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Key Points:

- Exposure to extreme heat is associated with an increase in outpatient visits for overall mental disorders
- Exposure to extreme heat is linked to a rise in visits for schizophrenia, mood disorders, and neurotic disorders
- The effects of heatwaves on outpatient visits for mental disorders vary depending on the definitions of heatwaves used

Supporting Information:

Supporting Information may be found in the online version of this article.

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Association Between Extreme Heat and Outpatient Visits for Mental Disorders: A Time-Series Analysis in Guangzhou, China

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Abstract Previous evidence on heatwaves' impact on mental health outpatient visits is limited, especially uncertainty on how different heatwave definitions affect this relationship. In this time-series study, we assessed the association between heatwaves and outpatient visits for mental disorders in Guangzhou, China. Daily outpatient visits for mental disorders and its specific categories (schizophrenia, mood, and neurotic disorders) were sourced from the Urban Resident-based Basic Medical Insurance (URBMI) and the Urban Employee-based Basic Medical Insurance (UEBMI) claims databases in Guangzhou from 2010 to 2014. The study employed nine heatwave definitions, based on combinations of three daily mean temperature thresholds (90th, 92.5th, and 95th percentiles) and durations (2, 3, and 4 days). Using quasi-Poisson generalized linear models (GLMs), we estimated the risks (at lag 0 day) and cumulative effects (lag 0–10 days) of heatwaves on mental disorder outpatient visits. Age, gender, types of medical insurance were considered as potential effect modifiers. We observed a positive association between heatwaves and increased total outpatient visits for mental disorders, both at lag 0 day and during lag 0–10 days. The impact of heatwave was significant at lag 0 day for schizophrenia, mood and neurotic disorders visits, it remained significant for neurotic and mood disorders visits during lag 0–10 days. Heatwave durations lasting more than 4 days were associated with higher relative risks of mental disorders at lag 0 day. Older adults had relatively higher effect estimations than younger individuals. This research highlights the effects of extreme heat on mental health.

Plain Language Summary The rising frequency, duration, and intensity of heatwaves underscore the critical need to understand their effects on mental health disorders. This study fills a significant gap in research by examining the relationship between different definitions of heatwaves and outpatient visits for mental disorders, considering variations across medical insurance types, age, and gender. These findings are helpful for developing targeted preventive measures and healthcare strategies to protect vulnerable populations.

1. Introduction

A mental disorder is a clinical syndrome characterized by significant disturbances in an individual's cognition, emotional regulation, or behavioral patterns, reflecting an impairment in the mental function (Stein et al., 2021). Mental disorders pose a significant risk to public health, with a worldwide prevalence of approximately 13% and increasing morbidity projected for the future (Castaldelli-Maia & Bhugra, 2022). This would represent a substantial significant source of socioeconomic burden (GBD 2019 Mental Disorders Collaborators, 2022).

Various risk factors, including external environmental determinants such as high temperatures, are associated with an increased risk of mental disorders (Clayton, 2021; Stein et al., 2021; Zhao et al., 2021). Nowadays, the changing climate has led to an increase in the frequency, duration, and intensity of extreme heat events, namely heatwaves, which has raising health risks in the general population (Ebi et al., 2021). These extreme heat events would also impact public mental well-being, resulting in potential risks to mental health (Li et al., 2023). Previous studies have reported a significant association between heatwaves and increased risks for hospital admissions and emergency department visits for mental disorders, as well as specific disorders such as schizophrenia, and neurological disorders (Dang et al., 2022; Hansen et al., 2008; Khalaj et al., 2010; Sherbakov et al., 2018; Trang et al., 2016; Xu, FitzGerald, et al., 2019). Although numerous investigations have been conducted, several study gaps remain in the previous evidence. First, prior studies focus on hospitalizations and emergency room visits for patients with mental disorders, which often represent more severe conditions on mental health (Alho et al., 2024;

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Crank et al., 2023; Dang et al., 2022). However, there is a paucity of studies examining the impact of heatwaves on outpatient visits for mental disorders. In fact, outpatient visits warrant more attention due to their substantial numbers. For example, a study from Japan reported that more than 90% of mood disorder patients are outpatients (Tokumitsu et al., 2021). Furthermore, seeking outpatient care is the most common way to access mental health services (Ahn-Horst & Bourgeois, 2024). Thereby mitigating the risks of outpatient visits for mental disorders during heatwaves is crucial to prevent more severe outcomes and to support the ongoing assessment and management of these conditions (Barker et al., 2020; Torrey & Drake, 2010).

