Preplanned Studies

The Combined Effects of High Temperatures and Ozone Pollution on Medical Emergency Calls — Jinan City, Shandong Province, China, 2013–2019

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Summary

What is already known about this topic?

Studies have extensively documented the separate and independent effects of extreme temperature and ozone on morbidity and mortality associated with respiratory and circulatory diseases.

What is added by this report?

The study revealed a significant association between elevated temperature, ozone pollution, and the combined effect of high temperature and ozone pollution with an increased risk of all-cause medical emergency calls (MECs) and MECs specifically related to neurological diseases.

What are the implications for public health practice?

Interventional measures should be implemented to mitigate exposure to high temperatures and ozone levels. Specifically, during the warm season, it is crucial for relevant authorities to focus on disseminating scientific information regarding the health impacts of elevated temperatures and ozone pollution. Additionally, timely public health advisories should be issued to alert the public effectively.

Epidemiological evidence demonstrates the significant impact of high temperature on both short-term and long-term health outcomes, resulting in increased morbidity and mortality rates for respiratory and circulatory diseases, among other health conditions (*1*). Simultaneously, there is a growing concern about ozone (O_3) pollution, which poses a pressing challenge to urban development (*2*). Numerous studies have established a strong association between O_3 pollution and the onset and progression of respiratory and circulatory diseases (*3*–*4*). However, there is still a research gap concerning the combined effects of these two variables. Recently, there has been a growing interest in using medical emergency calls (MECs) as indicators to explore the acute effects of high temperature and O_3 pollution (*5*–*7*). Addressing this research gap, our study focuses on Jinan City, Shandong Province, China, as a representative urban area grappling with the dual challenge of high temperature and O_3 pollution. We employed a time-stratified case-crossover study design to estimate the impacts of high temperature and O_3 pollution on MECs. The results indicate that high temperature, O_3 pollution, and their combination significantly increase the risk of all-cause MECs and MECs specifically related to neurological diseases. These findings provide essential information for the development of future measures to reduce exposure to high temperature and O_3 pollution. Moreover, emphasizing the necessity to consider the combined effects of high temperature and O_3 pollution is crucial for addressing emerging public health concerns.

For this research study, we collected daily data from the MECs of the Jinan Medical Emergency Center (JMEC) website (http://www.jn120.cn/). The data were collected from May 1 to September 30 for the years 2013–2019. There were minor fluctuations in the MECs rate during the study period, as shown in Supplementary Table S1 (available in https://weekly.chinacdc.cn/). The information obtained from the MECs included the patient's call time, primary statement, and preliminary diagnosis. The primary statement information referred to the main signs and symptoms provided during the telephone call, while the preliminary diagnosis information indicated the disease diagnosis given when the patient was admitted to the hospital's emergency department. JMEC oversees 66 first-aid service stations that are affiliated with hospitals, providing coverage across all ten administrative districts of Jinan City, as shown in Supplementary Table S2 (available in https://weekly.chinacdc.cn/). To classify the MECs, we used the International Classification of Diseases, 10th revision (ICD-10). We specifically screened for ICD-10 codes J00–J99, which are associated with respiratory diseases, I00–I99, which are related to circulatory diseases, and G00–G99, which pertain to neurological diseases.

Meteorological data collected daily throughout the study period were provided by the China Meteorological Science Data Sharing Service Network (http://data.cma.gov.cn/). This data included the daily mean maximum temperature (℃), relative humidity (%), pressure (hPa), and wind speed (m/s). The daily air pollutant data, such as fine particulate matter ($PM_{2.5}$), particulate matter (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and 8-hour ozone (O_3-8h, abbreviated as O_3), were obtained from the Jinan Ecological Environmental Protection Bureau. For this study, we determined the daily pollutant concentration level in Jinan by averaging the readings from all monitoring stations.

In the initial stage of our analysis, we began with a descriptive examination of the compiled data using various indicators, including mean, standard deviation, minimum, maximum, median, first quartile, and third quartile. Following this, correlation analysis was conducted to explore the relationship between temperature, ozone concentration, and MECs, as well as the associations between air pollutants and meteorological factors. Subsequently, a time-stratified case-crossover study design in combination with a conditional logistic regression model was employed to investigate the acute impacts of temperature and ozone pollution on MECs. Detailed information and sensitivity analyses for this core model can be found in the Supplementary Material (available in https://weekly.chinacdc.cn/). Based on a comprehensive review of previous studies and our analytical results, we selected a five-day period for our lag effect study. We examined the effects on the current day (Lag0), single-day lag effects (Lag1–Lag5), and cumulative lag effects (Lag01–Lag05) on MECs to identify the most impactful day and estimate the effect. The effect estimates were presented as odds ratios (*OR*s) along with their corresponding 95% confidence intervals (*CI*s). To address diseases with high sensitivity, a subgroup analysis focusing specifically on respiratory, circulatory, and neurological diseases was conducted. The R software (version R 4.2.0; R Studio Inc; the USA) was used for the analysis of time-stratified cross-case data. Statistical significance was considered at a *P*-value of less than 0.05.

Table 1 presents the daily levels of air pollutants, meteorological factors, and MECs in Jinan from 2013 to 2019. The total number of MECs recorded during this period was 275,868, with an average daily number of all-cause MECs at 258±40 cases. Among these cases, the number of MECs related to respiratory,

TABLE 1. Daily levels of air pollutants, meteorological factors, and MECs in Jinan City from 2013 to 2019.

