Short-term exposure to extreme temperature and outpatient visits for respiratory diseases among children in the northern city of China: A time-series study

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Abstract

Background

Although studies have indicated that extreme temperature is strongly associated with respiratory diseases, there is a dearth of studies focused on children, especially in China. We aimed to explore the association between extreme temperature and children’s outpatient visits for respiratory diseases and seasonal modification effects in Harbin, China.

Methods

A distributed lag nonlinear model (DLNM) was used to explore the effect of extreme temperature on the daily outpatient visits for respiratory diseases among children and lag effects as well as seasonal modification effects.

Results

Extremely low temperatures were defined as the 1st percentile and 2.5th percentile of temperature. Extremely high temperatures were defined as the 97.5th percentile and 99th percentile of temperature. At extremely high temperatures, both 26°C (97.5th) and 27°C (99th) showed adverse effects at lag 0–6 days, with relative risks (RRs) of 1.34 [95% confidence interval (CI): 1.21–1.48] and 1.38 (95% CI: 1.24–1.53), respectively. However, at extremely low temperatures, both − 26°C (1st) and − 23°C (2.5th) showed protective effects on children’s outpatient visits for respiratory diseases at lag 0–10 days, with RRs of 0.86 (95% CI: 0.76–0.97) and 0.85 (95% CI: 0.75–0.95), respectively. We also found seasonal modification effects, with the association being stronger in the warm season than in the cold season at extremely high temperatures.

Conclusions

Our study indicated that extremely hot temperatures increase the risk of children’s outpatient visits for respiratory diseases. Efforts to reduce the exposure of children to extremely high temperatures may have the potential to mitigate the burden of pediatric respiratory diseases, especially in the warm season.

Background

Climate change is one of the serious challenges of modern society. The *Lancet* Countdown on health and climate change [1] states that the world's average temperature has risen by 1.2°C relative to last century’s levels, and this trend will continue in the future. The number of extreme weather events is increasing [2]; in particular, extremes of hot and cold are becoming more frequent globally [3]. In China, extremely high temperature events have increased significantly since mid-1990 [4]. From 1991 to 2020, the average value of China's climate risk index (6.8) increased by 58% compared to 4.3 in 1961–1990 [5]. Extreme temperatures are significantly linked to a variety of adverse health outcomes (e.g., morbidity and mortality) [6–8], particularly with cardiovascular and respiratory diseases [9–11].

Studies have shown that respiratory diseases are directly affected by the atmospheric environment, including external meteorological changes and especially in regard to extreme temperatures [8, 12]. There are substantial differences among different populations’ vulnerability to temperature stress [13]. Compared to adults and elderly individuals, children appear to be more susceptible to temperature changes [14] and might be more vulnerable to respiratory and immune systems under development [15]. Although studies [16–20] have reported that extreme temperatures are associated with respiratory diseases among children in various climate regions, the results are inconsistent. For example, Wen et al. [20] found that extreme temperatures had no effects on children's respiratory diseases in China. In contrast, one study showed that both low and high temperatures were associated with a high risk of respiratory diseases in children, with relative risks (RRs) of 1.082 (95% CI: 1.025–1.142) and 1.099 (95% CI: 1.049–1.152) at extremely low temperatures and extremely high temperatures, respectively [16].

The southern and northern regions in China react differently to extreme temperatures [21, 22]. People in southern provinces were more susceptible to extremely cold events, while people in northern provinces tended to be more sensitive to heat waves [22]. Developing cities are more vulnerable to extreme climates than developed cities [23]. In China, few studies have examined the association between extreme temperature and children’s respiratory diseases, and studies have mainly been conducted in developed cities and southern areas [24–29]. Therefore, more similar studies are needed to explore the associations between extreme temperature and children’s respiratory diseases, especially in developing cities in China's northern region. Harbin, located in northern China and the capital of Heilongjiang Province, is a developing city, with a per capita gross domestic product (PGDP) of less than 50,000 yuan in 2020 [30]. In addition, extreme temperature events in Harbin have increased in recent years, and few studies have focused on the relationship between childhood respiratory diseases and extreme temperatures [31]. Therefore, it is necessary to conduct research in Harbin to fill the research gaps mentioned above.