Second, exposure assessment is considered as an important aspect of existing literature. However, in published studies, heatwaves were primarily defined as a single combination of temperature threshold and duration. For example, Dang et al. defined a heatwave as temperatures exceeding the 95th percentile of the local daily mean temperature for at least two consecutive days, then they observed that increased hospitalizations due to mental and behavioral disorders during heatwaves (Dang et al., 2022). One Australian investigation observed that heatwaves, defined as temperatures at or above the 95th percentile of mean temperature for three or more consecutive days in each community, were associated with higher risks of mental health-specific emergency department visits (Xu, FitzGerald, et al., 2019). A study from California found a positive correlation between heatwaves (identified as periods when daily mean temperatures were above the zone- and month-specific 95th percentile for at least two consecutive days) and hospitalizations due to mental health diagnoses (Sherbakov et al., 2018). Prior studies analyzing the impact of heatwaves on health risks have observed that different heatwave definitions resulted in distinct health risks (Guo et al., 2017; Yang et al., 2019). Thus, using a single definition of a heatwave seems limited in comparing the health risks of extreme heat on mental disorders across various heatwave definitions (Liu et al., 2021).

Lastly, when considering the health impacts of climate change, health impacts will not be the same, leading to varied levels of vulnerability among populations (Hess, 2023; Paavola, 2017). Previous studies focusing on the link between extreme heat and hospital admissions or emergency department visits for mental disorders have identified sociodemographic factors such as age, gender, and individual socioeconomic status (SES) as significant modifiers (Chan et al., 2018; Crank et al., 2023; Dang et al., 2022; Liu et al., 2018; Nori-Sarma et al., 2022; Sherbakov et al., 2018; Trang et al., 2016; Yoo, Eum, Gao, & Chen, 2021). However, the modification effect of sociodemographic factors on the correlation between heatwaves and outpatient visits for mental disorders remains unclear.

Therefore, this study aimed to examine the association between extreme heat and outpatient visits for mental disorders, considering different heatwave definitions. We also attempted to identify significant modifiers in this relationship. We hope to provide valuable evidence to the impact of extreme heat events on mental health, ultimately benefiting the development of adaptation and mitigation strategies.

2. Materials and Methods

2.1. Study Area and Data Collection

The study site is Guangzhou city, the capital of Guangdong Province, is one of the largest and most developed cities in Southern China (Figure S3 in Supporting Information S1). It is located at 113.3°E and 23.1°N. This city covers an area of 7,434 square kilometers and has a population of approximately 18.8 million, resulting in a population density of 2,512 people per square kilometer. In 2023, Guangzhou's total GDP was around 3.04 trillion RMB, with a per capita GDP of approximately 161,634 RMB (https://www.gz.gov.cn/zwgk/sjfb/tjgb/content/post_9570687.html). It has a maritime subtropical monsoon climate with abundant precipitation, sufficient sunlight, long summertime, and short frost periods. In recent years, the average annual temperature ranged from 21.5 to 22.2°C. During the hottest season, the average temperature reached up to 28.7°C, while during the coldest season, it dropped to around 13.5°C. Thus, there is no climatic winter in Guangzhou, and the area receives an average of 1,879 hr of sunshine per year. According to open-public data, the adjusted point prevalence rate of mental disorders in Guangzhou was 4.33% (Zhao et al., 2009). It was estimated that the comorbidity-adjusted disability-adjusted life years (DALYs) for mental disorders in Guangzhou city were 183,090 (95% uncertainty interval (UI): 122,811–292,087) (Tan et al., 2022).

Our data on outpatient visits for mental disorders were obtained from the Urban Resident-based Basic Medical Insurance (URBMI) and the Urban Employee-based Basic Medical Insurance (UEBMI) claims databases of

Guangzhou. We reviewed all the reimbursement claims submitted for outpatient care during 2010 and 2014 and mental disorders subjects were selected using the International Classification of Diseases Tenth Edition (ICD-10) (F00-F99). Considering the disease subtype, this study also investigated how temperature affected certain types of mental disorders, including schizophrenia (F20-F29), mood disorders (F30-F39), and neurotic disorders (F40-F48). The daily weather data on mean temperature, relative humidity, atmosphere pressure for Guangzhou from 2010 to 2014 were obtained from Guangzhou Meteorological Bureau. We also collected daily $PM_{2.5}$ from the CHAP (China High Air Pollutants) database (Weilnhammer et al., 2021).

