

Effects of Accumulated And Transient Heat Exposure On Schizophrenia Hospitalizations: A Time-Series Analysis On Hourly Temperature Basis

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Abstract

Background: Growing studies have shown that high temperature is a potential risk factor of schizophrenia occurrence. Therefore, elaborate analysis of different temperature exposure patterns such as cumulative heat exposure within a time period and transient exposure at a particular time point, is of important public health significance. This study aims to utilize hourly temperature data to better capture the effects of cumulative and transient heat exposures on schizophrenia during the warm season in Hefei, China.

Methods: We included the daily mean temperature and daily schizophrenia hospitalizations into the distributed lag non-linear model (DLNM) to simulate the exposure-response curve and determine the heat threshold (19.4°C). We calculated and applied a novel indicator—daily excess heat hourly (DEHH) to examine the effects of cumulative heat exposure over a day on schizophrenia hospitalizations. Temperature measurements at each time point were also incorporated in the DLNM as independent exposure indicators to analyze the impact of transient heat exposure on schizophrenia.

Results: Each increment of interquartile range (IQR) in DEHH was associated with elevated risk of schizophrenia hospitalizations from lag 1 (RR=1.036, 95% confidence interval (CI): 1.016, 1.057) to lag 4 (RR=1.025, 95% CI: 1.005, 1.046). Men and people over 40 years old were more susceptible to DEHH. Besides, we found a greater risk of heat-related schizophrenia hospitalizations between 0 am and 6 am.

Conclusions: This study revealed the negative effects of accumulated and transient heat exposures on schizophrenia hospitalizations. Our findings need to be further tested in other regions with distinct regional features.

Introduction

The health problems caused by climate change have attracted public attention and become a global challenge (Hajat et al. 2010; Guo et al. 2011; Cho et al. 2016; Cheng et al. 2017; Sun et al. 2020). *Lancet* reported that temperature rise and extreme weather events related to climate change have created a huge burden of disease worldwide (GBD 2019 Risk Factors Collaborators. 2020). Due to the heavy economic and social burden caused by mental illness, many researchers have already focused on the impact of high temperature on mental health (Hansen et al. 2008; McWilliams et al. 2013; Mullins et al. 2019). A study in Korea reported that daily high temperatures increase the risk of emergency hospital admissions for mental diseases and specific psychiatric conditions (i.e., schizophrenia, anxiety, depression and mania) (Lee et al. 2018). Recently, Zhang et al. found high temperature can increase the risk for five mental disorders morbidity (depressive disorders, organic mental disorders, anxiety, affective disorders and schizophrenia) (Zhang et al. 2020).

Among many mental disorders, schizophrenia is a chronic protracted neuropsychiatric disorder characterized by distortion of thinking, viewpoint, emotion, language, self-consciousness and behavior (Owen et al. 2016). According to the World Health Organization (WHO), nearly 23 million people worldwide suffered from schizophrenia in 2018 (Yi et al. 2019). Global Burden of Disease report of *Lancet* showed a 17.2% increase in schizophrenia-induced loss of health life between 2007 and 2017 (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). In addition, the prevalence of schizophrenia in China (4.2‰) is much higher than the global average level (2.64‰) (Huang et al. 2019). Gupta et al. found a positive correlation between temperature and schizophrenia in 1992 (Gupta et al. 1992). Thereafter, some studies revealed that monthly or daily high temperature can increase hospitalizations for schizophrenia (Clarke et al. 1999; Shiloh et al. 2005; Aviv et al. 2011; Wang et al. 2014; Pan et al. 2019; Zhang et al. 2020). Besides, increasing studies have raised that finer scale temperature exposure measurements can better capture the health impact of heat (Jiao et al. 2019; Guo. 2016; Hu et al. 2019), but it remained unknown regarding the temperature-schizophrenia relationship at a finer scale beyond daily scale.

Assessing the effect of heat on disease with daily temperature exposure data is admittedly important for disease warning (Cheng et al. 2017). However, daily mean temperature cannot consider hourly temperature change, which is also a potential

risk factor for health (Hu et al. 2019). Some heat-related assessments usually focus on days when the daily mean temperature is above the temperature threshold, which may not examine the practical effects of heat on disease, as hourly extreme high temperatures of these days can also have an adverse effect (Jiao et al. 2019). Thus, many studies suggested that the usage of hourly temperature data to assess the risk of morbidity and mortality is necessary (Lin et al. 2019; Xu et al. 2020; Jiao et al. 2019; Cheng et al. 2017; Zhang et al. 2017). For instance, Lin et al. suggested that a new indicator (ΔDH_{HOT}) calculated by summing temperatures that exceed the threshold throughout a day can assess the actual health impact of heat (Lin et al. 2019). Most of previous studies on the relationship between temperature and schizophrenia hospitalizations used daily mean temperature as exposure indicator (Sung et al. 2011; Wang et al. 2018; Pan et al. 2019), which may underestimate the impact of high temperature on schizophrenia. Therefore, it is necessary to apply a novel index - daily excess hourly heat (DEHH, similar to ΔDH_{HOT}) (Lin et al. 2019; Jiao et al. 2019) to make full use of the information of hourly temperature to explore the precise effect of accumulated high temperature within a day on hospitalization for schizophrenia.

Moreover, according to the previous research, specific temperature observation time has been shown to be strongly associated with heat- mortality relationship (Davis et al. 2016). Davis et al. found that the relative risk of heat - mortality at 2000 LST (8 p.m., LST: local standard time) at lag 1 was 1.040 (95% CI: 1.017, 1.062). This study suggested that transient heat exposure at different time points may have distinct health effects. However, for schizophrenia, prior studies have not yet examined whether the timing of temperature exposure or observation affects heat-schizophrenia relationships.

