and the risk of fatal AMI.

Figure 6 depicts the lag shift of extreme temperatures as a function of time lag. In the general population (Figs. 6−1), the impact of extremely cold temperatures (1st) reached the maximum on that day (RR: 1.12; 95% CI: 1.01–1.23) and subsequently began to drop. It is worth noting that it fluctuated again in the long term, reaching the maximum again at lag25 (RR: 1.08; 95% CI: 1.01–1.15), and the entire cold effect lasted 30 days (RR > 1). Cold temperatures (10th) had an impact similar to extremely cold temperatures (1st). It reached its peak on the same day, but the maximal effect was minor (RR: 1.06; 95% CI: 0.98–1.14). In the long term, it reached the maximum again in lag19, and the entire cold effect lasted 30 days (RR > 1). The impact of extremely hot

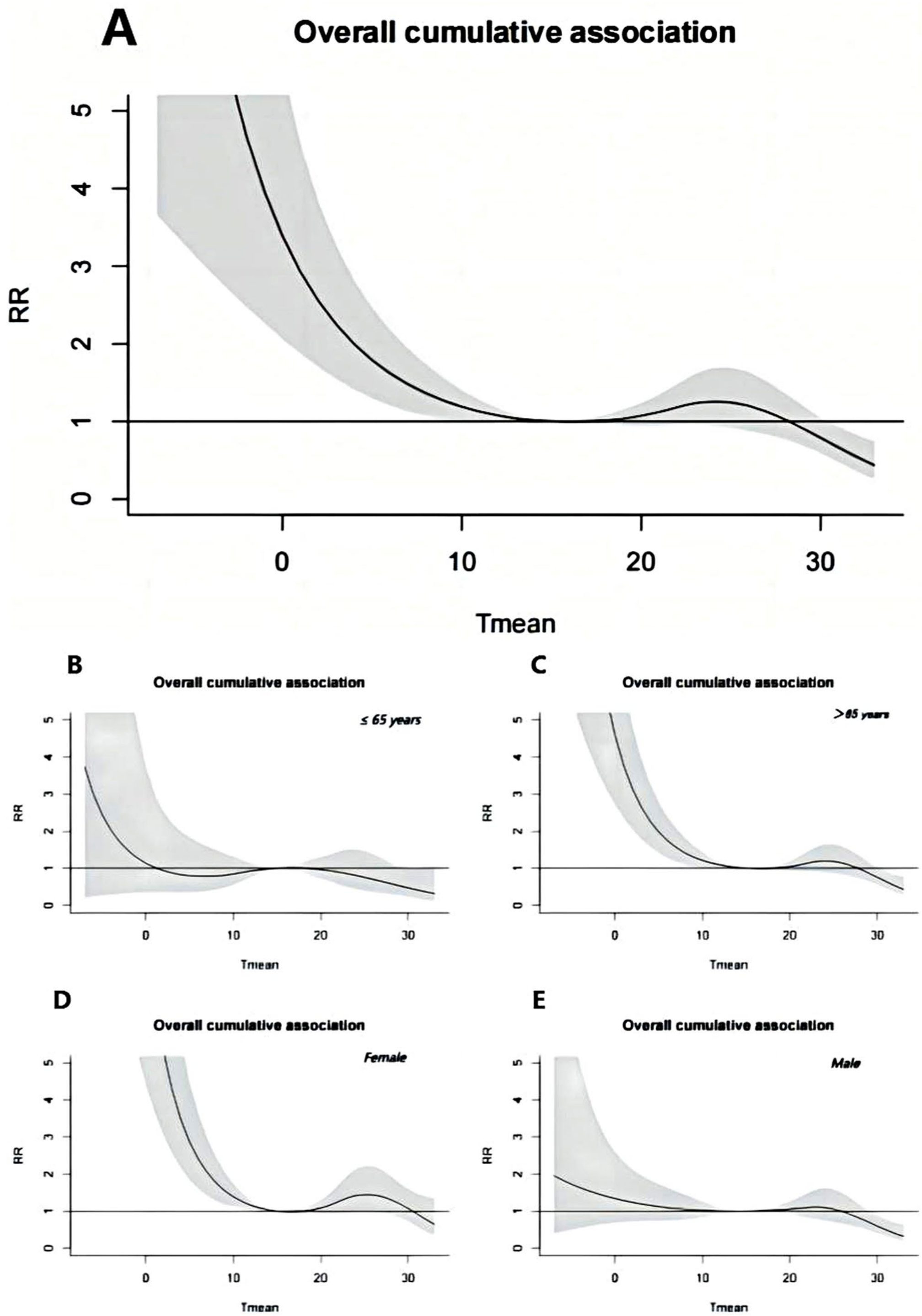

Fig. 4 Cumulative exposure – response curve of correlation between temperature and AM incidence in Xuzhou within 0 – 30 days. Overall population (**A**); Population under 65 years old (**B**); Population over 65 years old (**C**); Female population (**D**); Male population (**E**). The real black line is the odds ratio of AMI, and the gray area is 95% of the evidence interval

temperatures (99th) immediately appeared, reaching the maximum risk at lag0 (RR: 1.08; 95% CI: 1.01–1.15), and the thermal effect lasted only 7 days. The impact of high temperatures (90th) occurred on the fourth day, reaching the maximum risk (RR: 1.00; 95% CI: 0.96–1.05) at lag07 and reaching the maximum again at lag26 (RR: 1.02; 95% CI: 0.97–1.06), and the thermal effect lasted 27 days. Subgroup analysis revealed that the cold and heat effects occurred immediately in individuals above the age of 65 but were delayed in individuals under the age of