2.2. Heatwave Definition

In existing research, mean temperature is widely used as an indicator to assess heatwaves and their effects on mental health outcomes (Xu et al., 2017; Xu, FitzGerald, et al., 2019; Xu, Tong, et al., 2019; Yin et al., 2018). A systematic review reported that the heatwave definition most associated with mental health-related morbidity was "mean temperature ≥90th percentile for ≥3 days," followed by mean temperature ≥95th percentile for ≥3 days (Liu et al., 2021). Moreover, previous surveys have confirmed that mean temperature is a better predictor than other climate indices, as it accounts for temperature changes throughout the day, thereby more accurately reflecting the level of heat exposure people experience in real life (Tong et al., 2014). Therefore, mean temperature was used to define heatwaves in the present study. We adopted nine different heatwave criteria that were established by merging three relative temperature thresholds—namely the 90th, 92.5th, and 95th percentiles of daily mean temperatures during the warm months (May–October)—over the course of our study with three different duration thresholds of at least 2, 3, or 4 consecutive days. Additionally, to isolate the effects of heat from those of cold (Yang et al., 2019), our analysis was confined to the warm season (May–October, because the site is located in a subtropical climate, making these months the warmest of the year).

2.3. Potential Effect Modifiers

In this study, given the available data, we compared the differences in outpatient risks for mental disorders across age groups (<60 vs. ≥60) and gender (male vs. female), as age and gender are commonly used demographic factors. Our study further specifically focused on exploring how different types of health insurance (UEBMI vs. URBMI) influence the relationship between extreme heat and mental health. China's health insurance systems cover more than 95% of its population including those living in poverty. This coverage ensures that most healthcare services are affordable. The UEBMI (initiated in 1998) and the URBMI (launched in 2007) were the two main social health insurance schemes implemented for urban residents. The UEBMI was designed for urban employees and those retired, and its premium was mainly paid by both employees and their employers; the URBMI was for non-working urban residents, and its premium mainly came from individual residents and government subsidies (Meng et al., 2019). Individuals enrolled in the UEBMI scheme have a more comprehensive coverage of health services and a higher reimbursement ratio compared to those covered by the URBMI scheme (Liu et al., 2017). These two types of health insurance exhibit significant differences in terms of eligible populations, financing sources, and benefit packages (Zhang et al., 2018), which may also affect health risks. These disparities have been highlighted in several studies investigating the connection between air pollution and usage for mental health medical services (Gu et al., 2020; Ma et al., 2022). This suggests that those with higher benefits might have more resources and greater capacity to mitigate adverse outcomes. It also reflects how individual SES disproportionately affects one's response to extreme weather events, as it is linked to the resources available to mitigate adverse outcomes during such events weather (Cornelius et al., 2023; Lavigne et al., 2023).

2.4. Statistical Methods

This study employs a time-series analysis approach. We utilized a quasi-Poisson generalized linear model (GLM) to explore the influence of heatwaves on outpatient visits for mental disorders. The model can be articulated as follows:

$$\mathrm{Log}[E(Y_t)] = \alpha + \mathrm{HW}_t + \mathrm{ns}(\mathrm{year},3) + \mathrm{ns}(\mathrm{doy},4) + \mathrm{ns}(\text{relative humidity},3) + \mathrm{ns}(\text{atmosphere pressure},3) + \mathrm{ns}(\mathrm{PM}_{2.5},3) + \mathrm{DOW}$$

In this equation, t represented the day of the observation; $E(Y_t)$ denoted the expected number of outpatient visits for mental disorders on day t; the log function is used as the link function; α was the model intercept; HW_t is a binary variable indicating the presence of a heatwave (1) or absence (0). Additional covariates include: (a) the "year" and "day of year (doy)" terms to adjust for long-term trend and seasonality. To be specific, to account for long-term trends, we employed a natural cubic spline with 3 degrees of freedom (df) to capture residual temporal variability (Gasparrini & Armstrong, 2011). Assuming that this seasonal effect remains consistent across different years, then seasonality is modeled using a natural cubic spline with 4 dfs to describe variations during the summer season (Gasparrini & Armstrong, 2011; Li et al., 2022); (b) relative humidity and atmospheric pressure are controlled by a natural spline function with 3 df each (Ma et al., 2020); (c) Day of the week (DOW) is incorporated as a categorical variable; (d) the "$PM_{2.5}$" represents air quality, modeled with a natural spline with 3 df (Yang et al., 2019). To ascertain the lagged effects of heatwaves on outpatient visits (lag up to 10 days), we referenced prior study and explored the lag influences of heatwave effects on outpatient visits, utilizing a natural cubic spline with 4 df and two internal knots at equidistant intervals in the logarithmic scale of lag days, inclusive of the intercept (Guo et al., 2017). The effects were calculated by GLMs combined with a distributed lag model. All of effect estimates are expressed by relative risks (RRs) and 95% confidence intervals (CIs). According to previous studies (Yang et al., 2019; Yin et al., 2018), we primarily focus on reporting risk estimates at lag 0 and during 0–10 days in the main analysis, we also provide estimates of effects at lags of 2, 5, and 10 days, as well as for the periods 0–2 and 0–5 days in Supporting Information S1.