Variables	Mean±SD	Min	P_{25}	P_{50}	P_{75}	Max
Air pollution (μg/m^3)						
PM_{10}	57.09±28.72	3	36	51	73	196
$PM_{2.5}$	114.83±51.03	5	79	106	141	348
NO_2	38.13±12.56	9	29	36	45	88
SO_2	30.09±22.88	6	14	24	39	182
CO	969.75±324.51	363	735	910	1,116	2,598
O_3	154.67±47.87	30	122	157	187	266
Meteorological factor						
Temperature (℃)	30.38±4.06	15.6	27.9	30.9	33.3	39.9
Wind speed (m/s)	2.36±1.02	0.4	1.7	2.1	2.8	7.7
Relative humidity (%)	61.34±17.37	15	49	62	74	98
Pressure (hPa)	988.53±5.18	975	985	987	992	1,004
Medical emergency calls (calls/day)						
All-cause	258±40	161	230	252	278	395
Respiratory diseases	19±9	2	11	18	25	44
Cardiovascular diseases	35±10	6	28	35	42	63
Neurological diseases	39±8	15	33	39	44	78

Abbreviation: MECs=medical emergency calls; SD=standard deviation; Min=minimum; P_{25}=25th percentile; P_{50}=50th percentile; P_{75}=75th percentile; Max=maximum.

circulatory, and neurological diseases were 19±9, 35±10, and 39±8, respectively. Furthermore, the average maximum daily temperature reached 30.38±4.06 ℃, while the daily concentration of O_3 was 154.67±47.87 μg/m^3.

The chronological diagram presented in Supplementary Figure S1 (available in https://weekly.chinacdc.cn/) visually demonstrates consistent trends and potential relationships among temperature, O_3 concentration, and MECs. Additionally, the Spearman correlation analysis (Figure 1) indicates statistically significant correlations between these variables during the study period. Specifically, temperature and MECs, O_3 concentration and MECs, and temperature and O_3 concentration exhibited significant correlations. Notably, a strong positive correlation was observed between O_3 concentration and temperature (r=0.63, P<0.05). Further details on the correlation results between air pollutants and meteorological factors are provided in Supplementary Table S3 (available in https://weekly.chinacdc.cn/).

Figure 2 presents an analysis of the single-day lag effect concerning temperature, O_3 pollution, and their combined impact. Statistically significant independent effects of both temperature and O_3 pollution on all-cause MECs were noted from Lag0 to Lag3, with the most pronounced effect occurring at Lag0. The *OR* values for temperature and O_3 pollution were 1.013 (95% *CI*: 1.010, 1.015) and 1.0005 (95% *CI*: 1.0002, 1.0006), respectively. Notably, the combined influence of temperature and O_3 pollution demonstrated statistical significance from Lag0 to Lag5, peaking at Lag0, with an *OR* of 1.017 (95% *CI*: 1.010, 1.024). A trend of marginal decline in *OR* values was observed for both independent and combined effects of temperature and O_3 pollution with progressing Lag days. Additionally, subgroup analysis indicated significant impacts on MECs for neurological diseases, with *OR* values of 1.017 (95% *CI*: 1.010, 1.024), 1.001 (95% *CI*: 1.000, 1.002), and 1.022 (95% *CI*: 1.004, 1.041). However, the effects of MECs on respiratory and circulatory diseases were not statistically significant. The cumulative lag effect analysis of temperature, O_3 pollution, and their combined effect is depicted in Supplementary Figure S2 (available in https://weekly.chinacdc.cn/).

DISCUSSION

This study employs a time-stratified case-crossover design to investigate the combined effects of high temperature and O_3 pollution on MECs within Jinan City from 2013 to 2019. The results of our analysis confirm that both temperature and O_3 pollution independently increase the risk of MECs during the warm season, and their combined influence further escalates this risk. These findings differ somewhat from previous research studies (*6*–*7*). From a pathogenesis perspective, it is understood that both temperature and O_3 pollution can contribute to the development and occurrence of various respiratory, circulatory, and neurological disorders. This may occur through mechanisms such as inflammation and immune dysregulation. However, it is important to consider that regional disparities in weather conditions (such as temperature, humidity, and wind speed), demographic characteristics of the at-risk population, the composition of O_3 pollution sources, and the range of O_3 concentrations could account for the observed discrepancies. Additionally, variations in exposure durations and statistical analysis models may also play significant roles in explaining the differences encountered.

The results of the stratified analysis indicate that both temperature and O_3 pollution have a positive influence on neurological disorders in residents. This can be attributed to the reactive nature of O_3, an oxidant and reactive oxygen species. When inhaled, O_3 reacts with proteins and lipids, leading to the production of denatured proteins/lipids, carbon/oxygen free radicals, and toxic compounds. This triggers an oxidative stress response in lung macrophages, resulting in physiological disruptions (*8*). Additionally, higher temperatures exacerbate this issue by promoting immune cell activation and transition, leading to various immune adaptations that contribute to the development of neurological diseases (*9*). Interestingly, surface-level O_3 formation rates are closely linked to temperature, suggesting potential reciprocal influences between O_3 pollution and climate change. Therefore, the combination of these factors has a significant impact on population health. However, previous studies have primarily focused on the independent effects of meteorological factors or air pollution on neurological diseases. Hence, this study's examination of the combined implications of temperature and O_3 pollution on neurological diseases is of utmost importance. It is recommended that future research further investigates the risks associated with temperature and O_3 pollution on various neurological disorders, while also considering disease-specific sensitivities.