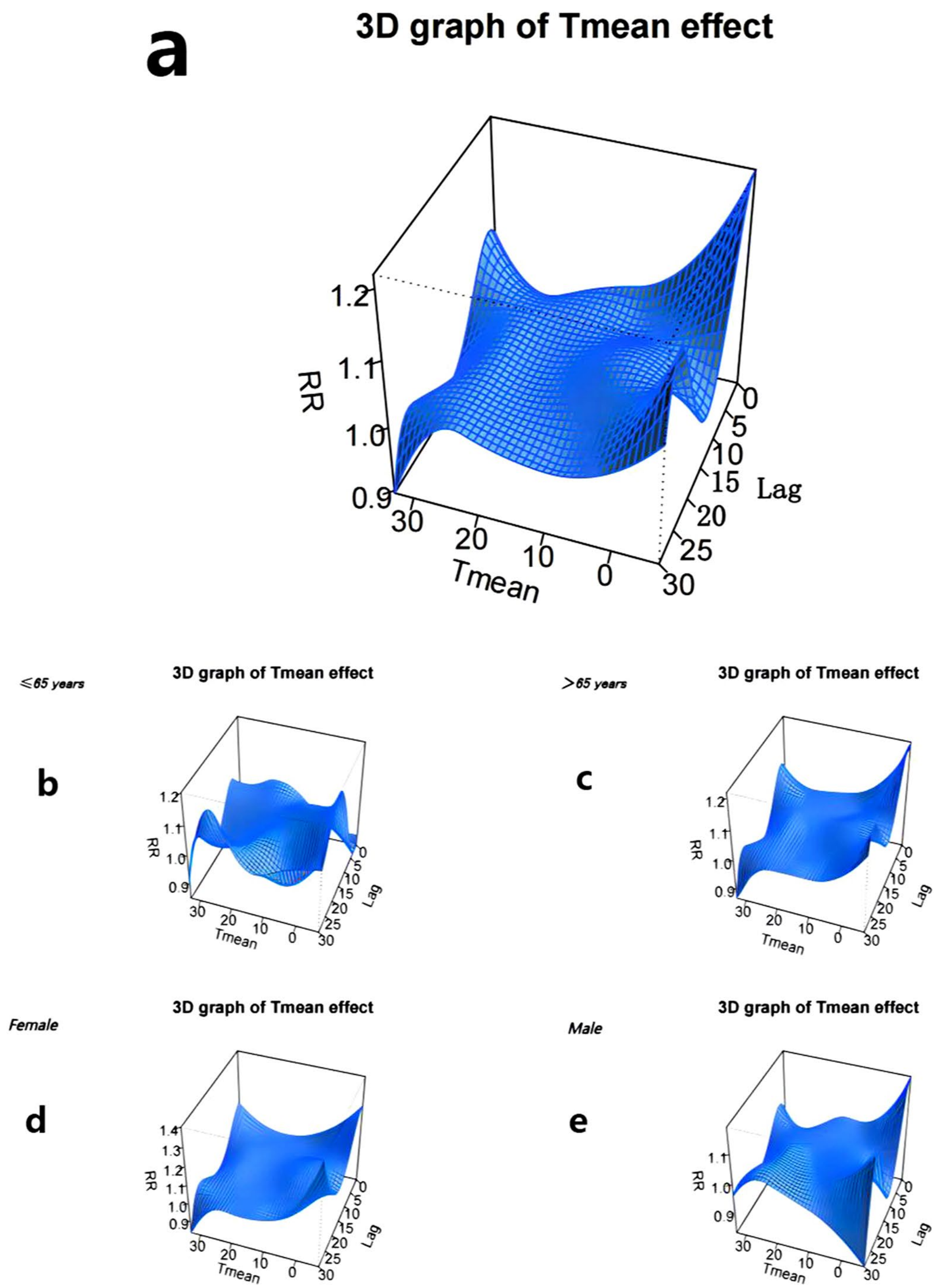

Fig. 5 The relationship between Tmean and lethal AMI. Overall population (**a**); Population under 65 years old (**b**); Population over 65 years old (**c**); Female population (**d**); Male population (**e**)

65 (extreme cold: lag09; cold: lag07; extreme heat: lag03; high temperature: lag02). The cold effect was immediate in individuals of both genders, while the heat effect was immediate in women but delayed in men (extreme heat: lag04; high temperature: lag19).

Discussion

In this study, based on 27,712 patients with fatal AMI, we evaluated the relationship between daily average temperature and the risk of fatal AMI. We found that there was a statistically significant correlation between

Table 3 Cumulative impact of extreme temperature on AMI events within 30 days of cumulative lag in Xuzhou (compared with reference temperature of 15 ℃)

CRR	Extreme cold temperature(-2℃)	Cold temperature(2℃)	Extreme hot temperature(31℃)	High temperature(27℃)
Total	4.66(1.76, 12.30)*	2.55(1.37, 4.75)*	0.67(0.40, 1.11)	1.12(0.72, 1.77)
Sex				
Male	1.47(0.39, 5.48)	1.24(0.53, 2.86)	0.49(0.25, 0.98)	0.91(0.49, 1.67)
Female	15.29(3.94, 59.36)*	12.78(2.24, 5.36)*	0.92(0.45, 1.90)	1.39(0.74, 2.63)
Age(year)				
18–65	1.47(0.14, 15.15)	0.94(0.20, 4.36)	0.42(0.11, 1.55)	0.64(0.23, 1.82)
>65	7.13(2.50, 20.35)*	3.15(1.61, 6.16)*	0.64(0.37, 1.12)	1.07(0.66, 1.75)

Note *: $p < 0.05$

low-temperature exposure and lethal AMI. Women and people≥65 years old were sensitive to cold, while high temperature had no effect on the occurrence of AMI. Cold temperatures cannot be disregarded because they considerably raise the risk of fatal AMI. The acute effect of cold exposure occurred on the same day, and the delayed effect continued for 30 days. These findings could help the local public health department develop preventive measures to lower the occurrence of fatal AMI.