Understanding the regional association between temperature and childhood respiratory diseases is crucial in drafting strategic plans for reducing the burden of respiratory diseases, especially with extreme weather events occurring more frequently. In our study, we aimed to (1) explore the short-term associations between extreme temperature and children's outpatient visits for respiratory diseases in Harbin using a retrospective time-series approach and (2) evaluate the seasonal modification effect on the association between extreme temperatures and outpatient visits for respiratory diseases.

Materials And Methods

Study Setting

Harbin (125.4°E–130.1°E, 44.0°N–46.4°N), located in northern China with a temperate zone, is the capital city of Heilongjiang Province. It has a monsoon climate with an annual average temperature of 5.6°C and covers an area of approximately 53,186 km² (Fig. S1). On the basis of the seventh national census launched in 2020, there are 1.285 million children younger than 18 years old in Harbin, accounting for 13.5% of the city's total population (http://tjj.hlj.gov.cn/tjsj/tjnj/).

Outpatient data of children's respiratory diseases

All children younger than 18 years old who visited Harbin Children's Hospital for pediatric respiratory diseases were included over the period studied. Harbin Children's Hospital is the only comprehensive children's hospital in Harbin and the largest children's hospital in the three northeastern provinces of China. In this study, outpatient data of children with respiratory diseases were obtained from the hospital's health information system from 1 January 2013 to 31 December 2019. All records coded 'J00–J99' according to the International Classification of Diseases 10th version (ICD-10) were considered respiratory diseases.

Meteorological and air pollution data

We collected daily mean temperature, daily mean relative humidity, and daily mean air pressure during the period studied from the China Meteorological Data Sharing Service System (http://data.cma.cn/), including 8 weather monitoring stations (Fig. S2). To allow for adjustment of covariates, we obtained the data on daily mean values of multiple air pollutants (including sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and airborne particulate matter with an aerodynamic diameter < 2.5 μm ($PM_{2.5}$) or 10 μm (PM_{10})) from the China National Environmental Monitoring Centre (https://www.cnemc.cn/), including 12 environmental monitoring stations (Fig. S2). Daily mean values of meteorological factors, SO_2, NO_2, CO, $PM_{2.5}$, and PM_{10} were calculated using the 24-h average monitoring records across all weather and environment monitoring stations. For missing air pollutant variables, including PM_{10} (n = 27), NO_2 (n = 27) and SO_2 (n = 27), we used the Kalman smoothing method to impute the missing values by the R package "imputeTS".

Statistical analysis

In the descriptive analyses, the mean, standard deviation (SD), quartiles (P_{25}, P_{50}, P_{75}), minimum (min), and maximum (max) were calculated to describe the distribution of the daily number of outpatient visits and meteorological variables. We used a distributed lag nonlinear model (DLNM) based on a quasi-Poisson regression to assess the impact of extreme temperatures on outpatient visits for respiratory diseases among children. The natural cubic spline (ns) function of time was used to adjust the long-term and seasonal trends with 7 degrees of freedom (*df*) per year [32]. Meanwhile, other significant potential confounders, such as the effect of the day of the week (DOW) and the public holiday effect, were also controlled. Public holidays and DOW were classified as categorical variables.

To adjust for the effects of other potential factors, including air pollutants and other meteorological factors, we adjusted for PM_{10}, SO_2, NO_2 and humidity, which was in line with previous studies [33, 34]. The variance inflation factor (VIF) values of the independent variables (including PM_{10}, SO_2, NO_2, temperature and humidity) were calculated [35]. The VIF values were lower than 5, which suggested that there was no underlying collinearity problem between independent variables (Table S1). In addition, we also calculated the Spearman rank correlation coefficients between the variables (Fig. S3).

Finally, we incorporated several covariates: (1) a ns function of time with 7 df per year to control for long-term and seasonal trends; (2) a ns function with 3 df for relative humidity, PM_{10}, NO_2, and SO_2 at the current day [36]; (3) a categorical variable of DOW; and (4) a binary dummy variable of public holidays. The model was described as follows (Eq. (1)):

$$Y_t \sim Poisson(\mu_t)$$

$$Log\left(\mu_t\right) = \alpha + \beta\left(temp_{t,l}\right) + ns\left(time_t, 7*7\right) + ns\left(rh_{,}3\right) + ns\left(PM_{10,}3\right) + ns\left(NO_{2,}3\right) + ns\left(SO_{2,}3\right) + DOW_t + Holiday_t \ (1)$$

where $Y_t$is daily children's outpatient visits for respiratory diseases on Day t, α is the intercept, $temp_{t,l}$is a matrix obtained by applying the DLNM to temperature, *β* is a vector of coefficients for $temp_{t,l}$, and *l* is the lag days. $DOW_t \text{and} Holiday_t$ are the category variables to control for day of the week and public holiday variable.