We further investigate whether age, gender and medical insurance that could modify the effects. The difference between two estimates was estimated by the 95% confidence interval (95% CI) as reported by Altman et al. (Altman & Bland, 2003).

In sensitivity analyses, we evaluated the impact on the heatwave effect by: (a) altering the df for meteorological variables (atmospheric pressure and humidity) from 5 to 6; (b) removing the variable representing air pollution ($PM_{2.5}$); (c) controlling for the daily mean temperature to explore its influence on the heatwave influences by a natural cubic spline with 3 dfs.

All statistical analyses were conducted using R software (version 4.2.2). A two-tailed P-value below 0.05 was deemed to indicate statistical significance.

3. Results

Table 1 presents descriptive statistics of outpatient visits along with distributions of meteorological and air pollution variables. During the warm seasons from 2010 to 2014, a total of 575,505 outpatient visits for mental disorders were selected. The majority of these cases involved 294,063 visits diagnosed with mood disorders (F30-F39). This was followed by 229,932 visits diagnosed with schizophrenia (F20-F29), and 51,510 visits diagnosed with neurotic disorders (F40-F48). During the study period, the average daily temperature was 26.7°C with a standard deviation (SD) of 2.62°C, as shown in Table 1. During the study period, the total number of heatwave days ranged from 20 to 78, varying according to the heatwave definitions HW1–HW9 (see Table 2).

Figure 1 illustrates the impact of heatwaves on outpatient visits for total mental disorders and their subtypes. As shown in Figure 1a, one definition of a heatwave (HW3) was linked to an increased risk of outpatient visits for all mental disorders (RR = 1.191, 95%CI: 1.039–1.366 at lag 0 day). We observed HW7 and HW3 were significant associated with increased risks of schizophrenia and neurotic disorders visits, respectively (i.e., RR = 1.160, 95% CI: 1.002–1.344 for schizophrenia and RR = 1.209, 95%CI: 1.005–1.454 for neurotic disorders). We found that two specific heatwaves (HW3 and HW8) were significantly associated with outpatient visits for mood disorders (i.e., RR = 1.234, 95%CI: 1.074–1.417 for HW3 and RR = 1.199, 95%CI: 1.015–1.415 for HW8). Additionally, for HW1–HW6, the effects of heatwaves on outpatient visits for all mental disorders at lag 0 were more pronounced for HWs lasting 4 days compared to those lasting two or 3 days, but this trend was not necessarily observed at higher thresholds. Similar findings were observed for the impact of heatwaves on outpatient visits for schizophrenia and mood disorders. Nevertheless, the association between heatwaves and outpatient visits for neurotic disorders did not exhibit a specific trend for the heatwave-mental disorders linkage under the influence of nine definitions. The relative risks of outpatient visit for mental disorders and their subtypes associated with heatwaves at lag 2, 5, and 10 days did not show specific trend between various definitions of heatwaves and mental disorders (Figure S1 in Supporting Information S1).

Table 1
Descriptive Statistics of Outpatient Visits and Distributions of Meteorological and Air Pollution Variables

Variables	Mean	SD	Minimum	Maximum
Descriptive statistics of outpatient visits				
Total outpatient visits for mental disorders	626	770	3	4,220
Outpatient visits for mental disorders by gender				
Male	304	384	1	1,870
Female	304	397	2	2,470
Outpatient visits for mental disorders by age group (year)				
<60	575	703	3	3,820
≥60	51	73	0	499
Outpatient visits for mental disorders by types of insurance schemes				
URBMI	77	68	1	446
UEBMI	548	712	1	3,940
Outpatient visits for mental disorders by subtypes of mental disorders (MD)				
Schizophrenia (F20-F29)	250	252	2	1,400
Mood disorders (F30-F39)	319	339	2	3,610
Neurotic disorders (F40-F48)	56	85	0	502
Meteorological and air pollution variables				
Daily mean temperature (°C)	26.7	2.62	17.3	32.2
Daily $PM_{2.5}$ ($\mu g/m^3$)	38.1	17.8	10.1	114
Daily relative humidity (%)	79.4	9.69	32.0	99.0
Daily atmospheric pressure (nPa)	1,000	4.83	987	1,020