Our study discovered that low-temperature exposure was associated with lethal AMI, whereas high-temperature exposure had no statistically significant association. Li Bai et al. reported that the 1st percentile temperature corresponds to the lowest risk temperature, and AMI increased by 29% (95% confidence interval 15–45%) [21]. In our study, the effect of very low temperature on lethal AMI was greater than that of moderate low temperature. Residents must enhance their adaptability to extremely low temperatures for local climate change since they are unable to adapt to extremely low temperatures, which may result in more AMI incidents. At the same time, moderate low temperatures also have risks. The 30-day cumulative CRR of the cold temperature (2 ℃) for the general population is 2.55 (1.37–4.75). A study in India found that [22] moderate cold temperatures are estimated to have a high attribution risk, with an IHD value of 9.7% [3.7–15.3], and moderately cold temperatures exceed the effect of extreme cold. This implies that we need not only take precautions to stay warm in extremely cold weather but even in moderate cold weather. To stay warm, we should pay close attention to the weather forecast in real time.

In Xuzhou, there is no correlation between extremely high temperatures and the risk of lethal AMI. Similarly, Xiao QianHuang et al. found that the temperature and the risk of AMI present a double peak shape when the temperature is 26 ˚. The second peak started at point C, and RR increased again, although not significantly (RR: 0.999, 95% CI: 0.986–1.012) [23]. However, Jaime Madrigano and researchers discovered that exceptionally high temperatures in the first two days were associated with an increased risk of death from AMI (RR: 1.44, 95% CI: 1.06–1.96) [24]. The risk of moderately high temperatures (90th percentile temperature) and extremely high temperatures (95th percentile temperature) increased by 18% (RR: 1.18, 95% CI: 0.95–1.47) and 36% (RR: 1.36, 95% CI: 1.06–1.73), respectively, in hospitalized patients with AMI in Vietnam [25]. The CRR curve in our study indicated an increasing trend at the early stage under extremely high temperatures, but no statistical significance was found. The differences between several studies could be the cause of the disparate outcomes of high temperatures on AMI. Different climates, ethnicities, genders, age distribution, economic levels, habits and activity patterns, use of air conditioners and other cooling facilities, and the diversity of study methods may all contribute to these variances.

We discovered that at cold temperatures, women are more prone to the harmful consequences of fatal AMI. Several earlier studies have confirmed our point of view [19, 26, 27]. The possible reason is that in our data, the average age of the women was higher than that of the men, and the elderly population accounted for a large proportion of women. According to certain research, women have lower thermogenic muscle mass than men, and because of the increased blood distribution in the uterus and ovary, it is more difficult for women to regulate body temperature [9]. It is also believed that estrogen enhances vasoconstriction activity under cold induction, which is associated with estrogen-dependent increased expression of cold-sensitive α (2 C) -ARs [28]. There are various viewpoints, though. Men are thought to engage in more outside activities and are more susceptible to cold temperatures, according to Jane Wichmann et al. [29].

In a national study conducted in China, RenJie Chen et al. reported that in temperate monsoon and subtropical monsoon climate regions, the death risk and burden of specific subgroups aged≥75 years are more prominent [8]. XiaoLe Liu et al. concluded in their research that patients over the age of 65 are more vulnerable to the adverse effects of AMI caused by low temperatures [28]. These data imply that cold exposure may be a risk factor for acute heart attacks in the elderly. The elderly's