The purposes of our study are to investigate the impact of accumulated heat exposure within 24 hours on schizophrenia by quantifying the relationship between DEHH and hospitalization for schizophrenia and to identify potential susceptible populations. Further, the effect of temperature exposure at different time points on schizophrenia hospitalizations was explored to identify the potentially sensitive exposure windows.

Materials And Methods

2.1. Study site

Following previous studies on heat and health, in order to capture the impact of heat on schizophrenia admissions, we limited the study period to the warm season (from May to September) of 2005–2019 in Hefei (Son et al. 2012; Lin et al. 2013; Cheng et al. 2018a). Hefei is the capital city of Anhui province with an area of 11,445 km² and a population of over 7.3 million (National Bureau of Statistics of China, 2016).

2.2. Data collection

2.2.1. Meteorological data

Hourly temperature data was obtained from the National Centers for Environmental Information (NCEI) (<https://www.ncdc.noaa.gov>) during 2005–2019 of Hefei, China. NCEI of National Oceanic and Atmospheric Administration (NOAA) provided public access to the Nation's treasure of climate and historical weather data and information, which has been widely used (Jiao et al. 2019; Zhang et al. 2019).

Daily meteorological data were acquired from Hefei Meteorological Bureau including humidity, wind speed and sunshine duration, etc. Daily air pollutants data (2013–2019) such as fine particulate matter $\leq 2.5 \mu\text{m}$ (PM_{2.5}), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO) and ozone (O₃) were collected from Hefei Environmental Monitoring Center.

2.2.2. Schizophrenia data

We obtained daily data on schizophrenia hospitalizations from Anhui Mental Health Center during 2005–2019. Anhui Mental Health Center is the largest psychiatric hospital in Anhui Province and covers a wide range of areas (Pan et al.

2019). Additionally, this 3A (first-class) hospital has an advanced electronic data storage system that records all admitted patients. The information of patients mainly includes the date of admissions, residence address, age, gender, date of birth, etc. Only schizophrenic inpatients living in Hefei were included in this study. The diagnosis of schizophrenia was confirmed based on the 10th version of International Classification of Diseases (ICD-10), and the code was F20.0-F20.9. Finally, a total of 53,288 cases were collected from 2005 to 2019.

2.3. Definition and calculation of hourly excess heat exposure within a day

We used a novel index—DEHH (daily excess hourly heat) in this study. DEHH is a cumulative temperature variable generated by adding the temperature values that exceed the specific heat threshold per hour within a day (Jiao et al. 2019; Lin et al. 2019). The calculation formula is as follows:

$$DEHH = \sum_0^{23} \Delta t_i$$

$$\Delta t_i = \begin{cases} t_i - t_h, & t_i \geq t_h \\ 0, & t_i < t_h \end{cases} \quad (1)$$

where i referred to the hour time of observation; t_i was the temperature at the observation time; t_h was the heat threshold; Δt_i was the difference between t_i and t_h .

The heat threshold is the temperature above which hospitalization risk begins to increase, which is conceptually the same as the minimum risk temperature (MRT) (Petitti et al. 2016; Pan et al. 2019). To determine the heat threshold, we first calculated the daily mean temperature by averaging the daily maximum and minimum temperature (Cheng et al. 2018b). Second, we included the daily mean temperature into the distributed lag non-linear model (DLNM) to simulate the exposure-response curve. Finally, we determined the heat threshold (19.4°C) through the curve (Supplementary Fig. 1), which was close to the heat threshold (19.0°C) reported in our previous study in Hefei (Pan et al. 2019).

2.4. Statistical analyses

2.4.1. Effect of DEHH on hospitalization for schizophrenia

The relationship between temperature and disease is generally non-linear (such as U-shape and J-shape) (Gasparrini et al. 2015). The distributed lag non-linear model (DLNM) can effectively evaluate the non-linear and delayed effects of environmental exposure on disease (Gasparrini et al. 2017). Therefore, our study employed the DLNM to examine the relationship between DEHH and schizophrenia hospitalizations. We applied a quasi-Poisson link to consider over-dispersed daily schizophrenia hospitalization counts (Gasparrini et al. 2010; Pan et al. 2019). Optimal degrees of freedom (df) were chosen based on the quasi-Poisson Akaike information criteria (Q-AIC) (Gasparrini et al. 2010). The formula of model is as follows:

$$\text{Log}[E(y_t)] = \alpha + cb(DEHH_{t,l},\beta) + ns(\text{humidity},3) + ns(DTR,3) + ns(\text{time},3) + \gamma DOW + \eta \text{Holiday} \quad (2)$$

where t meant the calendar day of observation; $E(y_t)$ was the predicted counts of schizophrenia admissions on day t ; α was the intercept of the model; cb represented the “cross-basis matrix” in DLNM; β referred to the regression coefficient; l represented the lag days; ns meant natural cubic spline function in the model. The potential influence of relative humidity and diurnal temperature range (DTR) were controlled with ns of 3 df . We used a ns with 3 df to control for long-term trend and seasonality. Day of the week (DOW) and public holidays ($Holiday$) were incorporated into the model as dummy variables. Based on the lowest Q-AIC values of model, the maximum lag of 7 days was selected to capture the effects of heat on hospitalization for schizophrenia. Previous studies also suggested that the health impacts of heat last for

approximately a week (Xiao et al. 2015; Guo. 2016; Lin et al. 2019). In order to identify potentially vulnerable groups, we also conducted subgroup analysis by gender (male, female) and age (0–40 years old, > 40 years old) (Wei et al. 2020).