Figure 1b illustrates the cumulative relative risks of outpatient visits for total mental disorders and their subtypes associated with heatwaves over lag 0–10 days. Among the nine definitions studied, HW1–HW3, HW5, and HW7–HW8 were linked to higher outpatient visits for total mental disorders (e.g., RR = 1.251, 95% CI: 1.067–1.468 for HW1 and RR = 1.236, 95% CI: 1.051–1.453 for HW2). Daily outpatient visits for schizophrenia were not significantly associated with heatwave exposure. However, HW1, HW2, and HW3 were found to increase the risks of outpatient visits for mood disorders (e.g., RR = 1.271, 95% CI: 1.082–1.493 for HW1). Moreover, HW2, HW4, and HW5 were associated with increased risks for neurotic disorders visits (e.g., RR = 1.298, 95%CI: 1.038–1.603 for HW2). Not specific trend was observed for the cumulative relative risks of outpatient visits for mental disorders and their subtypes associated with heatwaves during 0–10 days (Figure 1b). Similar findings were noted for lags over 0–2 and 0–5 days (as shown in Figure S2 of the Supporting Information S1).

Table 2
Characteristics of Nine Types of Heatwave Definitions From 2010 to 2014 in Guangzhou

Heatwave definitions	Threshold	Duration	Number of heatwave days	Intensity
HW1	90th (29.7°C)	≥2	78	Low
HW2	90th (29.7°C)	≥3	60	Low
HW3	90th (29.7°C)	≥4	30	Low
HW4	92.5th (30.0°C)	≥2	64	Moderate
HW5	92.5th (30.0°C)	≥3	48	Moderate
HW6	92.5th (30.0°C)	≥4	24	Moderate
HW7	95th (30.3°C)	≥2	40	High
HW8	95th (30.3°C)	≥3	26	High
HW9	95th (30.3°C)	≥4	20	High