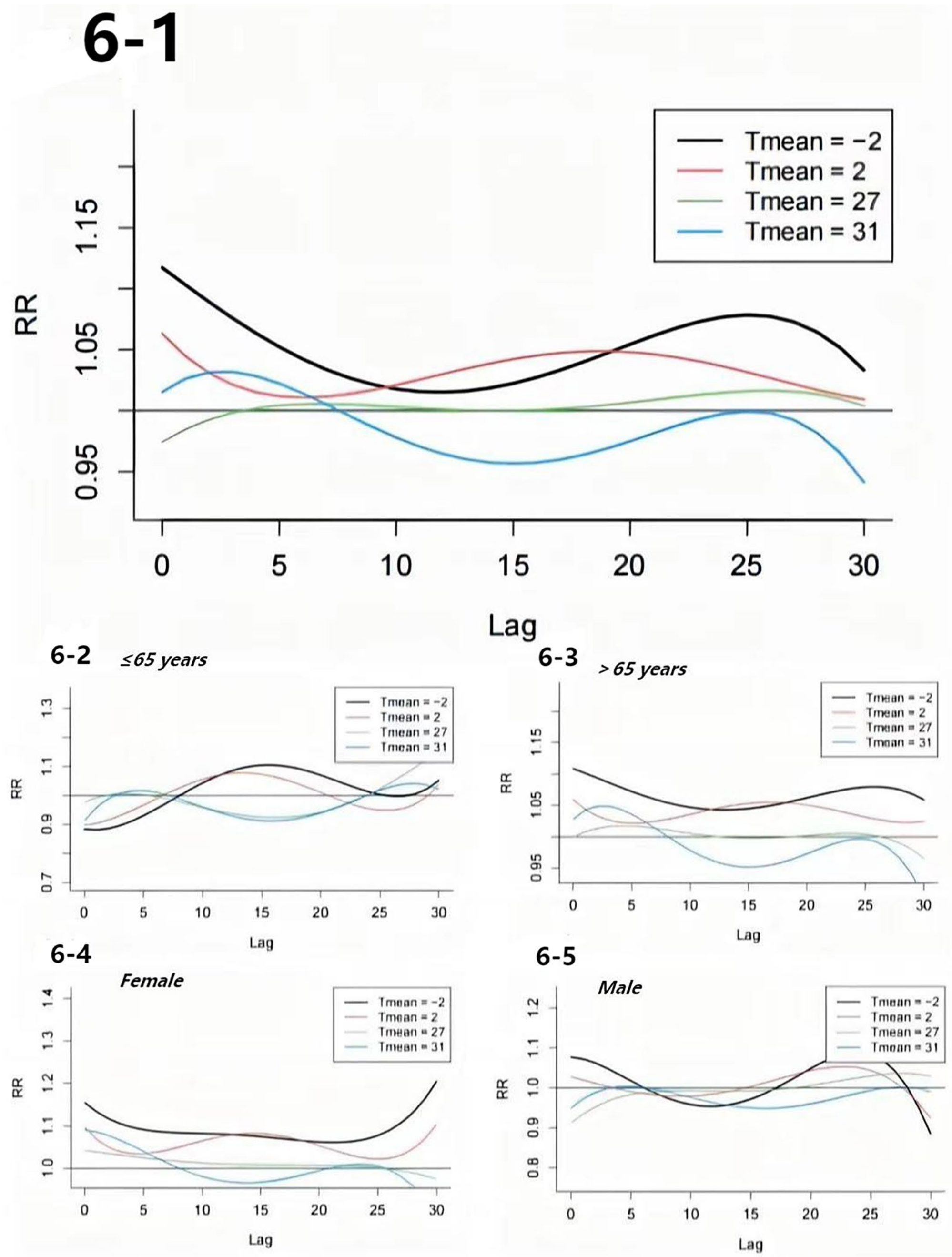

Fig. 6 Lag change of extreme temperature with time. Overall population (**6-1**); Population under 65 years old (**6-2**); Population over 65 years old (**6-3**); Female population (**6-4**); Male population (**6-5**)

ability to perceive and self-regulate weather temperature has likely decreased, making it difficult for them to anticipate temperature changes and take timely precautions against the cold. In addition, Jing Cai and other researchers found that a decline in temperature increased the response of biomarkers of inflammation, coagulation, and vasoconstriction [30]. In a study of 12 healthy men, David G et al. found that peripheral vasoconstriction brought on by exposure to cold increased wave reflection and central systolic pressure. The study also revealed that during cold exposure, the change in central blood pressure was not visible in the measurement of brachial artery blood pressure, which may make monitoring the change in central blood pressure challenging [31]. Another study discovered that the amplitude of the pressor response generated by cold exposure in the elderly was more than double that of young adults [32]. Because the elderly have more comorbidities, the pathophysiological alterations induced by cold may further increase their risk of fatal AMI, according to the findings of the above-mentioned study.

