J Korean Med Sci. 2026 Apr 6;41(13):e25
https://doi.org/10.3346/jkms.2026.41.e25
eISSN 1598-6357·pISSN 1011-8934

JKMS

Original Article

Public Health & Preventive Medicine

Extreme Ambient Temperature and Differential Risk of Mental Disorder-Related Emergency Department Visit by Disorder, Sex and Age: A Case-Time Series Analysis in Korea

Hoyol Jhang,[1] **Whanhee Lee**,[2] **Jong-Tae Lee**,[3,4] **Yoonhee Kim**,[5] **Shengzhi Sun**,[6] **Shu-Sen Chang**,[7] **and Seung-Ah Choe**[4,8]

[1]Department of Public Health, Korea University, Seoul, Korea
[2]School of Biomedical Convergence Engineering, Pusan National University, Busan, Korea
[3]Department of Public Health Science, Korea University, Seoul, Korea
[4]Research and Management Center for Health Risk of Particulate Matter, Korea University, Seoul, Korea
[5]Department of Global Environmental Health, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan
[6]School of Public Health, Capital Medical University, Beijing, China
[7]Institute of Health Behaviors and Community Sciences, College of Public Health, National Taiwan University, Taipei, Taiwan
[8]Department of Preventive Medicine, Korea University College of Medicine, Seoul, Korea

Received: Feb 25, 2025
Accepted: Jul 11, 2025
Published online: Dec 12, 2025

Address for Correspondence:
Seung-Ah Choe, MD, PhD
Department of Preventive Medicine, Korea University College of Medicine; Research and Management Center for Health Risk of Particulate Matter, Korea University, 145 Anam-ro, Seongbuk-gu, Seoul 02841, Korea.
Email: seungah@korea.ac.kr

ORCID iDs
Hoyol Jhang
https://orcid.org/0000-0001-5504-763X
Whanhee Lee
https://orcid.org/0000-0001-5723-9061
Jong-Tae Lee
https://orcid.org/0000-0002-8510-3054
Yoonhee Kim
https://orcid.org/0000-0003-2517-1087
Shengzhi Sun
https://orcid.org/0000-0002-3708-1225
Shu-Sen Chang
https://orcid.org/0000-0001-5012-1132
Seung-Ah Choe
https://orcid.org/0000-0001-6270-5020

ABSTRACT

Background: The impacts of extreme ambient temperatures on mental health may vary by type of disorders, age and sex. We examined the association between extreme ambient temperatures and emergency department (ED) visits for prevalent mental disorders, stratified by age and sex.

Methods: We analyzed the National Emergency Department Information System data in 2015–2021, Korea. Using a case-time series design, we calculated relative risks (RRs) of ED visits for prevalent mental disorders at extremely high (97.5th percentile) and low (2.5th) ambient temperatures, stratified by age (0–19, 20–39, 40–64, and ≥ 65) and sex. A lag period of 0–5 days was considered for ambient temperature and air pollution.

Results: Of 1,351,463 ED visits due to mental disorders, neurotic, stress-related and somatoform disorder (anxiety disorder, 31.5%), organic mental disorder (OMD, 25.2%), substance use disorder (SUD, 24.5%) and mood disorder (MD, 15.2%) were common. At extreme high temperatures, the RR of anxiety-related visits was 2.25 (95% confidence interval [CI], 1.87–2.71), with men 20–39 years at higher risk (4.02; 95% CI, 2.77–5.85) than women (1.65; 95% CI, 1.17–2.32, *P* for difference < 0.001), versus minimum-risk ambient temperature. Extreme heat also raised RR for OMD in men 40–64 years (1.49; 95% CI, 1.01–2.21), SUD in women 20–39 years (2.72; 95% CI, 1.85–3.99) and MD in women ≥ 65 years (2.00; 95% CI, 1.42–2.80). Risk estimates at extreme low temperatures were generally imprecise, except for anxiety in men 20–64 years. These associations were not replicated among children and adolescents (0–19 years).

Conclusion: Our findings emphasize the need for more tailored climate change adaptation strategies considering the varying vulnerabilities of populations to mental disorders.