Furthermore, to unravel the temporal evolution of the impact of DEHH-schizophrenia during the 15-year study period, we adopted a time-stratified approach. We fit a piece-wise model for each 3-y period (each period was changed by one year) (Renzi et al. 2017; Cheng et al. 2019). For instance, the first time period was 2005–2007, the second was 2006–2008 and the last was 2017–2019. In addition, in the sensitivity analysis, we used different period intervals for time-stratified analysis.

2.4.2. Impact of the transient heat exposure on schizophrenia hospitalizations

Davies et al. showed temperature observation time can influence the strength of temperature-mortality correlation by incorporating 24 hourly temperature measurements into the model as independent exposure variables (Davis et al. 2016). Therefore, we focused on the impact of transient heat exposure on schizophrenia. Following previous literature (Davis et al. 2016), we analyzed the heat effect on schizophrenia hospitalizations at different time points within a day. The formula is as follows:

$$\text{Log}[E(yt)] = a + cb(\text{TEMP}_{t,i,\beta}) + ns(\text{humidity},3) + ns(\text{DTR},3) + ns(\text{time},3) + \gamma\text{DOW} + \eta\text{Holiday} \quad (3)$$

where *TEMP* meant 24 hourly independent temperature variables; Other details were given in formula (2).

2.5. Sensitivity analyses

We tested the robustness of our findings by the following analysis. First, we varied the degree of freedom of daily relative humidity (3–5 *df*) and daily DTR (3–5 *df*) in the model. Second, we adjusted for seasonality and long-term trend by changing the *df* for time (3–5 *df*). Third, we added the daily air pollutants (PM_{2.5}, NO₂, SO₂, CO, O₃) into the model to examine the impact of pollutants on the main results. In addition, in the time-stratified study, we also set the time interval as 4-y period and 5-y period to check the stability of our results.

We used the "*dlm*", "*ggplot2*", "*plyr*" and "*splines*" packages in R software (version 3.6.3) for statistical analysis and making figures. When two-sided *p* value was less than 0.05, the statistical tests were deemed statistically significant. Measurements of the association were expressed as the relative risk (RR) estimates and 95% confidence interval (CI) for per interquartile range (IQR) increment of DEHH and 24 hourly temperature measurements on each day, respectively.

Results

Table 1 summarized the daily hospitalization for schizophrenia and meteorological variables. During the 15-year study period, there were 21,169 cases of schizophrenia in warm season. The daily mean count of schizophrenic admissions was 9.2. The number of male cases was slightly less than female. In terms of age group, the count of patients under 40 years old (14,637) was about twice that of over 40 years old (6,532). The daily mean temperature, relative humidity and DTR of the warm season were 25.8°C, 77.2% and 7.9°C, respectively. The average daily concentrations of PM_{2.5}, NO₂, SO₂, CO and O₃ were 44.5 µg/m³, 30.9 µg/m³, 10.7 µg/m³, 0.8 µg/m³, 109.0 µg/m³, respectively. The daily average value of DEHH and IQR were 154.4°C and 129.8°C, respectively. The hourly maximum temperature was 41.0°C and the minimum temperature was 9.0°C during the whole study period. Figure 1 showed the time trend distribution of DEHH, mean temperature and schizophrenia cases during the warm season of 2005–2019 in Hefei, China.

Table 1
Descriptive statistics of daily hospitalization for schizophrenia and meteorological variables during the warm season (May-September) of 2005–2019 in Hefei, China.

Variables	Sum	Mean ± SD	Min	P25	P50	P75	Max
Schizophrenia cases	21,169	9.2 ± 3.84	0	7	9	12	28
Gender							
Male	10,538	4.6 ± 2.48	0	3	4	6	17
Female	10,631	4.6 ± 2.46	0	3	4	6	16
Age							
0–40 years old	14,637	6.4 ± 2.98	0	4	6	8	21
> 40 years old	6,532	2.8 ± 1.86	0	1	3	4	12
Meteorological variables							
Mean temperature (°C)	-	25.8 ± 3.8	14.0	23.0	26.0	28.9	35.5
Maximum temperature (°C)	-	29.8 ± 4.3	16.0	27.0	30.0	33.0	41.0
Minimum temperature (°C)	-	21.9 ± 3.9	9.0	19.0	22.0	25.0	31.0
Relative humidity (%)	-	77.2 ± 11.3	30.0	70.0	78.0	85.0	100.0
DTR (°C)	-	7.9 ± 3.0	1.0	6.0	8.0	10.0	18.6
DEHH (°C)	-	154.5 ± 83.5	0.0	88.4	153.6	218.2	366.8
PM _{2.5} (µg/m ³) ^a	-	44.5 ± 83.5	5.0	26.0	39.0	55.0	289.0
NO ₂ (µg/m ³) ^a	-	30.9 ± 11.8	8.0	22.0	29.0	37.0	92.0
SO ₂ (µg/m ³) ^a	-	10.7 ± 5.7	2.0	6.5	10.0	13.0	43.0
CO (µg/m ³) ^a	-	0.8 ± 0.2	0.3	0.6	0.7	0.9	2.1
O ₃ (µg/m ³) ^a	-	109.0 ± 46.7	13.0	72.0	106.0	141.0	264.0
^a Data of air pollutants were obtained in Hefei, China during 2013–2019.							

SD: Standard Deviation; DEHH: Daily excess heat hourly.