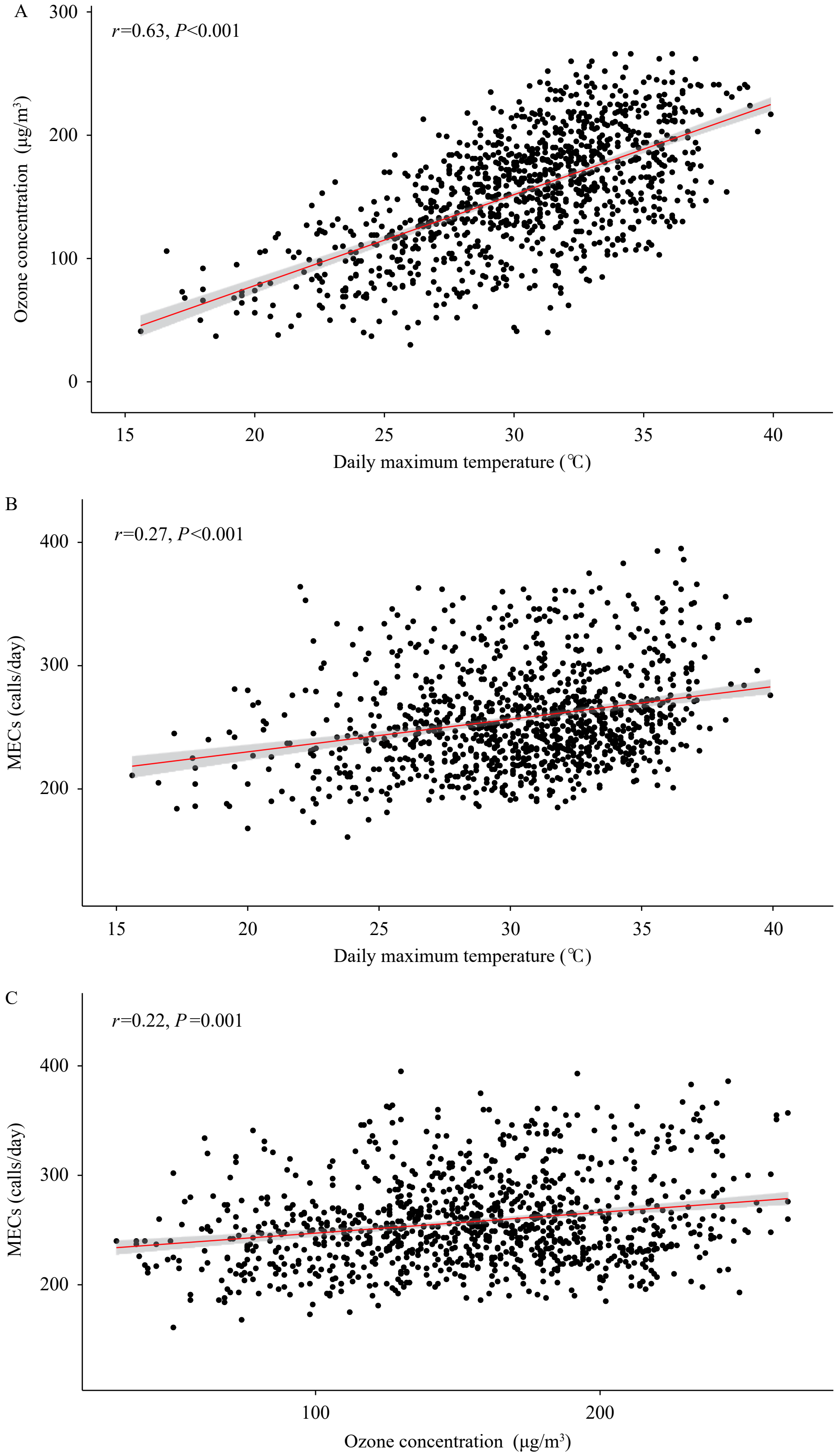
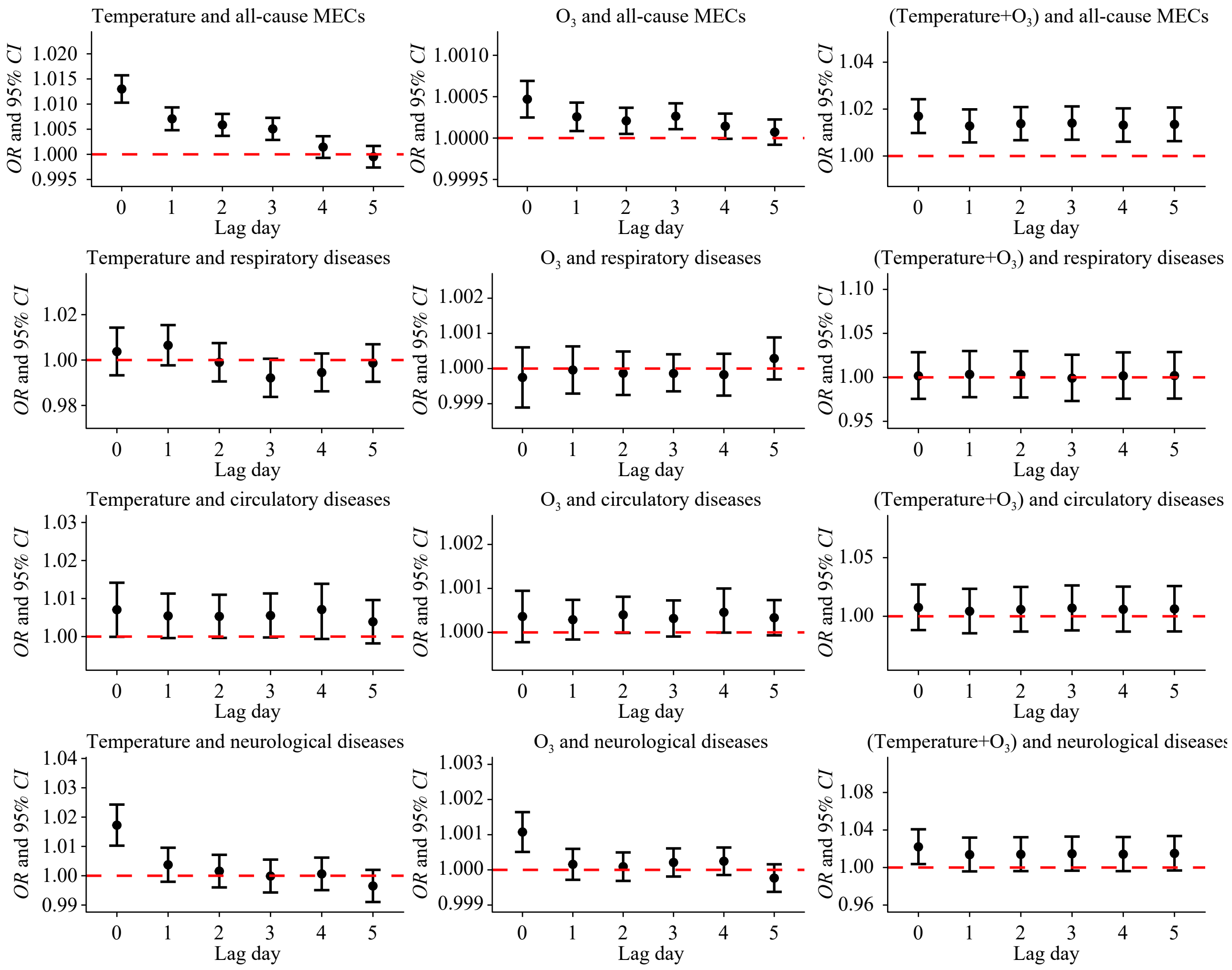