Funding

This study was supported by the National Research Foundation of Korea [Grant No. 2018R1D1A1B07048821 and 2022R1A2C1006364], and the National Institute of Environmental Research (NIER) funded by the Ministry of Environment (MOE) of the Republic of Korea (NIER-2021-03-03-007). The funder had no involvement in any aspect of the study, including its design, data collection, analysis, interpretation, or manuscript preparation.

Disclosure

The authors have no potential conflicts of interest to disclose.

Data Availability Statement

The data from this study are available upon the approval of the National Medical Center of Korea.

Author Contributions

Formal analysis: Jhang H. Funding acquisition: Lee JT. Investigation: Jhang H, Lee W, Kim Y, Sun S, Chang SS. Methodology: Jhang H, Lee W, Choe SA. Project administration: Choe SA. Resources: Choe SA. Writing - original draft: Jhang H. Writing - review & editing: Lee W, Lee JT, Kim Y, Sun S, Chang SS, Choe SA.

Keywords: Mental Disorder; Ambient Temperature; Heat; Cold; Emergency Department; Sustainable Development Goals; Korea

INTRODUCTION

Extreme ambient temperature changes substantially affect people's lives. Severe heatwaves, heavy rainfalls, and extreme cold have increased the risk of cardiovascular and respiratory deaths among the population.[1] In a physiological response to ambient heat, people experience heat stress which reduces working capacity and cognitive function, impairs productivity, and pose a higher risk of accidents in the workplace.[2] Extreme heat also triggers a surge in emergency department (ED) visits for cardiovascular and respiratory disorders.[3] In addition, with growing concern over the physical health risks of extreme ambient temperatures, researchers are increasingly turning their attention to its mental health implications.[4,5]

Although there is some research evaluating the association between mental disorder-related ED visits and extreme ambient temperatures, limited studies are available regarding the specific type of mental disorders sensitive to extreme ambient temperatures. Mental disorders constitute a heterogeneous group of mental disorders, encompassing conditions such as substance use disorders (SUD) and somatoform disorders. For instance, SUD frequently presents symptoms of intoxication or withdrawal, often requiring urgent medical intervention.[6] Conversely, somatoform disorders are characterized by the presence of physical symptoms that lack a clear medical explanation. Effective management necessitates comprehensive diagnostic evaluation to divide organic pathology.[7]

The susceptibility to different mental disorders could considerably vary depending on age and sex, particularly in response to extreme heat or cold. For example, older adults, often with compromised thermoregulation and underlying health conditions, may be more vulnerable to heat stroke and hypothermia, which can exacerbate existing mental health issues.[8] The consequences of heat exposure in infants, children, and adolescents may differ from those in adults, given the unique susceptibility of children due to their developing bodies and different behavioral patterns.[9] Younger individuals, especially those with pre-existing bipolar disorder or schizophrenia, tend to exhibit mood instability and psychotic episodes relevant to ambient temperature fluctuations.[10] This feature was replicated in a study in South Korea, where patients with intellectual disability or mental disorder were at higher risk for ED admissions due to heat-related health problems, and among those with mental disorder, women and those aged 65 years or older were particularly at risk.[11] Sex or gender has been known to be a contributing factor, as some studies suggest that heat-related mortality tends to be higher in women than in men.[12] Literature examining the variations in heat-related mental health risks across different type of mental disorders, age and sex together have been limited and showed inconsistency. To address the knowledge gaps on the differential susceptibility to heat, this study aimed to investigate differential associations across different mental disorders leveraging national population data. Because the association between temperature and mental disorder types may differ by age and sex, we examined the relationship between extreme ambient temperatures and ED visits stratified by age and sex.