We defined the cross-basis matrices for temperature, which was specified using the B-spline (bs) function with internal knots at the 25th, 50th and 75th percentiles. Regarding the space of lags, time lags ranging from 0 to 27 days were evaluated according to a previous study [37]. The max lag is determined by a lag-response plot (Fig. S4), which shows that the max lag period can be extended to 6 days and 10 days for the hot effect and cold effect, respectively. In addition, considering that both cold and hot effects were not significant at a lag of 2 days, we also analyzed the effect with a lag of 0–1 days. The knots for lags are placed at equally spaced log values of lag using the function lognots. RRs were calculated using 7°C (median temperature) as a reference value [33]. We computed the 1st, 2.5th, 97.5th, and 99th percentiles of the temperature (− 23, -26, 26, and 27 ℃) as the extremely low and high temperatures to explore the cold and hot impacts, respectively. The lag effects along lags of 1 and 6 at specific temperatures (26 and 27 °C) were calculated to estimate the cumulative effects of extremely high temperatures. The lag effects along lags of 1 and 10 at specific temperatures (-23 and − 26 ℃) were calculated to estimate the cumulative effects of extremely low temperatures.

To analyze the seasonal modification effects, we stratified the data into the warm season (April to September) and cold season (October to March) [38], and the model was slightly different from Eq. (1). Specifically, ns with 3 df per season (6 months) was used for time to adjust for long-term trends. We statistically tested the seasonal modification effect regarding the effects of extreme temperatures on outpatient visits for respiratory diseases by computing the 95% CI of the relative difference in RRs between warm and cold seasons. The relative difference in RRs is the ratio of two RRs, which was regarded as the relative risk ratio (RRR). The formula for calculating RRR is as follows [39]:

$$exp\left[(E_1 - E_2) \pm 1.96\sqrt{SE_1^2 + SE_2^2}\right]$$

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We conducted a Z-test to test the statistical significance of RRR as follows [40]:

$$Z = \frac{E_1 - E_2}{\sqrt{SE_1^2 + SE_2^2}}$$

3

where E_1 and E_2 refer to ln(RR) in cold and warm seasons, and SE_1 and SE_2 are their standard errors, respectively [41].

Sensitivity analyses were applied to verify the robustness of associations for extreme temperatures on outpatient visits for children’s respiratory diseases reported in the primary model by (1) changing the df from 6 to 10 for the time in the models; (2) changing the df of ns functions from 1 to 7 for relative humidity; and (3) adjusting for the impacts of CO and other air pressure based on the primary model.

All statistical tests were two-tailed, and p values < 0.05 were defined as statistically significant. We conducted all statistical analyses using R Software (Version 3.6.1).

Results

Descriptive results

From January 1, 2013, to December 31, 2019, there were a total of 10,57521 daily outpatient visits to Harbin Children's Hospital for respiratory diseases. The average daily number of outpatient visits was 414 cases, ranging from 62 to 1,407. The average daily temperature and relative humidity in Harbin during the study period were 4.51°C and 65.43%, respectively. The mean concentrations of PM_{10}, NO_2, and SO_2 were 83.17 μg/m^3, 43.74 μg/m^3, and 31.47 μg/m^3, respectively. The average daily number of outpatient visits, mean temperature, relative humidity and air pollutants in the warm and cold seasons are shown in Table 1. The daily distribution of children’s outpatient visits for respiratory diseases, weather conditions and air pollutants during the study period are shown in Fig. S5.