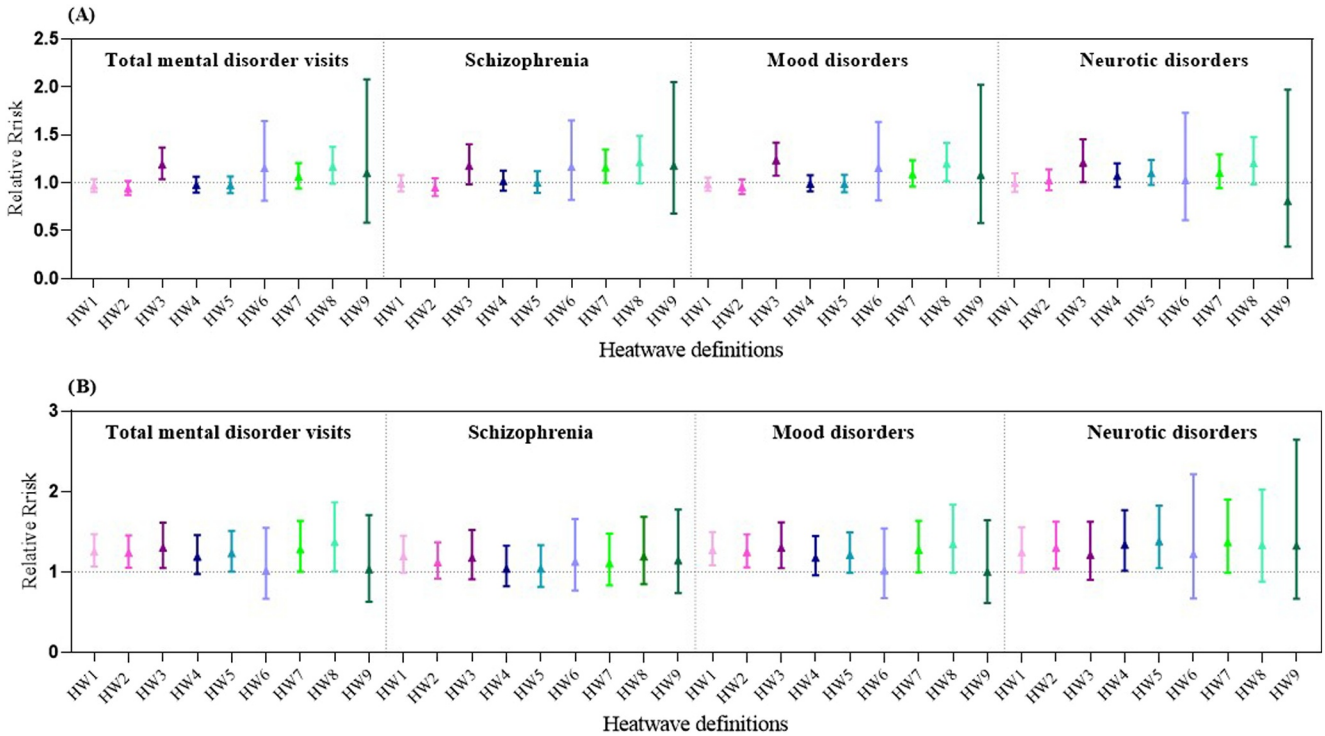

Figure 1. The association between heatwave and outpatient visits for mental disorders and its subtypes. (a): the relative risks of outpatient visits for mental disorders and its subtypes associated with heatwaves at lag 0 day; (b) cumulative relative risks of outpatient visits for mental disorders and its subtypes associated with heatwaves (over 0–10 days).

Figure 2 details the relative risks of outpatient visit for total mental disorders during heatwaves, with a focus on the influence of age, gender and medical insurance. Older adults aged over 60 years (RR = 1.323, 95% CI: 1.095–1.559) exhibited significant effect estimates for outpatient visits compared to those under 60 years. However, only one point (specifically defined by HW7, as illustrated in Figure 2) showed a statistically significant difference between age groups.

To confirm the robustness of these findings, several sensitivity analyses were performed. After adjusting for different degrees of freedom in relative humidity and air pressure, further controlling the mean temperature variable, and removing the air pollution variable, the effect estimations for outpatient visits for mental disorders at the lag 0 day and over 0–10 day period remained unchanged, as shown in Tables S1 and S2 of the Supporting Information S1. Therefore, the sensitivity analyses did not alter the main findings.

4. Discussion

Different from previous studies focusing on hospitalizations or emergency room visits, this study explored the impact of extreme heat events on outpatient visits for mental disorders and its subtypes based on over 5.7 million visit records in Guangzhou, China. Our study addressed some existing research gaps by focusing on various definitions of heatwaves, healthcare utilization in outpatient visits for mental disorders, and the examination of effect modification factors. Summarily, findings suggested that heatwaves were associated with a higher likelihood of outpatient visits for mental disorders, including some specific subtypes, like mood disorders, although the effect estimations were varied by heatwave definitions. We noted that older adults were found to be more affected by high-intensity heatwave days.

In the present study, we first analyzed the influences of nine heatwave definitions combined with three thresholds and duration days on outpatient visits for mental disorders. We reported the effect estimations at lag 0 day and during 0–10 days period, highlighting the immediate and delayed impacts of heatwaves on mental health. Overall, different definitions of heatwaves resulted in varying estimates of outpatient visit risks. However, the statistically significant effect magnitudes for these risks were generally consistent. Our study suggested that the adverse