Figure 2 showed the lag effects of each IQR increment in DEHH on total schizophrenia hospitalizations and subgroups. The effects of DEHH on total schizophrenia admissions appeared at lag 1 (RR = 1.036, 95% CI: 1.016, 1.057), and persisted up to lag 4 (RR = 1.025, 95% CI: 1.005, 1.046) (data were shown in Table 2). Subgroup analyses by gender illustrated that the effect of DEHH on male schizophrenics was from lag 0 (RR = 1.059, 95% CI: 1.005, 1.116) to lag 3 (RR = 1.036, 95% CI: 1.006, 1.067) (Fig. 2b). However, we did not find a significant association between DEHH and female schizophrenics (Fig. 2c). For cases over 40 years old, DEHH presented significant effect from lag 1 (RR = 1.049, 95% CI: 1.011, 1.087) to lag 3 (RR = 1.039, 95% CI: 1.011, 1.077) (Fig. 2d). For cases under 40 years old, we didn't observe a significant association (Fig. 2e). The exposure-response relationship of DEHH on total schizophrenic admissions and subgroups were shown in Supplementary Fig. 2. Table 3 showed the cumulative effects of DEHH on total schizophrenia hospitalizations and subgroups from lag 0–0 to lag 0–7. For total cases, the greatest RR of the cumulative effects was 1.189 (95% CI: 1.051,

1.279) at lag 0–5. Meanwhile, the cumulative effects of DEHH on schizophrenia hospitalizations was found only in males and cases over 40 years old in subgroup analyses.

Table 2

The single-day relative risk (RR) estimates of each increment of interquartile range (IQR, 129.8°C) in daily excess heat hourly (DEHH) on total schizophrenia hospitalizations and subgroups during the warm season of 2005–2019 in Hefei, China.

Single-day	Relative risks (95% confidence intervals)				
	Total	Male	Female	0–40 years old	> 40 years old
Lag 0	1.033(0.997,1.070)	1.059(1.005,1.116)	0.998(0.949,1.049)	1.007(0.961,1.054)	1.050(0.985,1.119)
Lag 1	1.036(1.016,1.057)	1.053(1.022,1.084)	1.010(0.981,1.039)	1.015(0.990,1.042)	1.049(1.011,1.087)
Lag 2	1.037(1.021,1.054)	1.045(1.021,1.070)	1.019(0.996,1.042)	1.022(1.000,1.043)	1.046(1.016,1.076)
Lag 3	1.034(1.014,1.055)	1.036(1.006,1.067)	1.022(0.994,1.051)	1.023(0.997,1.051)	1.039(1.001,1.077)
Lag 4	1.025(1.005,1.046)	1.023(0.993,1.054)	1.017(0.989,1.046)	1.018(0.991,1.045)	1.027(0.991,1.065)
Lag 5	1.010(0.994,1.026)	1.007(0.983,1.030)	1.004(0.981,1.027)	1.005(0.985,1.025)	1.010(0.982,1.040)
Lag 6	0.991(0.972,1.010)	0.989(0.961,1.017)	0.985(0.958,1.013)	0.987(0.965,1.010)	0.990(0.956,1.025)
Lag 7	0.970(0.938,1.004)	0.970(0.923,1.020)	0.964(0.919,1.011)	0.967(0.928,1.009)	0.969(0.911,1.030)

Bold font indicated that the results are statistically significant ($p < 0.05$).

Table 3

The multi-day relative risk (RR) estimates of each increment of interquartile range (IQR, 129.8°C) in daily excess heat hourly (DEHH) on total schizophrenia hospitalizations and subgroups during the warm season from 2005–2019 in Hefei, China.

Multi-day	Relative risks (95% confidence interval)				
	Total	Male	Female	0–40 years old	> 40 years old
Lag 0–0	1.033 (0.997,1.070)	1.059 (1.005,1.116)	0.998 (0.949,1.049)	1.006 (0.961,1.054)	1.050 (0.985,1.119)
Lag 0–1	1.071 (1.014,1.130)	1.115 (1.029,1.208)	1.007 (0.933,1.087)	1.022 (0.953,1.097)	1.101 (0.998,1.213)
Lag 0–2	1.111 (1.045,1.181)	1.165 (1.064,1.276)	1.026 (0.941,1.120)	1.045 (0.965,1.131)	1.151 (1.030,1.285)
Lag 0–3	1.149 (1.077,1.225)	1.207 (1.097,1.327)	1.049 (0.956,1.152)	1.069 (0.983,1.162)	1.196 (1.064,1.344)
Lag 0–4	1.177 (1.099,1.261)	1.234 (1.114,1.366)	1.068 (0.966,1.180)	1.088 (0.994,1.191)	1.228 (1.083,1.393)
Lag 0–5	1.189 (1.105,1.279)	1.242 (1.114,1.384)	1.072 (0.963,1.194)	1.093 (0.993,1.204)	1.241(1.086,1.418)
Lag 0–6	1.178 (1.093,1.270)	1.228 (1.099,1.372)	1.056 (0.943,1.183)	1.079 (0.978,1.191)	1.229 (1.070,1.410)
Lag 0–7	1.143 (1.052,1.242)	1.192 (1.054,1.347)	1.018 (0.896,1.156)	1.044 (0.938,1.162)	1.190 (1.022,1.386)

Bold font indicated that the results are statistically significant ($p < 0.05$).

Fig. 3 demonstrated the temporal variation in the cumulative effects of DEHH on schizophrenia hospitalizations during the warm season of 2005-2019 in Hefei, China. A consistent and clear temporal variation pattern was observed at lag 0-4 and lag 0-7. At lag 0-7, hospitalization for schizophrenia was found to be the strongest associated with DEHH in the period of

2010-2012 (RR=1.505, 95% CI: 1.186, 1.909). Besides, Fig. 3 indicated that DEHH was more strongly associated with hospitalization for schizophrenia in the middle stage of the entire study period (data were shown in Supplementary Table 1). In total, the cumulative effects of DEHH represented a complex change, showing a tendency of early upward and later downward.