Table 1

Descriptive statistics of children outpatient visits for respiratory diseases, weather conditions and air pollutants by seasons (overall, warm, and cold) in Harbin from January 1, 2013, to December 31, 2019

Season	Variables	Mean	SD	Min	P25	P50	P75	Max
Whole year	Daily counts, mean	413.74	198.94	62.00	244.00	400.50	537.00	1407.00
	Mean temperature (°C)	4.51	15.55	-33.50	-10.30	7.10	18.41	30.80
	Relative humidity (%)	65.43	14.91	15.00	56.50	67.00	76.00	98.00
	PM_{10} (μg/m^3)	83.17	67.56	1.00	42.00	65.00	101.05	844.92
	$N0_2$ (μg/m^3)	43.74	20.64	10.00	29.00	39.00	54.00	161.17
	SO_2 (μg/m^3)	31.47	35.73	2.82	8.50	16.96	41.00	233.36
Warm	Daily counts, mean	391.65	175.77	96.00	248.00	385.00	496.00	1407.00
	Mean temperature (°C)	17.36	6.48	-3.20	13.30	18.40	22.20	30.80
	Relative humidity (%)	66.64	17.29	15.00	56.00	70.00	80.00	98.00
	PM_{10} (μg/m^3)	63.76	45.12	11.00	35.00	51.70	79.17	518.00
	$N0_2$ (μg/m^3)	34.32	13.11	10.00	25.00	32.00	40.00	107.83
	SO_2 (μg/m^3)	11.06	6.79	2.82	7.00	9.00	13.00	48.58
Cold	Daily counts, mean	435.94	217.59	62.00	242.50	414.00	582.00	1217.00
	Mean temperature (°C)	-8.40	10.50	-33.50	-16.60	-10.30	0.30	20.65
	Relative humidity (%)	64.22	11.95	19.00	56.80	65.00	73.00	97.00
	PM_{10} (μg/m^3)	102.66	79.69	1.00	53.00	79.00	124.52	844.92
	$N0_2$ (μg/m^3)	53.19	22.43	11.00	37.00	50.00	65.23	161.17
	SO_2 (μg/m^3)	51.97	40.92	4.91	23.61	40.92	66.50	233.36

Exposure - lag - response relationship

Figure 1 displays the 3-D exposure-response plot of the mean temperature on daily outpatient visits for respiratory diseases along lag days. Overall, the effect of temperature on the risk of daily outpatient visits for children's respiratory diseases was nonlinear. From the 3-D plot, we found that extremely high temperatures presented a harmful effect, while extremely low temperatures presented a protective effect. The harmful effects of the hot effect lasted for approximately one week, and the effect decreased rapidly with the increase in lag days. Compared to the hot effect, the protective effect of the cold effect lasted approximately two weeks, and the effect gradually diminished with the increase in lag days.

The overall exposure-response relationship between temperature and daily outpatient visits for children's respiratory diseases showed a nonlinear curve with a reference of 7°C (shown in Fig. 2). The histogram in the graph reflects the distribution of the number of outpatient visits for children's respiratory diseases at different temperatures. Hot exposure on outpatient visits for children's respiratory diseases showed harmful effects at both lag 0–1 day and lag 0–6 days. In contrast, cold exposure on outpatient visits for children's respiratory diseases showed a protective effect at both lag 0–1 days and lag 0–10 days.

The RRs of hot exposure on outpatient visits for children's respiratory diseases at lag 0–1 day were 1.17 (95% CI: 1.09–1.26) and 1.20 (95% CI: 1.10–1.29) for extremely high temperatures (97.5th and 99th percentiles, respectively). Extremely high temperature was still a risk factor when the lag time was extended to 6 days, with RR values of 1.34 (95% CI 1.21–1.48) and 1.38 (95% CI 1.24–1.53). The RRs of cold exposure on outpatient visits for children's respiratory diseases at lag 0–1 day were 0.73 (95% CI: 0.67–0.79) and 0.72 (95% CI: 0.67–0.78) for extremely low temperatures (1st and 2.5th percentiles, respectively). In addition, extremely low temperature was still a risk factor when the lag time was extended to 10 days. Detailed results are presented in Table 2.

Table 2
The cumulative effects (RR and 95% CI) of extreme temperature on children's outpatient visits for respiratory diseases, with the 1st, 2.5th, 97.5th, and 99th percentiles of daily mean temperature relative to the reference 7 °C at different lag days in Harbin

	1st (-26 °C)	**2.5th (-23 °C)**	**97.5th (26 °C)**	**99th (27 °C)**
Lag 0–1	0.73 (0.67, 0.79)	0.72 (0.67, 0.78)	1.17 (1.09, 1.26)	1.20 (1.10, 1.29)
Lag 0–6	0.61 (0.54, 0.69)	0.61 (0.54, 0.68)	1.34 (1.21, 1.48)	1.38 (1.24, 1.53)
Lag 0–10	0.59 (0.51, 0.69)	0.59 (0.51, 0.68)	1.40 (1.25, 1.58)	1.45 (1.28, 1.65)