JKMS

METHODS

Data source

We obtained data from the National Emergency Department Information System (NEDIS) from January 1, 2015, to December 31, 2021, a nationwide database maintained by the National Medical Center of Korea. The NEDIS is an emergency information network established by the Ministry of Health and Welfare, collecting anonymized data on ED visits at all 410 hospitals with EDs across the country. This comprehensive database includes patient's age, sex, date of visit, home addresses recorded at the municipality level (*gun, gu*), primary diagnosis made by physicians, and pre- and post-ED visit status, transmitted automatically from each hospital to a central server.[13] The reliability of NEDIS data is supported by the national emergency medical institution evaluation, which reported a 94.4% ED input rate and a 95.8% completion rate.[14,15]

Data on all cases of mental disorder-related ED visits from January 1, 2015 to December 31, 2021 were retrieved from the NEDIS database. Young children are less able than adults to regulate their core body temperature and thus to protect themselves from exposure to extreme temperatures, so their responses to extreme heat or cold may be different from those of adults.[16] In addition, since young children and adolescents have generally lower rates of ED visits, so our analysis was conducted separately for young population (0–19) and adults, with a primary focus on adults. Eleven subgroups of mental, behavioral, and neurodevelopmental disorders (F00–F99), as classified by the International Classification of Diseases-10, were identified for analysis. Although the original dataset listed each ED visit separately, the provider removed all personal identifiers, making it impossible to distinguish repeat visits by the same individual. Consequently, the only feasible approach was to aggregate visits into municipality-level daily counts for analysis. Our analysis thus focused on municipality-level incidence of ED visits for mental disorder, stratified by age and sex. Age- and sex-specific mid-year population estimates for each municipality sourced from the Korean Statistical Information Service were used to calculate the age- and sex-specific daily incidence of mental disorder-related ED visits over the study period.[17] There were 252 municipalities, but since 2016, three municipalities were merged into one. Considering the study period from 2015 to 2021, a total of 253 municipalities were identified.

Measurement of ambient temperature

There are various ways to quantify temperature. Among them, the apparent temperature is calculated by a combination of temperature, humidity, wind speed, and radiant heat. On the other hand, the ambient temperature is the temperature of the air itself in the environment, and is an objective physical quantity measured by a standard thermometer.[18] Since the apparent temperature estimates the overall thermal comfort level of the human body in the surrounding atmospheric environment, the ambient temperature is more appropriate for consistent measurement of extreme temperatures. Ambient temperature data were sourced from the public database of the Korea Meteorological Administration (KMA), which operates a network of weather observation stations across South Korea. The KMA uses the Automated Synoptic Observing Systems (ASOS) and Automatic Weather Systems (AWS) to collect ground-based meteorological data. ASOS stations provide simultaneous observations from multiple locations to assess atmospheric conditions, while AWS stations focus on monitoring weather phenomena for the purpose of monitoring natural disasters. Currently, Korea has 96 ASOS stations and 464 AWS stations.[19] Each ASOS station, covering an average area of 36 km by 36 km, is designed to provide real-time local weather data and

https://doi.org/10.3346/jkms.2026.41.e25

forecasts. We assigned the daily average ambient temperature to each municipality. For 152 municipalities having multiple observation stations, we used average of the multiple measurements. For 27 municipalities without measurement data, we used the average ambient temperature of the province to which the municipality belongs.

Covariates

Confounding factors were identified a priori using a directed acyclic graph (**Supplementary Fig. 1**). The explanatory model incorporated daily mean concentrations of air pollutants, relative humidity, the level of urbanization in the municipality, and the year of the visit. The air pollutants considered were particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$), and nitrogen dioxide (NO_2), both of which have the potential to influence mental disorders.[20] Excluding two islands (Ulleung-gun in Gyeongsangbuk-do and Jeju-do) due to unavailable exposure modeling data, we used machine-learning-validated models to predict daily mean concentrations of ambient $PM_{2.5}$ and NO_2 at a 1 km^2 spatial resolution across all contiguous municipalities in Korea.[21-24] Pollutant concentrations for each municipality were determined using centroid points within municipality boundaries, with daily averages of the two air pollutants assigned to individuals residing in the respective municipalities. Daily average relative humidity (%) was sourced from ground-based meteorological data, following the same methodology as ambient temperature assignment.[25] The patient's home address and ED visit date of the NEDIS data served as the matching keys. KMA data and air pollutant data were linked based on Korea area codes and observation dates. This combined data allowed us to assess the association between extreme ambient temperatures and ED visits for mental disorders, with additional analyses stratified by sex and age.