Figure 4 presented the effects of temperature observation time on heat-schizophrenia relationships in warm season from lag 1 to lag 5. The RR estimates by each IQR increment were statistically significant from 0 am at lag 1 (RR = 1.034, 95% CI: 1.013, 1.054) to 3 am at lag 3 (RR = 1.024, 95% CI: 1.010, 1.039). Overall effects of temperature observation time on heat-schizophrenia were gradually decreased from lag 1 to lag 5, and almost no statistical significance was observed after lag 4 (the RR estimates were not shown in the figure at lag 6 and lag 7). In short, Fig. 4 showed the impacts of heat on hospitalization for schizophrenia varied with the time from lag 1 to lag 5, and the strongest association occurred at 5 am at lag 1 (RR = 1.045, 95% CI: 1.025, 1.066). Our results suggested that there may be a stronger association between heat and schizophrenia at dawn (0 am-6 am) (data were shown in Supplementary Table 2). In addition, in order to reflect the integrity of the effect of heat on the admissions for schizophrenia, we presented the RR estimates of lag 0 in Supplementary Fig. 3. However, the hourly temperature effect pattern on the day of onset (lag 0) should be carefully interpreted, as temperature "exposure" measurement on that day may occur after hospitalizing (Davies, et al. 2016).

Our findings remain stable through varying the degrees of freedom for relative humidity (3–5 *df*), DTR (3–5 *df*), the seasonality and long-term trend (3–5 *df*) (Supplementary Fig. 4). We found similar estimates of heat effects before and after controlling for the air pollutants (Supplementary Table 3). Furthermore, in the time-stratified analysis, the overall trend was consistent after splitting the time period into an interval of 4 and 5 years (Supplementary Fig. 5 and Fig. 6).

Discussion

On the basis of hourly temperature data, this study employed a novel heat exposure indicator, daily excess heat hourly (DEHH), to initially examine the relationship between accumulated heat exposure within a day and schizophrenia hospitalizations. The results showed that DEHH was associated with an increased admissions risk of schizophrenia from lag 1 to lag 4. Subgroups analyses showed that males and people over 40 years old were more susceptible to DEHH. Time-stratified analysis observed complex fluctuations in schizophrenia hospitalizations risk associated with DEHH, rather than a monotonous upward or downward trend. We also found the effects of transient heat exposure on schizophrenia hospitalizations at different time points within a day.

In the context of global warming, extreme high temperature events due to climate change are considered to be closely related to mental illness (Vida et al. 2012; Trang et al. 2016; Lee et al. 2017; Almendra et al. 2019). Early, several studies from Scotland, Canada, and other countries reported that monthly ambient high temperature has an effect on the aggravation of psychosis in schizophrenics (Clarke et al. 1999; Shiloh et al. 2005; McWilliams et al. 2013; Wang et al. 2014). Later, Wang et al. suggested that elevated daily mean temperature increased the risk of admissions for schizophrenia during the warm season (Wang et al. 2018). More recently, Zhang et al. found a non-linear relationship between daily high temperature and schizophrenia morbidity (Zhang et al. 2020). Nevertheless, some research suggested hourly temperature exposure at a finer scale may better capture the health effects of temperature than daily temperature (Jiao et al. 2019; Lin et al. 2019). Furthermore, current studies on the relationship between temperature and schizophrenia have been limited to monthly and daily temperatures exposure (Sung et al. 2011; Wang et al. 2018; Pan et al. 2019; Zhang et al. 2020), which may overlook the effect of temperature on schizophrenia within a shorter period of time. In the present study, we utilized DEHH, which can fully integrate the information of hourly temperature to explore the cumulative effect of heat within a day on schizophrenia hospitalizations.

Consistent with previous studies that used daily mean temperature as exposure variable, we applied DEHH to identify the association of heat with schizophrenia admissions from a more precise perspective. In the analysis of different individual

characters, we found that males were more susceptible to DEHH, which has also been recognized in previous investigations (Wang et al. 2018; Pan et al. 2019). Men are usually more involved in physical work than women, thereby they have more chances to be exposed to high temperatures (Xu et al. 2020). High intensity of work, mental stress and some life habits (such as alcohol abuse and smoking) in males also seem to explain this phenomenon (Trang et al. 2016; Pan et al. 2019). For different age groups, we discovered that DEHH had a greater impact on people over 40 years old. In general, compared with young people, the elderly was less able to adapt and regulate their physiology to heat (Ha et al. 2014; Ma et al. 2017; Pan et al. 2019).

By innovatively incorporating hourly temperature variable and daily schizophrenia admissions into the model, we discovered that heat exposure at different time points within a day may have different impacts on schizophrenia. Results suggested the harmfulness of transient heat exposure on schizophrenia hospitalizations. Importantly, higher risk heat-related schizophrenia hospitalizations were observed at dawn (0 am-6 am). A possible explanation for this unusual phenomenon was that high temperatures could reduce the sleep quality in people (Zheng et al. 2019), contributing to the development of prodromal symptoms of schizophrenia (paranoia and hallucinations) (Waite et al. 2019). In addition, other factors (such as high blood glucose and blood pressure in the morning) may have influenced the results (Pickering et al. 2006; Guo. 2016).

Some strengths are evident in this study. First, based on hourly temperature measurements, it is the first study to apply DEHH to explore the effect of heat on schizophrenia hospitalizations. DEHH synthesizes hourly temperature exposure information to make exposure assessments more accurate. Second, time-stratified design was also used for the first time in the study of heat and schizophrenia, giving the public a better grasp on temporal trend of heat effect on schizophrenia. Third, we analyzed the heat exposure at a fixed time point on schizophrenia hospitalizations. Our findings can be used to prompt local mental health institutions of the time to arrange emergency preparedness and provide adequate medical resources before the high risk of morbidity.