FIGURE 1. Spearman correlation analysis between temperature, O_3, and MECs in Jinan from May to September 2013–2019. (A) represents the correlation analysis between O_3 and temperature; (B) represents the correlation analysis between temperature and MECs; (C) represents the correlation analysis between O_3 and MECs.



Temperature and all-cause MECs

O_3 and all-cause MECs

(Temperature+O_3) and all-cause MECs

Temperature and respiratory diseases

O_3 and respiratory diseases

(Temperature+O_3) and respiratory diseases

Temperature and circulatory diseases

O_3 and circulatory diseases

(Temperature+O_3) and circulatory diseases

Temperature and neurological diseases

O_3 and neurological diseases

(Temperature+O_3) and neurological disease

FIGURE 2. The lag effects of temperature, ozone (O_3), and their combined effects on all-cause morbidity and morbidity rates for various systemic diseases during the warm season in Jinan from 2013 to 2019.

Note: The variable “Temperature+O_3” in this study represents the combined impact of high temperature and ozone pollution.

Abbreviation: *OR*=odds ratio; *CI*=confidence interval; MECs=medical emergency calls.

In our stratified analysis, we have also found that the combined effect of warm season temperature and ozone pollution on emergency calls for respiratory and circulatory diseases was not statistically significant. This finding contradicts previous research (*6*–*7*). The apparent discrepancies in research outcomes might be attributed to variations in research design methodologies, geographic differences in warm season temperature ranges and levels of O_3 pollution, as well as variations in the characteristics of the study populations, all of which may influence the direction of the study’s impact.

However, this study has several limitations that should be considered. Firstly, the use of urban monitoring data averages to represent individual exposure levels may introduce variability into the estimates of combined effects on study outcomes. Secondly, the study was unable to investigate the susceptibility of different genders and age groups, which could have provided valuable insights into the potential heterogeneity of the effects. Thirdly, it should be noted that this study assumes Jinan City is representative of other cities, and outcomes may differ in cities with diverse geographical locations and climate patterns. Lastly, since the COVID-19 epidemic in 2020, the disease composition of MECs has changed significantly, so this study only analyzes data up to 2019.

In conclusion, there was a significant rise in heat-related morbidity cases among residents due to the combined impact of high temperature and O_3 pollution. Of particular concern were the increased incidences of neurological disorders associated with these environmental factors. These findings highlight the urgent need for increased awareness and action from relevant agencies. During the peak of summer, it is crucial to prioritize the dissemination of scientific knowledge regarding meteorological factors and the health implications of O_3 pollution. Specifically, when faced with elevated temperatures and heightened O_3 levels, it becomes imperative for authorities to issue public health warnings as a proactive measure in order to reduce potential health risks.

Conflicts of interest: All authors had no conflicts of interest.

Funding: Big-data Research Project of Jinan Health Committee; Special Project of Public Health Plan of Jinan Health Committee.

doi: 10.46234/ccdcw2024.007

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Submitted: November 18, 2023; Accepted: December 28, 2023

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SUPPLEMENTARY MATERIAL

Methods

An Overview of Jinan City

Jinan City, the capital of Shandong Province, is situated between 36°01′–37°32′ N latitude and 116°11′–117°44′ E longitude. It spans a total area of 10,244 km^2 and is divided into 10 administrative districts, and the rate of medical emergency calls (MECs) showed minor fluctuations from 2013 to 2019 (Supplementary Table S1)(1). The city exhibits a classic temperate monsoon climate characterized by chilly winters, hot summers, and distinct seasonal changes. What's more, Jinan City, renowned as one of China's traditional "furnace cities", experiences severe heat in the summer months. Since 1951, there has been a steady increase in the city's temperature at a rate of 0.24 ℃ per decade, exhibiting an almost linear upward trend (2). Notably, the highest recorded temperature was 39.9 ℃ on July 13, 2015. Jinan suffers from substantial air pollution, with a historical $PM_{2.5}$ record peaking at 443 $\mu g/m^3$ during the 2013 haze incident (3). It serves as a pivotal link between two prominent economic zones, the Beijing-Tianjin-Hebei Regions and the Yangtze River Delta. In recent years, Jinan has undergone swift industrialization and urbanization processes. Almost 40% of Jinan's gross domestic product (GDP) stems from key industries such as power plants, manufacturing, textile and steel production, chemical manufacturing, light industry, and building materials (3). Consequently, Jinan City has been identified as one of the top ten cities in China for air pollution, with escalating O_3 pollution observed since 2013.

MECs Data Collection

Established in 1956, the Jinan Medical Emergency Center (JMEC) is charged with managing emergency health requests from the population via a "120" hotline available round the clock. JMEC oversees 66 first-aid service stations affiliated with hospitals, providing coverage across all ten administrative districts of Jinan City (Supplementary Table S2). For this research, daily data from JMEC's MECs were gathered for the period spanning May 1 to September 31 for the years 2013–2019.