A vast number of studies have revealed that the cold effect lasts a long time and has a clear hysteresis effect, whereas the thermal effect appears rapidly and disappears quickly. Yu MingGuo et al. analyzed death and temperature data from 12 countries, including China. When analyzing the nonlinear and delayed association between temperature and mortality, they discovered that the influence of low temperature (the hundredth percentile and the lowest mortality temperature) was delayed by approximately 2 days, continued for at least 10 days, and could even last longer. The effects of high temperature (99th percentile temperature and minimum mortality temperature) occur immediately, usually lasting only 3 or 4 days [33]. Several more studies found similar results [34–36]. According to our findings, the cold effect (1th) has the greatest impact on that day, and the entire cold effect can endure for 30 days. The extremely high temperatures (99th) had an instantaneous effect, and the thermal effect lasted only 7 days. The fourth day was affected by high temperatures (90th), and the thermal effect lasted for 27 days. Women and people 65 years of age and above experienced the cold and hot effects instantly, whereas people under 65 experienced a delay. Only the heat effects were delayed in men. The above results show that we should not only consider the occurrence of extreme temperatures but also take into consideration the lag times of cold and heat effects on different categories of people.

Conclusions and limitations

Women and individuals over the age of 65 have been recognized as vulnerable subgroups to cold exposure. The cold weather should not be overlooked, and patients should be encouraged to stay warm and limit their outdoor activities. In this study, no association between hyperthermia and fatal AMI was found. The temperature may have a greater impact in general as a result of population aging and climate change. Our study provides quantitative evidence on how cold weather affects health, which could inform public health interventions and policy changes. For instance, during periods of extremely low and moderate cold weather, we can disseminate information about health risks through various channels such as TV news, radio broadcasts, mobile phone text messages, and emerging media platforms like microblogs and TikTok. This targeted outreach is especially crucial for women and the elderly.Secondly, our results may have implications for other regions, such as conducting surveys on AMI deaths in areas with climates similar to Xuzhou or comparing changes in AMI deaths before and after implementing enhanced preventive measures against low-temperature weather in these areas.

Our findings should be interpreted in light of limitations.First of all, this study is a retrospective study and may have bias. Second, individual temperature exposure data could not be collected when the general temperature of Xuzhou City was used as the exposure temperature for the entire population. Furthermore, additional precise information about the patients was not acquired, such as hypertension, diabetes history, rigorous activity, overwork, emotional arousal, and whether they were outside. Finally, the heating conditions in Xuzhou might have had some influence on the research findings; however, those data were not acquired for this study.

Abbreviations

AMI	Acute myocardial infarction
DLNM	Distributed nonlinear lag model
CDC	Disease Control and Prevention Center
GAM	Generalized additive model
NS	Natural smooth spline
DOW	Day of the week
CRR	Cumulative relative risk
CI	Confidence interval

Acknowledgements

The authors would like to thank Xuzhou CDC for providing all the registered death data from January 2018 to December 2020.

Author contributions

HM, WB, and CL contributed to the study design. PL, PC, PZ, and GC were responsible for investigating patient deaths due to acute myocardial infarction in Xuzhou City. HM, WB, X Z, and SH collected data on daily temperatures and meteorological factors in Xuzhou City. Statistical analysis was performed by HM and WB. HM drafted the initial manuscript, which was subsequently revised by CL. YY, ZW, and MC contributed to monitoring research.All authors were involved in the study design, data analysis, and revision of the manuscript and read and approved the final manuscript. Drs CLhad full access to all of the data in the study and take the responsibility for the integrity of the data and the accuracy of data analysis.

Funding

This research was supported by the Clinical Medicine Expert Team Project of Xuzhou in China grant number (2019208002).

Data availability

The datasets of this article can be obtained from the corresponding author on reasonable requirements.

Declarations

Ethical approval and consent to participate

This study was conducted according to the guidelines laid out in the Declaration of Helsinki, and all of the procedures involving human subjects were approved with a full review by the medical research ethics committee of the affiliated hospital of Xuzhou Medical University (9 September 2020, No XYFY2020-KL142-01). This study is registered at the ClinicalTrials.gov (NCT 04550312). All participants received written information about the research and signed an informed consent form.

Consent for publication

Not applicable.

Competing interests
The authors declare no competing interests.

Received: 13 December 2022 / Accepted: 12 September 2024
Published online: 27 September 2024

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