It is necessary to mention the limitations of this study. First, the present study is an ecological research and will inevitably cause ecological bias. Second, a single city study has limited the extrapolation of the conclusion, as climate characteristics and population acclimatization across different regions are heterogeneous (Cheng et al. 2019). Further research on the relationship between DEHH and schizophrenia in different study settings is needed. Finally, in the analysis of the influence of time points on heat-schizophrenia relationships, it should be noted that only the temperature varies at the hourly level—hospitalization varies daily rather than hourly. We can only make a rough estimate of the specific time point when hospitalization risk of schizophrenia is higher. Further analyses need be made to explore the influence of hourly temperature on schizophrenia by obtaining more detailed hospitalizations data.

Conclusions

In conclusion, we applied a novel index—daily excess heat hourly (DEHH) to explore the influence of heat on schizophrenia hospitalizations. The results suggested that DEHH increased the risk of schizophrenia hospitalizations. DEHH may be a surrogate indicator for the precise assessment of the relationship between heat and schizophrenia. Furthermore, by exploring the effect of exposure timing on heat-related schizophrenia hospitalizations, it may help health authorities and policymakers to better formulate relevant protection measurements to reduce the risk of schizophrenia. This study revealed the effect of accumulated and transient heat exposure within a day on schizophrenia from different perspectives. We recommend that hourly weather observations should be taken into account when assessing heat impact on schizophrenia hospitalizations.

Declarations

Declaration of competing interest

The authors declare they have no competing financial interests.

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Availability of data and materials

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

Author contributions

Chao Tang: Conceptualization, Data curation, Formal analysis, Visualization, Software, Writing - original draft. **Qingru Li:** Investigation, Formal analysis, Data curation, Methodology, Software. **Zhenhai Yao:** Conceptualization, Methodology, Data curation. **Jian Cheng:** Methodology, Software, Supervision, Validation. **Yangyang He:** Data curation, Visualization. **Xiangguo Liu:** Data curation, Methodology. **Rubing Pan:** Software, Visualization. **Qiannan Wei:** Data curation, Conceptualization. **Weizhuo Yi:** Software, Visualization. **Yifu Ji:** Writing – review & editing, Project administration. **Hong Su:** Conceptualization, Investigation, Writing – review & editing, Funding acquisition, Supervision, Validation.

Ethics approval

This study was approved by the Ethical Committee of Anhui Medical University (Hefei, Anhui, China).

Consent to participate

Not applicable (This study do not contain any individual person's data in any form).

Consent to publication

The authors declare that they agree with the publication of this paper in this journal.

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Figures

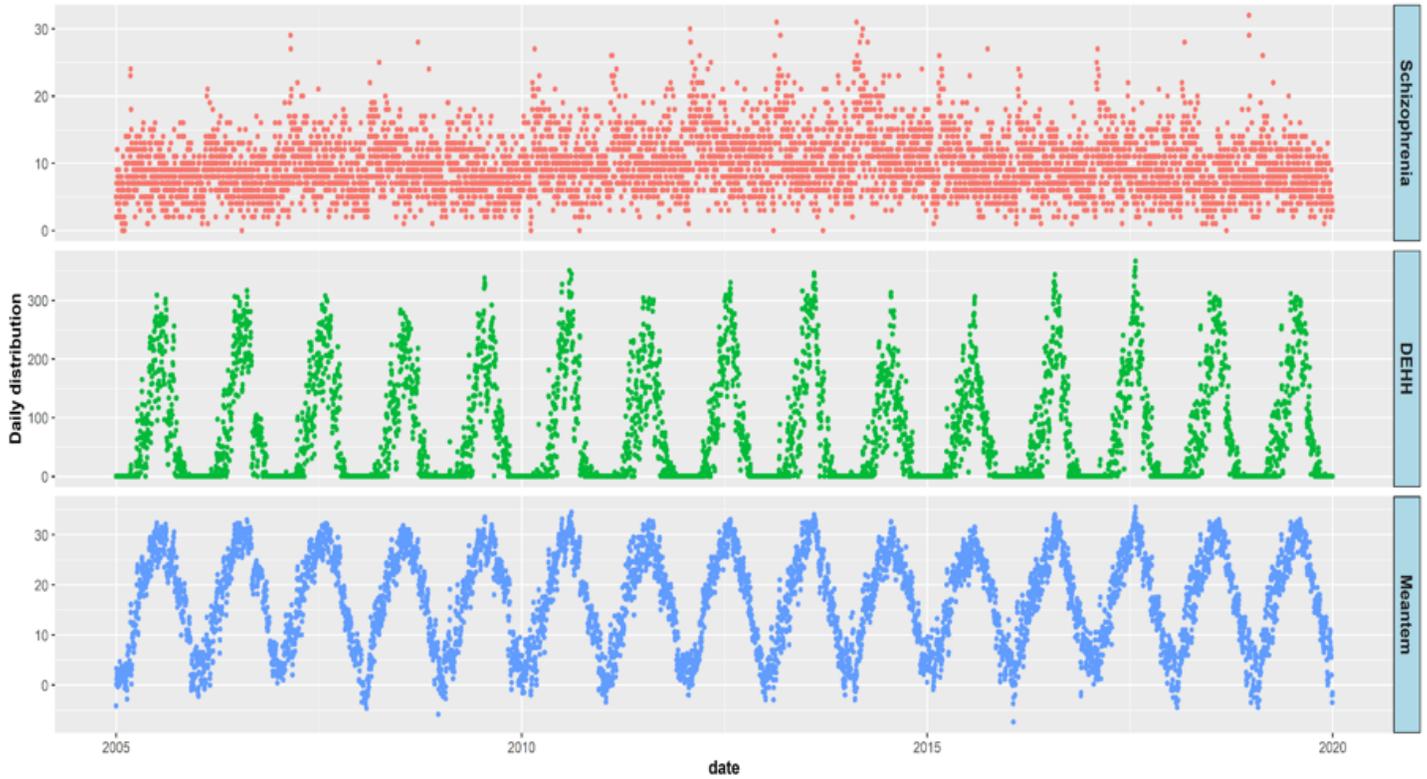


Figure 1

The time trend distribution of daily excess heat hourly (DEHH), mean temperature and schizophrenia cases during the warm season of 2005-2019 in Hefei, China.