Upon receipt of a call through the hotline, the physicians on duty promptly register pertinent emergent medical information. This includes the caller's telephone number, the time of the call, the address of either the patient or the accident, and any reported health complaints. These health complaints are then categorized into respective clinical diagnostic descriptors while also inquiring about additional health-related issues. Emergency calls can be divided into two main types: emergency and non-emergency. For the purpose of this study, non-emergency calls — which encompass calls associated with accidents, service types such as transfers, evacuations, equipment rentals, testing, and trauma — were excluded in order to establish a database of MECs.

The Time-Stratified Case-Crossover Model Analysis

The fundamental principle underpinning the time-stratified case-crossover study involves time stratification, wherein the case phase and control phase occur within the same time stratum. Specifically, within a given time stratum, multiple control periods, both preceding and following the case period, are matched according to the same year, month, and weekday (4). This design permits an event day to correspond to 3 to 4 control days. For example, if an event day occurs on May 16, 2013 (a Thursday), other Thursdays in May of 2013 would be selected as control days. Furthermore, in consideration of confounding factors, relative humidity (RH) is incorporated into the regression model as a covariate. The fundamental equation for this core model is presented below:

$$Log[E(Y_t)] = \alpha + \beta_1 temperature + \beta_2 O_3 + \beta_3 (temperature + O_3)_t + RH + stratum \quad (1)$$

Where $E(Y_t)$ is the expected number of MECs at time t; t is event date; α is the intercept; β is vector of regression coefficients; and $(temperature{+}O_3)_t$ is the interaction between temperature and O_3 concentration on day t; *stratum* is the categorical variable, which is the matching variable of year, month, and week.

Several sensitivity analyses were carried out to evaluate the robustness of the main findings. Under optimal effect periods, the main model was adjusted by incorporating the air pollutants ($PM_{2.5}$, NO_2) and meteorological factors (wind speed, pressure), separately.

SUPPLEMENTARY TABLE S1. The information of resident population and MECs rate in Jinan City from 2013 to 2019.

Year	Resident year-end population	MECs volume	MECs rate (%)
2013	6,999,000	35,380	0.51
2014	7,067,000	38,547	0.54
2015	7,132,000	41,453	0.58
2016	7,233,000	34,459	0.48
2017	7,321,000	38,373	0.52
2018	7,460,400	37,573	0.50
2019	7,613,000	42,571	0.56

Abbreviation: MECs=medical emergency calls.

SUPPLEMENTARY TABLE S2. The information of JMECS.

S.N.	Name of JMECS	District/country	Area type
1	Shanghe County People’s Hospital	Shanghe	Rural
2	Shanghe County Chinese Medicine Hospital	Shanghe	Rural
3	Shanghe County Puji Hospital	Shanghe	Rural
4	Jiyang District People’s Hospital	Jiyang	Rural
5	Jiyang District Chinese Medicine Hospital	Jiyang	Rural
6	Zhangqiu District People’s Hospital	Zhangqiu	Rural
7	Zhangqiu District Chinese Medicine Hospital	Zhangqiu	Rural
8	Zhangqiu District Wenzu Health Centre	Zhangqiu	Rural
9	Zhangqiu District Shuizhai Health Centre	Zhangqiu	Rural
10	The Second Hospital of Shandong University	Tianqiao	Urban
11	Tianqiao District Daqiao Township Health Centre	Tianqiao	Urban
12	Provincial Third Hospital	Tianqiao	Urban
13	Provincial Third Hospital Xincheng Campus	Tianqiao	Urban
14	Jinan Hebei Fourth Hospitals	Tianqiao	Urban
15	Jinan Central Hospital Huashan Station	Tianqiao	Urban
16	Jinan Fourth People’s Hospital	Tianqiao	Urban
17	Huanghe Hospital	Tianqiao	Urban
18	Jinan Central Hospital Gangou Station	Licheng	Urban
19	People’s Liberation Army Hospital 960	Licheng	Urban
20	Jinan Third People’s Hospital	Licheng	Urban
21	Jinan Third People’s Hospital Tangwang	Licheng	Urban
22	Jinan Seventh People’s Hospital	Licheng	Urban
23	Jinan Jigang Hospital	Licheng	Urban
24	The Second Hospital of SU	Licheng	Urban
25	Shandong University School Hospital	Licheng	Urban
26	Licheng District People’s Hospital	Licheng	Urban
27	Jinan Puxian Hospital	Licheng	Urban
28	Jinan Lingang Hospital	Licheng	Urban
29	Jinan Tangye Hospital	Licheng	Urban
30	Jinan MECS	Lixia	Urban
31	Jinan Central Hospital Yajuyuan Station	Lixia	Urban