Modification effect

Generally, a modification effect by season was found on associations between extremely high temperature and children's outpatient visits for respiratory diseases ($p < 0.05$), with stronger risk associations in the warm season than in the cold season, especially for extremely high temperatures (Table 3). The critical values (1st, 2.5th, 97.5th, 99th) of temperature during the warm season were 0°C, 2°C, 27°C, and 28°C, respectively. The critical values (1st, 2.5th, 97.5th, 99th) of temperature during the cold season were − 28°C, -26°C, 12°C, and 14°C, respectively. A statistically significantly stronger effect was found in the warm season than in the cold season for extremely high temperatures (99th) at a cumulative lag of 0–6 days [RR = 1.15 (95% CI: 1.05–1.26) versus 0.98 (95% CI: 0.87–1.12); RRR = 1.12 (1.07, 1.43).

Table 3
Cumulative effect (RR and 95% CI) of extreme temperature (1st, 2.5th, 97.5th and 99th percentiles) on children's outpatient visits for respiratory diseases stratified by cold and warm seasons, with respect to the reference of median of daily average temperature at different lag days in Harbin

Temperature percenties	**Lag (day)**	**Warm season**	**Cold season**	**Difference test**	**z**	***p***
		RR (95% CI)	**RR (95% CI)**	**RRR (95% CI)**		
1st	Lag 0–1	1.02 (0.95, 1.10)	1.00 (0.94, 1.05)	1.08 (0.98, 1.19)	0.58	0.56
	Lag 0–6	1.00 (0.91, 1.10)	0.99 (0.93, 1.06)	1.22 (1.06, 1.40)	0.17	0.86
	Lag 0–10	1.06 (0.95, 1.17)	0.98 (0.92, 1.05)	1.17 (0.94, 1.47)	1.12	0.26
2.5th	Lag 0–1	1.01 (0.92, 1.10)	1.00 (0.94, 1.06)	1.07 (0.99, 1.16)	0.23	0.82
	Lag 0–6	1.00 (0.90, 1.12)	0.99 (0.91, 1.07)	1.17 (1.05, 1.30)	0.23	0.82
	Lag 0–10	1.05 (0.93, 1.19)	0.98 (0.90, 1.07)	1.10 (0.97, 1.26)	0.94	0.35
97.5th	Lag 0–1	1.08 (1.02, 1.13)	1.02 (0.94, 1.12)	1.04 (0.96, 1.13)	1.01	0.31
	Lag 0–6	1.11 (1.04, 1.18)	0.98 (0.88, 1.10)	1.25 (1.10, 1.41)	1.88	0.06
	Lag 0–10	1.09 (1.02, 1.18)	0.98 (0.87, 1.10)	1.45 (1.26, 1.68)	1.61	0.11
99th	Lag 0–1	1.10 (1.03, 1.17)	1.03 (0.93, 1.13)	1.05 (0.96, 1.15)	1.16	0.25
	Lag 0–6	1.15 (1.05, 1.26)	0.98 (0.87, 1.12)	**1.24 (1.07, 1.43)**	**1.99**	**0.04**
	Lag 0–10	1.12 (1.01, 1.25)	0.98 (0.85, 1.12)	1.44 (1.21, 1.72)	1.65	0.10

Sensitivity analysis

Sensitivity analysis was conducted by changing the df for time (6 to 10 per year) and relative humidity (1 to 7), and similar results to those of the original analysis were obtained (Table S2-S3). Furthermore, the results remained stable after incorporating other potential covariables (CO and air pressure) into the primary model, indicating the relative robustness of the primary model applied in our study (Table S4).

Discussion

To the best of our knowledge, this is the first study conducted in Harbin to explore the relationship between extreme temperatures and children's outpatient visits for respiratory diseases. This study indicated that the relationship between temperature and children's outpatient visits for respiratory diseases was nonlinear. At extremely low temperatures, both − 26°C (1st) and − 23°C (2.5th) showed protective effects on daily outpatient visits for children with respiratory diseases at lag 0–1 day and lag 0–10 days, with 27%, 28%, 41% and 41% reductions in children's outpatient visits for respiratory diseases, respectively. However, at extremely high temperatures, both 26°C (97.5th) and 27°C (99th) showed adverse effects at lag 0–1 day and lag 0–6 days, with 17%, 20%, 34% and 38% increases in children's outpatient visits for respiratory diseases, respectively. A modification effect by season was found for associations of extreme temperatures with children’s outpatient visits for respiratory diseases. Specifically, the hot effect was particularly greater during the warm season than during the cold season.