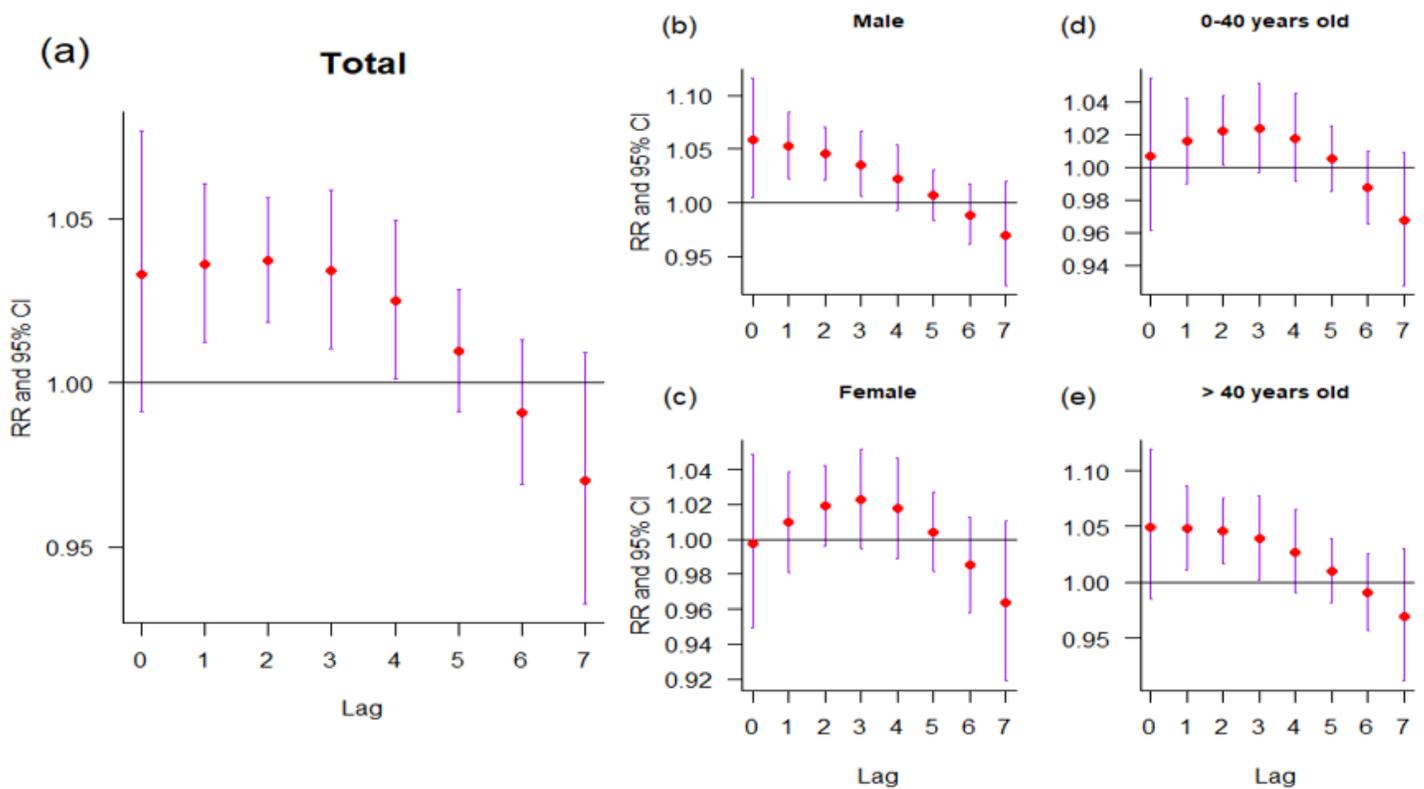


Figure 2

The lag effects of each increment of interquartile range (IQR, 129.8°C) in daily excess heat hourly (DEHH) on total schizophrenia hospitalizations and subgroups during the warm season of 2005–2019 in Hefei, China.