Continued

S.N.	Name of JMECS	District/country	Area type
32	Jinan Central Hospital Qilu Garden Station	Lixia	Urban
33	Thousand Buddha Mountain Hospital	Lixia	Urban
34	Jinan Hospital	Lixia	Urban
35	Provincial Hospital East Campus	Lixia	Urban
36	Qilu Hospital	Lixia	Urban
37	Jinan First People’s Hospital	Lixia	Urban
38	Shandong Chinese Medicine Hospital East Campus	Lixia	Urban
39	Lixia District People’s Hospital	Lixia	Urban
40	Lixia District Third PH	Lixia	Urban
41	Jinan Puji Hospital	Lixia	Urban
42	Jinan Fifth People’s Hospital	Huaiyin	Urban
43	Jinan 106 Hospital	Huaiyin	Urban
44	Jinan Fifth People’s Hospital Dajin Station	Huaiyin	Urban
45	Huaiyin District People’s Hospital	Huaiyin	Urban
46	Shandong Hand-Foot Surgery Hospital	Huaiyin	Urban
47	Provincial Hospital West Campus	Huaiyin	Urban
48	Jinan 106 Hospital West Station	Huaiyin	Urban
49	Jinan Zhongde Orthopaedic Hospital	Huaiyin	Urban
50	Jinan Maternal and Child Health Centre	Shizhong	Urban
51	Jinan Chinese Medicine Hospital	Shizhong	Urban
52	Jinan MECS Second Station	Shizhong	Urban
53	Shizhong District People’s Hospital	Shizhong	Urban
54	Shandong Provincial Police General Hospital	Shizhong	Urban
55	The Second Affiliated Hospital of Shandong University of Traditional Chinese Medicine	Shizhong	Urban
56	Jinan Santa Maria Hospital	Shizhong	Urban
57	Jinan Central Hospital Shandong Power Station	Shizhong	Urban
58	Jinan Microsurgery Hospital	Shizhong	Urban
59	Changqing District People’s Hospital	Changqing	Rural
60	Changqing District Chinese Medicine Hospital	Changqing	Rural
61	Changqing District Zhangxia Station	Changqing	Rural
62	Changqing District Xiaoli Station	Changqing	Rural
63	Pingyin County People’s Hospital	Pingyin	Rural
64	Pingyin Traditional Chinese Medicine Hospital	Pingyin	Rural
65	Pingyin County Dong’a Town Centre Health Centre	Pingyin	Rural
66	Pingyin County Xiaozhi Township Health Centre	Pingyin	Rural

Abbreviation: S.N.=serial number; JMECS=Jinan Medical Emergency Centre Station; MECs=medical emergency calls.

RESULTS

Correlation Analysis

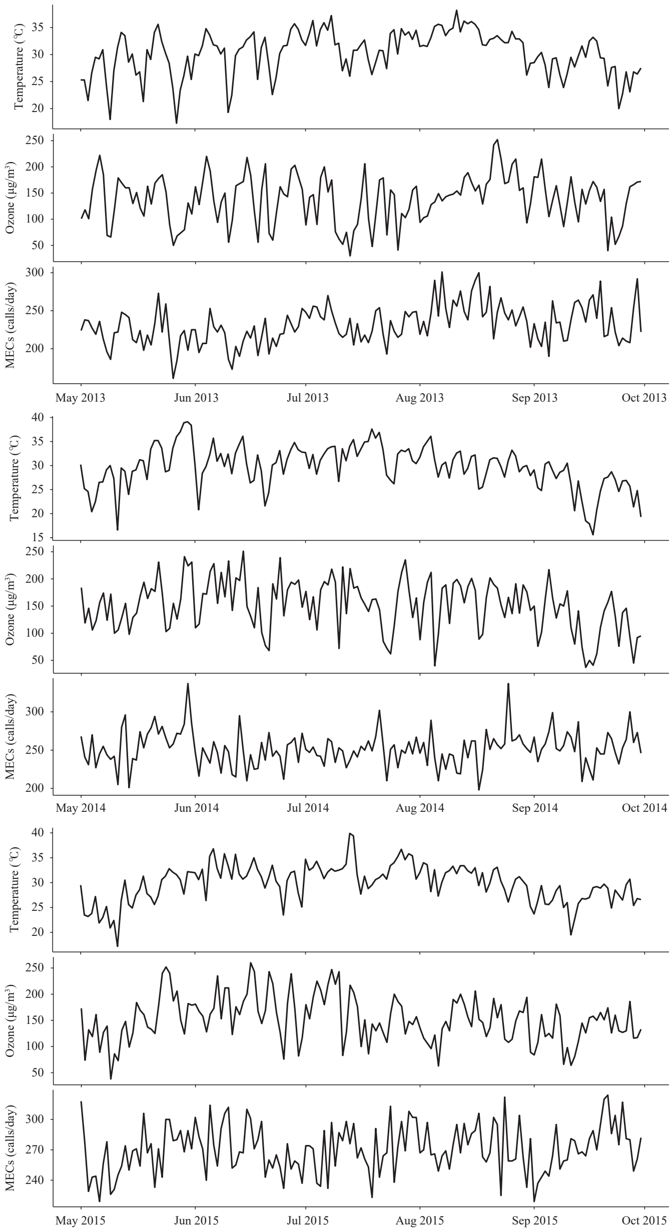
The chronologically displayed diagram depicting the correlations among temperature, O_3 concentration, and MECs demonstrates a high degree of consistency, suggesting potential relationships (Supplementary Figure S1). Furthermore, temperature demonstrates a positive correlation with wind speed and a negative correlation with