Our research found a nonlinear relationship between temperature and respiratory diseases, and it showed an S-shaped curve relationship. Many studies have described nonlinear associations between temperature and respiratory disease [18, 34, 42], which was consistent with our study. However, the associations obtained by most studies were V-, J-, and U-shaped [18, 34, 42]. The exposure-response relationships were largely influenced by climatic region [43, 44], geographic location [45], and living conditions [46]. China is a vast country, and the climatic characteristics of different regions vary significantly. Because of the variation in geographic, socioeconomic, and climatic factors, the effects of temperature on respiratory diseases show great differences among different study regions [38].

Our study indicated that extremely hot temperatures increased the risk of children’s outpatient visits for respiratory diseases. Previous studies [47, 48] have shown that under the background of global warming, the harmful effects of heat on human health are becoming increasingly serious, which is consistent with our study. Hot weather increases the surface temperature of the skin, reduces the heat dissipation function, and increases the internal temperature of the human body, which makes the human organs and systems unable to operate normally [49]. In addition, extremely high temperatures tend to cause imbalances in body temperature regulation related to increased heart and respiratory rates and damage to the heart, lungs, kidneys, and liver [50]. For children, body resistance is weaker to the outside environment. When extremely high temperatures occur, the external temperature will quickly influence children's bodies, and they are more inclined to respiratory diseases [45].

Our research showed that the effect on respiratory diseases at extremely cold temperatures was a protective effect, which was contrary to previous studies [16, 36, 51]. A possible reason for the inconsistent results is that the extremely low temperatures between our study area and other study areas are different. For example, the extremely low temperatures (1st) in Lanzhou [16] and Guangzhou [51] were − 16°C and 8.2°C, respectively, which were higher than the extremely low temperature in our study (-26°C). It might be that extreme cold temperature events reduce the number of outpatient visits due to the convenience and accessibility of hospitalization in this cold area [52], which accounts for a portion of the inconsistent results. Although the cold temperature may trigger childhood respiratory disease (e.g., asthma) as airway cooling on cold days may aggravate inflammation, which results in a narrowing of airways [53], the influence of temperature will be affected by regional habits [54]. The inconsistent results may be due to the climate characteristics and living habits in different regions [19]. The geographical location of Harbin determines that its climate is characterized by long winters and short summers. In Harbin, the average temperature in January ranged from − 15 °C to -30 °C, and the lowest temperature once reached − 37.7 °C. To avoid severe cold weather, the homes of Harbin residents are equipped with central heating equipment, and people tend to stay indoors and turn on heating equipment in October when the weather is cold [55, 56]. Less frequent going outside at extremely low temperatures decreased the frequency of exposure. In addition, people living in cold regions have increased adaptive capability against cold exposure [14]. Therefore, these may be the main reasons why the extremely low temperature in Harbin is a protective factor for respiratory diseases. More research is needed in the future to verify the underlying mechanism.

Our results suggested that the effects of extremely high temperatures on children’s outpatient visits for respiratory disease were more significant during the warm season than during the cold season. To our knowledge, this is the first study to explore the modifying effect of seasons on the association between extreme temperature and respiratory diseases among children, which has rarely been examined in previous studies [24, 26]. However, the underlying mechanisms regarding seasonal modification on the association between extreme temperature and respiratory disease are still unclear, and the number of studies is limited. Therefore, further epidemiological studies should be conducted to explore the underlying mechanisms of seasonal-specific effects on extreme temperature-respiratory disease associations.

Our study has several limitations. First, the main limitation is the ecological design that limits the transferability of the results to the individual level. Under this design, we could not calculate the individual-level variation in the distribution of the health, exposure and covariate data. Second, a measurement bias in exposure has long been recognized. We relied on fixed-site monitoring station measurements rather than individual exposure, which could introduce exposure misclassification. Third, due to the limited availability of data, we only selected one hospital as the study site, which may lead to selection bias. In addition, this study was conducted in only one city, where the results might not be generalized to other areas because population behaviors, geographical location, and weather conditions may differ.