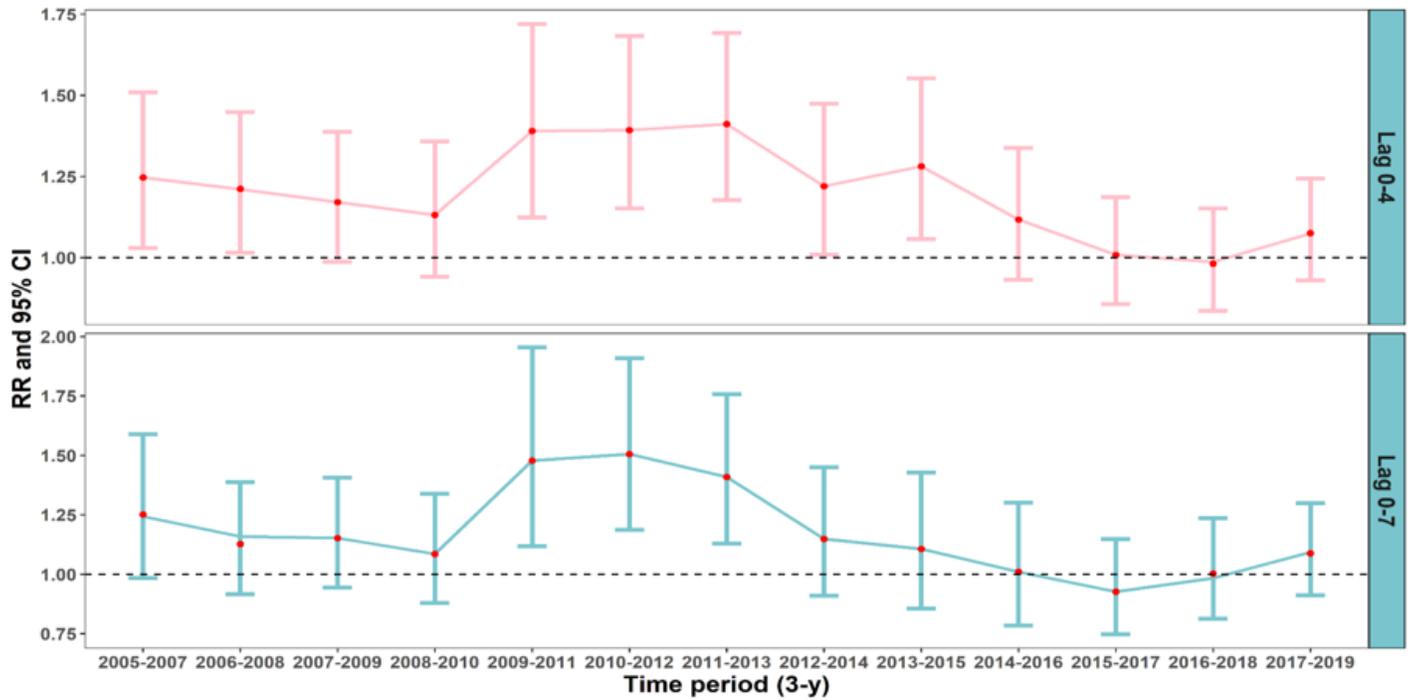


Figure 3

The temporal variation in the cumulative effects of daily excess heat hourly (DEHH) on schizophrenia hospitalizations at lag 0-4 and lag 0-7 during the warm season of 2005-2019 in Hefei, China.

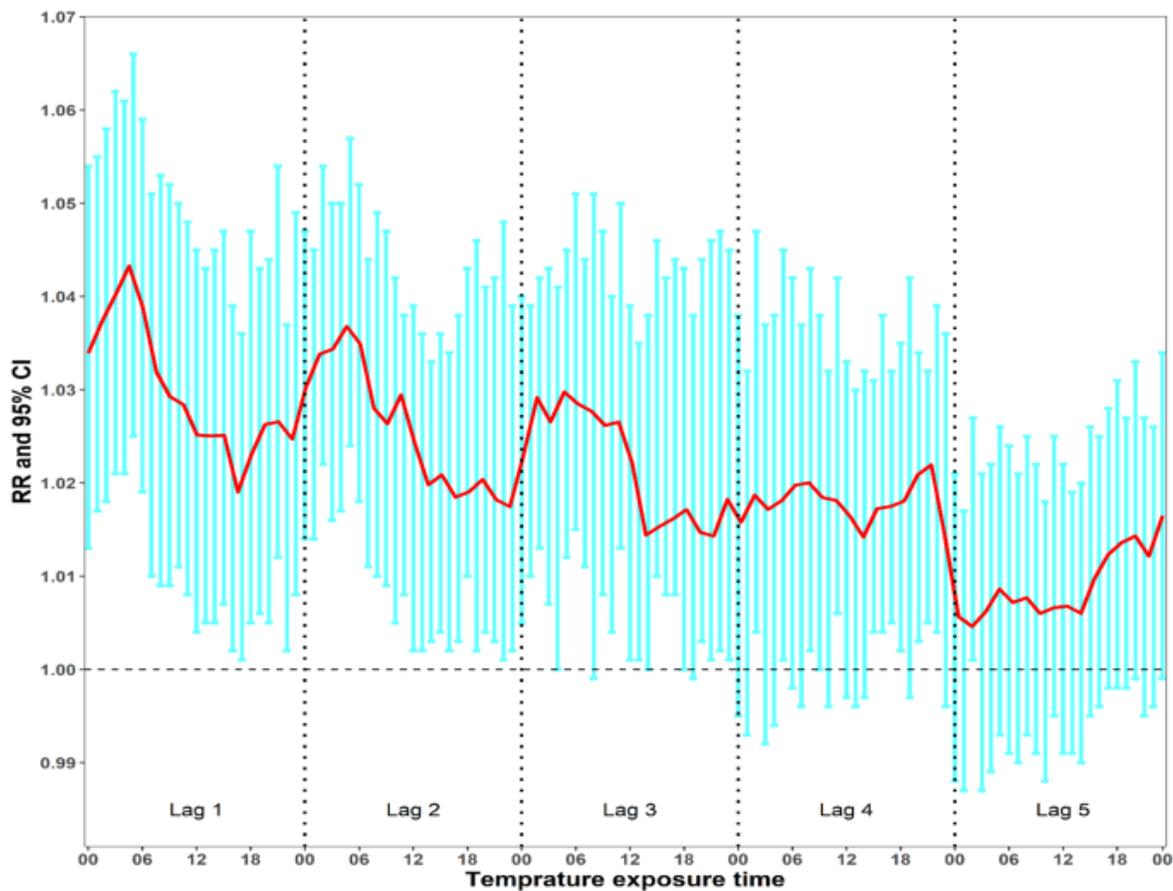


Figure 4

The effects of temperature observation time on heat-schizophrenia relationships from lag 1 to lag 5 during the warm season of 2005-2019 in Hefei, China.

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