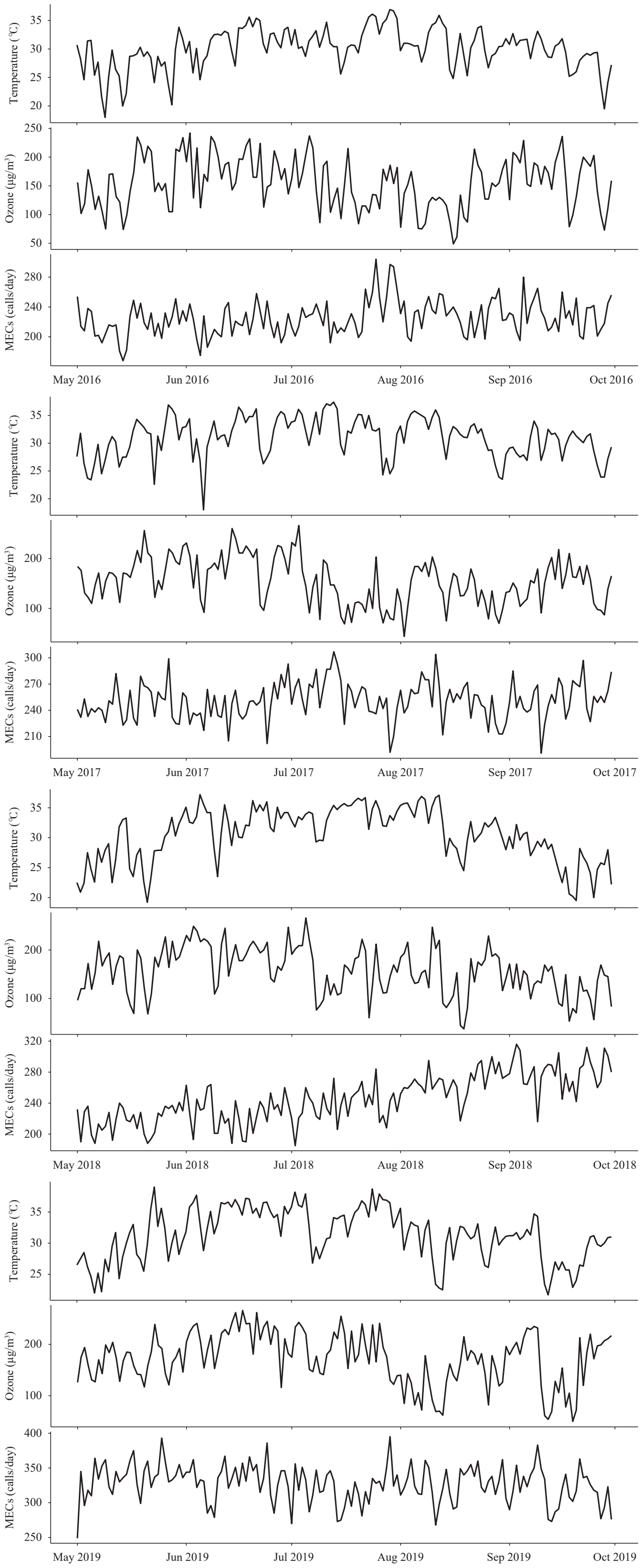
SUPPLEMENTARY TABLE S3. Correlation coefficient (r_s value) between meteorological factors and air pollutants in Jinan City, from May to September 2013–2019.

Variables	RH (%)	WS (m/s)	$PM_{2.5}$	PM_{10}	NO_2	SO_2	CO	O_3
Pressure (hPa)	−0.13*	−0.19*	0.04*	0.12*	0.10*	0.10*	−0.13*	−0.15*
Temperature (℃)	−0.29*	0.10*	−0.01*	−0.01*	−0.25*	−0.09*	−0.12*	0.63*
RH (%)		−0.38*	0.06*	−0.29*	−0.04*	−0.13*	0.16*	−0.56*
WS (m/s)			0.08*	0.09*	−0.36*	0.08*	−0.18*	0.04*
$PM_{2.5}$				0.87*	0.54*	0.66*	0.68*	0.14*
PM_{10}					0.57*	0.65*	0.55*	0.25*
NO_2						0.63*	0.62*	−0.02*
SO_2							0.62*	0.02*
CO								−0.07*

Abbreviation: RH=relative humidity; WS=wind speed.

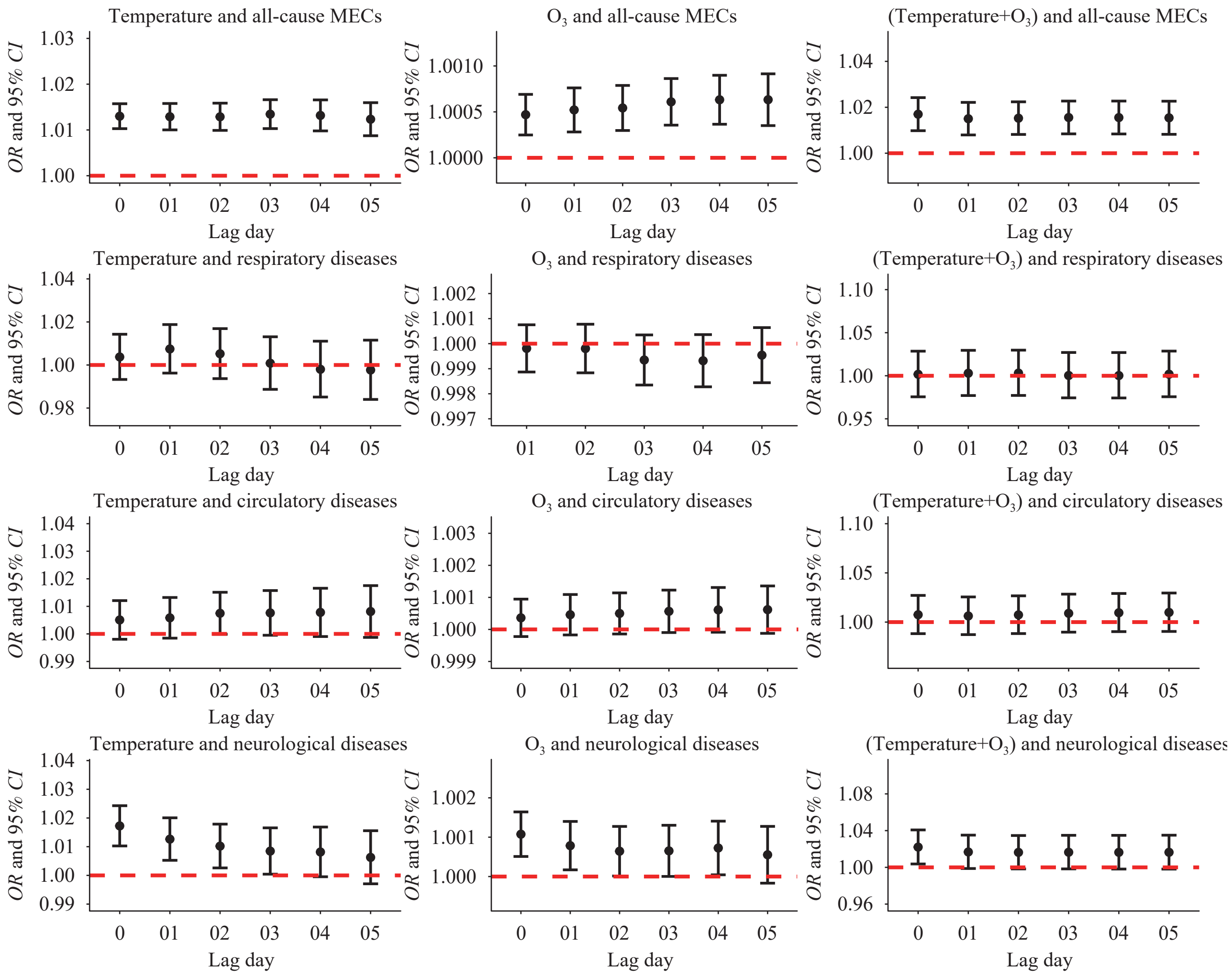
* P<0.05.