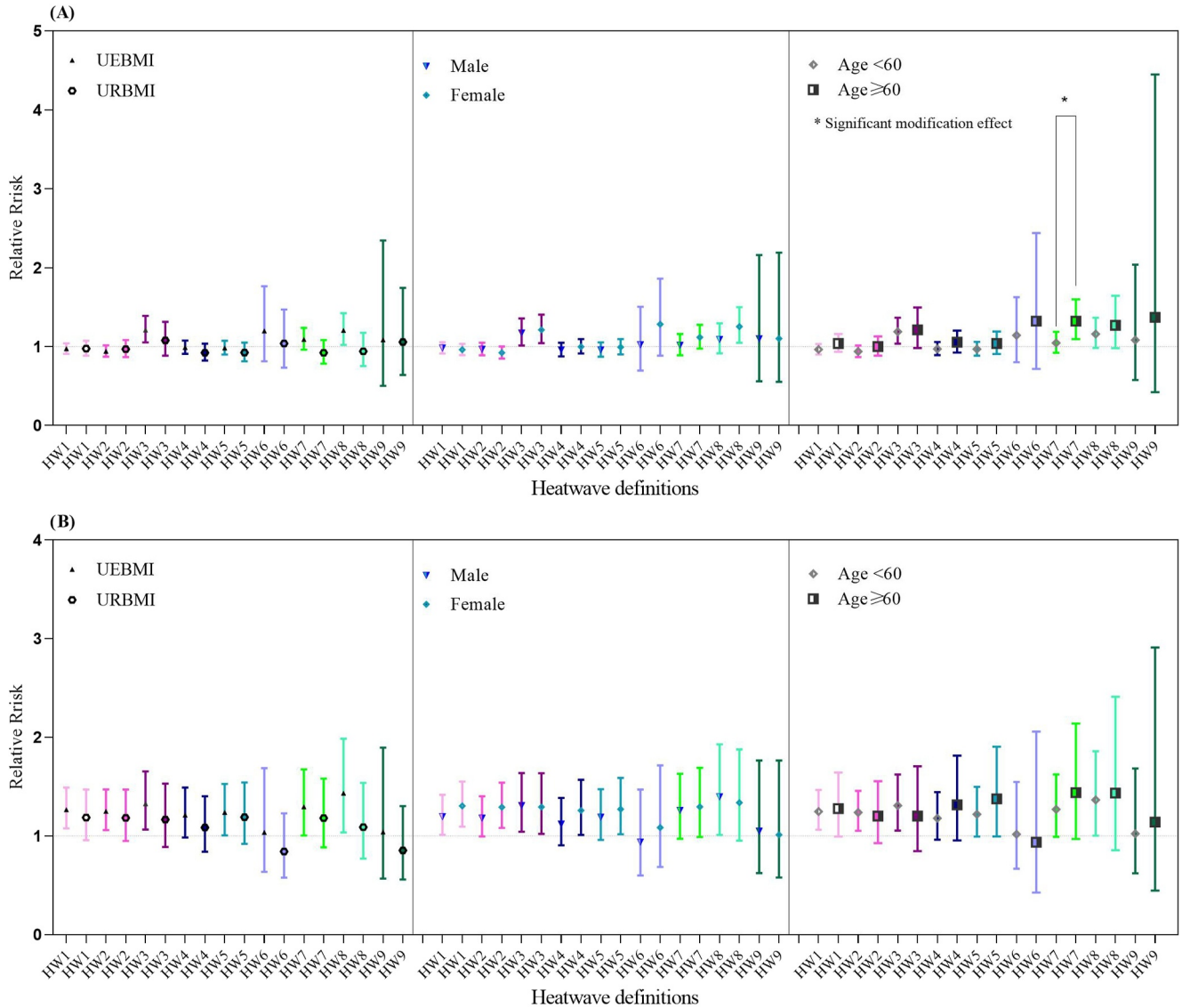

Figure 2. The association between heatwave and outpatient visits for mental disorders stratified by age, gender and medical insurance types. (a): the relative risks of outpatient visits for mental disorders associated with heatwaves at lag 0 day stratified by age, gender and medical insurance types; (b) cumulative relative risks of outpatient visits for mental disorders associated with heatwaves (over 0–10 days) stratified by age, gender and medical insurance types.

effects of exposure to heatwaves on the number of total outpatient visits attributed to mental disorders and its subtypes. This finding was generally consistent with published literature reported the effects of extreme ambient heat exposure on increased hospitalizations (Crank et al., 2023; Dang et al., 2022; Xu, Tong, et al., 2019) and emergency visits for mental disorders (Lavigne et al., 2023; Xu, FitzGerald, et al., 2019; Yoo, Eum, Gao, & Chen, 2021; Yoo, Eum, Roberts, et al., 2021).Based on our analysis, under definitions of low and moderate intensity heatwaves, the impact of extreme heat events on mental disorders at lag 0 day was most pronounced for heatwave durations of at least 4 days, compared to two or 3 days. However, this trend was not evident at higher thresholds. For cumulative effects, we did not identify obvious and specific trend in outpatient visits for mental disorders and their subtypes associated with heatwaves. Many prior studies have also found that estimations of health impacts vary due to different definitions of heatwaves. For instance, previous studies indicated that higher temperature thresholds correlate with increased health risks, but extended durations do not always lead to higher impact estimates (Guo et al., 2017; Hu et al., 2020; Yin et al., 2018). One multicity's study from China found that the severity of heatwave-related mortality increases with the temperature threshold and duration of the heatwaves (Yang et al., 2019), while another suggested that prolonged heatwave durations may pose greater risks to

cardiovascular mortality (Dong et al., 2016). The possible explanation for our findings is that the central nervous system is particularly vulnerable to hyperthermia, especially when it is prolonged or extreme (Walter & Carraretto, 2016). Additionally, sustained high temperatures over several days or weeks can affect individuals' mental status and behavior, leading to increased irritability and psychological distress (Liu et al., 2021). According to these conclusions, our observation suggests that protecting populations from prolonged heat exposure may have beneficial effects on reducing the risk of mental disorders. Our study further enriches prior evidence that heatwaves not only lead to severe mental health disorders requiring hospitalization or emergency visits, but also increase the risk of outpatient visits, highlighting the broader impact of extreme heat on mental health.