Conclusions

The results of our study indicate that extremely high temperatures increase the risk of outpatient visits for respiratory diseases among children, while extremely high temperatures show a protective effect in northern China. This study provides evidence of the short-term effects of extreme temperature on outpatient visits for respiratory disease and can provide suggestions for public health intervention. Efforts to reduce children's exposure to extremely high temperatures may potentially mitigate the burden of pediatric respiratory diseases, especially in the warm season. Nonetheless, large-sample, multicenter, and multicountry prospective studies are warranted to confirm the results of our study.

Declarations

Acknowledgments

Not applicable.

Statement

We confirm that all methods were carried out in accordance with relevant guidelines and regulations.

Authors' contributions

Ya Wu: Methodology, Data curation, Formal analysis, Writing-review & editing. Xiaobo Liu: Methodology, Data curation, Validation. Lijie Gao: Methodology, Visualization. Xiaohong Sun: Data curation, Validation. Qianqi Hong: Data curation, Validation. Qian Wang: Methodology, Software, Visualization. Zhen Kang: Validation. Chao Yang: Conceptualization, Supervision. Sui Zhu: Conceptualization, Supervision, Writing-review & editing.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Ethics approval and consent to participate

This study was approved by the Ethics Committee of Harbin Center for Disease Control and Prevention prior to the data being collected, with a waiver of informed consent because data were analyzed at aggregated level and no participants were contacted.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

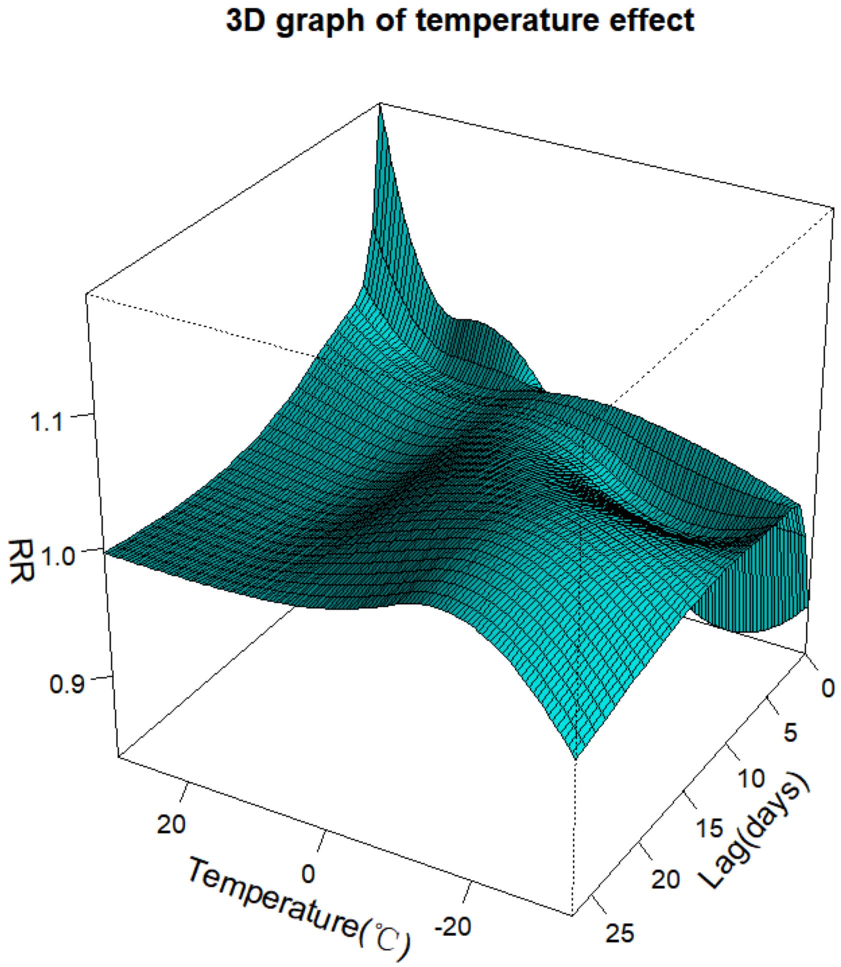

Figure 1

3-D graph of the RR with temperature and lag compared with a reference temperature of 7 °C.