SUPPLEMENTARY FIGURE S1. Time sequence diagram of temperature, O_3 concentration, and MECs in Jinan, from May to September 2013–2019.

Abbreviation: MECs=medical emergency calls; May=May; Jun=June; Jul=July; Aug=August; Sep=September; Oct=October.



SUPPLEMENTARY FIGURE S2. The cumulative lag effect of temperature, O_3, and temperature combined with O_3 on the all-cause MECs and MECs for different system diseases in the warm season of Jinan, 2013–2019.
Note: The variable "Temperature+O_3" in this study represents the combined impact of high temperature and ozone pollution.
Abbreviation: *OR*=odds ratio; *CI*=confidence interval; MECs=medical emergency calls.

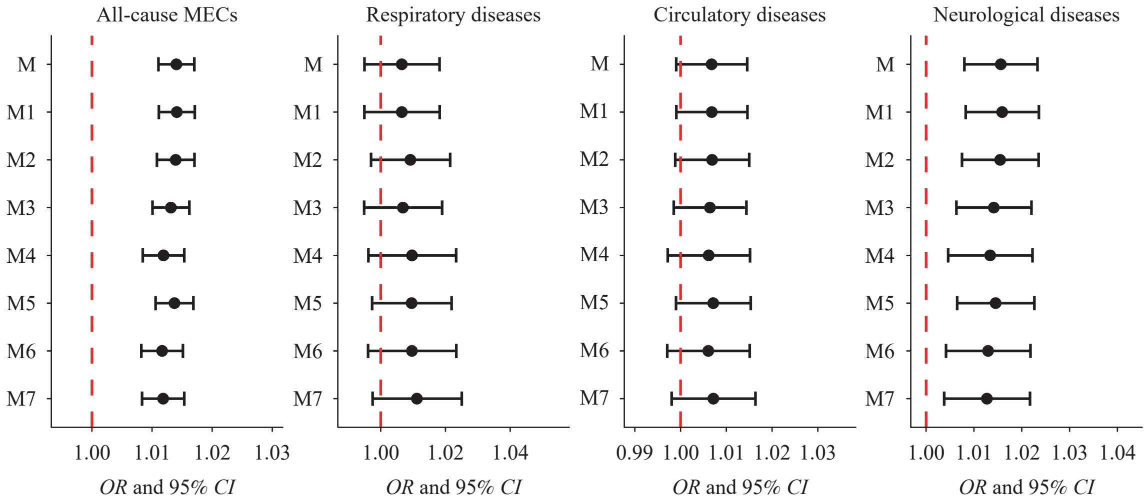
relative humidity and other atmospheric pollutants. O_3 concentration is positively correlated with wind speed, $PM_{2.5}$, PM_{10}, and SO_2, but it is negatively correlated with relative humidity, NO_2, and CO (Supplementary Table S3).

Effects of Temperature and Ozone Pollution on Medical Emergency Calls

Supplementary Figure S2 illustrates the results of the cumulative lag effect analysis for temperature, O_3 pollution, and their combination. Our analysis revealed statistically significant impacts of temperature, O_3 pollution, and the combination of temperature and O_3 pollution on all-cause mortality and morbidity events. Notably, the most pronounced effects were observed at Lag03, Lag04, and Lag0 for temperature, O_3 pollution, and the combination, respectively. Furthermore, our investigation uncovered that the cumulative lag effects of temperature and O_3 pollution on mortality and morbidity events related to respiratory, circulatory, and neurological diseases were consistent with the findings from the single-day lag effect analysis.

Sensitivity Analysis

This study employs a sensitivity analysis to assess the robustness of the estimated effect value by the master model, taking into account the presence of additional air pollutants and meteorological factors such as $PM_{2.5}$, NO_2, wind speed, pressure, and a combined category of all these factors, throughout the perpetual duration of optimum effect.



SUPPLEMENTARY FIGURE S3. The effects of temperature combined with O_3 pollution on MECs of different system diseases after adding other factors.

Note: M refers to the master model, M1 represents the adjustment of $PM_{2.5}$, M2 represents the adjustment of NO_2, M3 represents the adjustment of wind speed, M4 represents the adjustment of pressure, M5 represents the adjustment of $PM_{2.5}$ and NO_2, M6 represents the adjustment of wind speed and pressure, and M7 represents the adjustment of $PM_{2.5}$, NO_2, wind speed, and pressure.

Abbreviation: *OR*=odds ratio; *CI*=confidence interval; MECs=medical emergency calls.

Supplementary Figure S3 displays the estimated effect value and the corresponding confidence interval of temperature combined with O_3 pollution on various health outcomes (including all-cause, respiratory diseases, circulatory diseases, and neurological diseases). Notably, these estimates remain mostly unchanged when relevant parameters are altered. These findings demonstrate the appropriateness of the chosen model parameters in this study and validate the robustness of the model fitting results.

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