The biological mechanisms underlying the impact of extreme heat on mental disorders are complex. On the one hand, previous studies have highlighted the influence of stress hormones, which can lead to mental disorders (Zhang et al., 2020). The serotonin system (5-hydroxytryptamine, 5-HT) is a crucial element in the modulation of emotional states and cognitive function and has been used to explain the significant association between heat exposure and mental disorders (Zhang et al., 2020). On the other hands, heat stress can induce neurodegeneration, particularly under conditions of heat stroke, which can lead to excitotoxicity, necrosis, and apoptotic death of neuronal cells (Li et al., 2023). These alterations in neuronal cells and neural networks contribute to the pathology of mental disorders. Regarding some specific mental disorders, related mechanisms have not been fully established. Exposure to extreme heat temperatures may cause dysregulation of the serotonin system, resulting in an increased risk of mood disorders and schizophrenia (Hasegawa et al., 2005; Sung et al., 2011). Heat also affects the levels and balance of neurotransmitters such as serotonin and dopamine in the brain, influencing mood, cognitive function, and the performance of complex tasks, which could contribute to the onset or exacerbation of schizophrenia symptoms (Barron et al., 2017; Berry et al., 2010; Nakagawa & Ishiwata, 2021). Cortisol levels, an important stress hormone, increase under heat exposure, which is associated with neurotic disorders (Lenze et al., 2011).

Consistent with previous studies, we found that older adults may be a potentially vulnerable population (Paavola, 2017; Yoo, Eum, Gao, & Chen, 2021; Yoo, Eum, Roberts, et al., 2021). However, it is important to note that our current findings may be weakened by the fact that, except for HW7, all heatwave definitions show no differences between age groups. Older adults are particularly sensitive to heat due to their reduced capacity for homeostasis and thermoregulation, which are consequences of aging, along with the presence of pre-existing chronic conditions (Yang et al., 2019). Communities play a crucial role in education and awareness campaigns that might promote climate-resilient practices and protect vulnerable populations (Zhang et al., 2023). Additionally, most older adults live within the community. Given their vulnerability, we recommend that policymakers could consider including the mental health risks associated with extreme heat in health education programs related to climate change. Meanwhile, minimizing disparities in medical resource utilization during extreme weather is important for alleviating the impact of associated illnesses and advancing social justice. While our findings did not show a significant impact of health insurance types on the relationship between extreme heat and outpatient visits for mental disorders. Because relative to UEBMI scheme received higher benefits, the URBMI scheme usually provided coverage for individuals who were economically disadvantaged, unemployed, or children (often have lower educational levels and SES compared to those covered by the UEBMI) (Ma et al., 2022). These factors facilitate their adaptation and recovery during extreme heat events and also profoundly influences adaptive behaviors (Paavola, 2017).

There are several limitations that should be acknowledged. First, our sample was drawn from a single large city, our findings should be cautiously generalized to other regions. Second, the time-series study was limited in its ability to account for individual heat exposure. This aspect should be further explored in future studies. Lastly, in recent years, there has been an increase in the frequency, intensity, and duration of heatwaves. It is necessary to use recent data to confirm our study's findings.

5. Conclusion

In conclusion, this study emphasized that heatwaves increased the risk of outpatient visits for both total mental disorders and some specific mental disorders. For low and moderate intensity heatwave definitions, heatwave exposure lasting more than 4 days may be associated with increased risks, although this is not necessarily for more extreme thresholds. Moreover, we found a potential susceptibility among older adults.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The daily weather data on mean temperature, relative humidity, atmosphere pressure for Guangzhou from 2010 to 2014 were obtained from Guangzhou Meteorological Bureau. Daily PM2.5 from the CHAP (China High Air Pollutants) database (https://weijing-rs.github.io/product.html). The open-source software used for data analyses —"R" can be found at the following respective urls: https://cran.r-project.org/bin/windows/base/old/. The outpatient visits data used in this study are not publicly available due to confidentiality of patient information. Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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