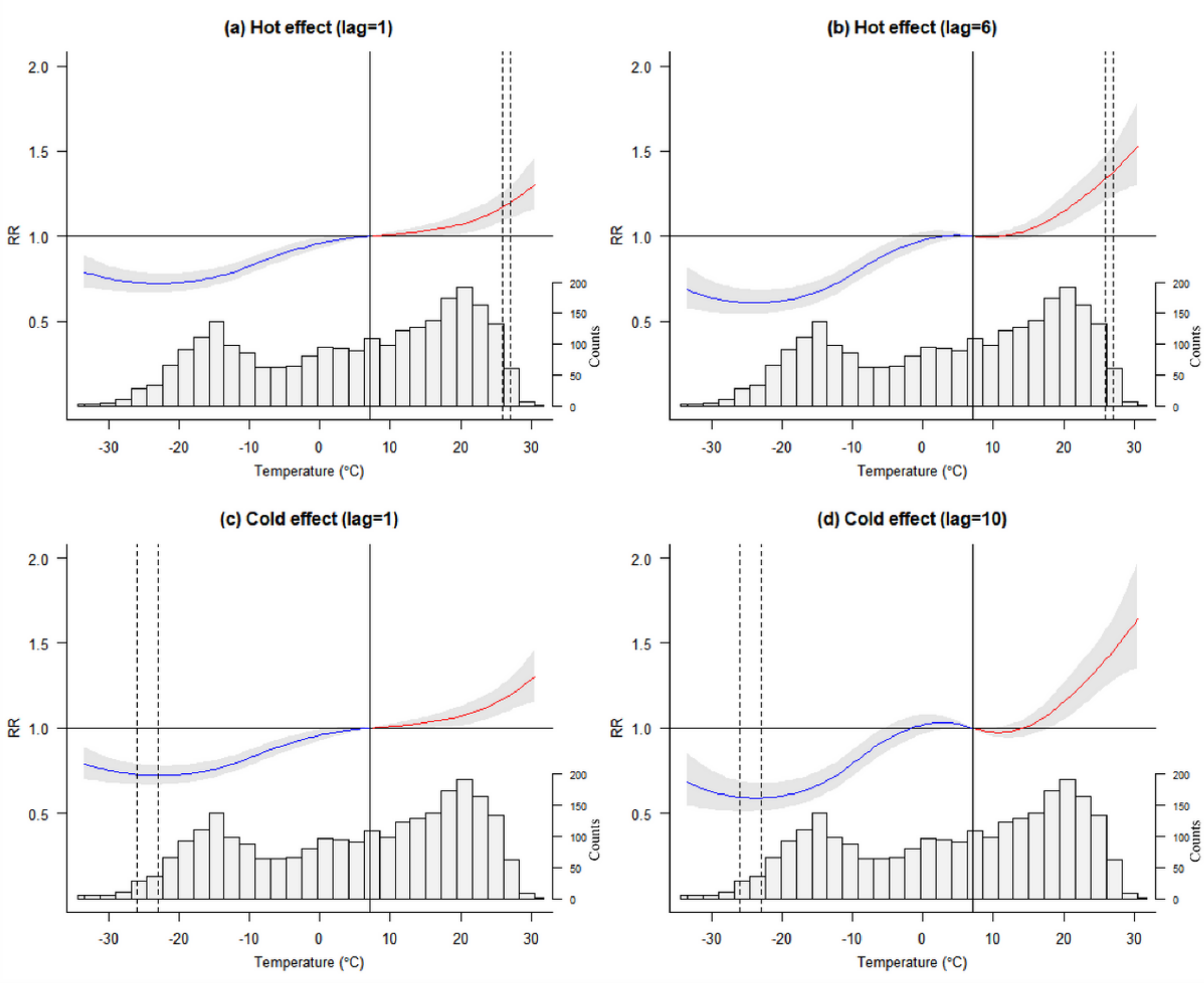

Figure 2

The overall exposure-response relationship between temperature and daily outpatient visits for children's respiratory diseases at extremely high and low temperatures on different lag days. The vertical dashed lines from left to right represent the 97.5th and 99th percentiles of the temperature in order (a, b); the vertical dashed lines from left to right represent the right represent the 1st and 2.5th percentiles of the temperature in order (c, d); reference level at 7 °C (50th percentile, the solid vertical line)

Supplementary Files

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