Statistical analysis

Summary statistics were calculated to present the characteristics of mental disorder-related ED visits stratified by age (0–19, 20–39, 40–64 and ≥ 65 years) and sex (men, women). Daily mean of municipality-level incidence of ED visits for mental disorders-related ED visits per 100,000 person-days at the municipal level was calculated for overall and prevalent mental disorders. 95% confidence interval (CI) was calculated using standard deviation.

We applied a case time series design, which is appropriate for taking into account a self-matched structure for analyzing time-varying risk factors and transient health associations. A case time series design model used equation[26]:

$$g[E(y_{it})] = \xi_{i(k)} + f(x_{it}, l) + \sum_{j=1}^{J} s_j(t) + \sum_{p=1}^{P} h_p(z_{ipt})$$

A case represents a municipality-level incidence of mental disorder-related ED visits. In the equation, t represents time and y_{it} represents incidence for each of the $i = 1, \ldots, 253$ municipalities. We modelled the relationships over a lag period of 0–5 days (corresponds to l), using an unconstrained distributed lag linear model (DLM) for the linear association with air pollution, and natural-spline distributed lag non-linear models (DLNM) for specifying non-linear dependencies with ambient temperature and relative humidity. These variables are used in equation at x. The 0–5 lag for ambient temperature and air pollutants were determined in reference to prior studies.[16,27] We fitted a cross-basis function of a natural cubic spline for the exposure-response association with three degrees of freedom and a natural cubic spline for the lag-response association with one internal knot for ambient

temperature and relative humidity. Utilizing a conditional quasi-Poisson log-link regression model, we included distinct, year, month strata as stratified intercepts (corresponds to $\varsigma i(k)$ for each time stratum k), day of the week (in particular, it is widely known that ambient temperatures are lower on weekends than on weekdays[28-30]), and natural splines of time (with 4 df/year) to take into account of differential baseline risk and trends among the various spatiotemporal strata (corresponds to other terms, represents trends or seasonality using multiple transformations of sj, and potential time-varying predictors hp) such as ambient temperature, relative humidity, $PM_{2.5}$, and NO_2.[31]

Lag-cumulative relative risks (RRs) for heat and cold were defined as the risks at the point of extremely high (97.5th percentile) and at the extremely low (2.5th percentile of the distribution) ambient temperatures relative to the risk at the minimum risk ambient temperature (MRT).[27] We used a consistent MRT to simplify the interpretation of RR changes across all four mental disorders, as well as across different age and sex groups, following the approach used in previous studies.[32,33] The net RR cumulated in the lag period of 0–5 days as overall lag-cumulative exposure-response associations between daily mean ambient temperature and ED visits was calculated. We quantified the short-term effects of ambient temperature on mental disorder-related ED visits by calculating lag-specific RRs for 1°C increase from the mean ambient temperature. To evaluate potential effect modification by age and sex, we conducted stratified analyses for each mental disorder and check Cochran's Q test. We conducted four sensitivity analyses to assess the robustness of the results: 1) modeling with lag period up to 7 days,[34] 2) applying lag-cumulative RR of ED visits for heat-related mental disorder for extreme heat and cold, by adjusting only one air pollutant ($PM_{2.5}$ or NO_2), 3) replacing degree of freedom of 4 with 8 for year, and 4) adopting from unconstrained DLM to constrained DLM for air pollutants. R software (version 4.3.2; R Foundation for Statistical Computing, Vienna, Austria) was used for all statistical analyses. The nonlinear associations between ambient temperature and mental disorder-related ED visit were modeled using the '*dlnm*', and the conditional quasi-Poisson regression models were fitted using the '*gnm*' package.

Ethics statement

This study was approved by the Korea University Institutional Review Board and the requirement for informed consent was waived (KUIRB-2023-0264-01).

RESULTS

Study population characteristics, meteorological factors, and air pollution levels

In 1,351,463 ED visits due to mental disorders, anxiety disorder[35] (31.5%; F40–F48), organic mental disorder (OMD, 25.2%; F00–F09), SUD (24.5%; F10–F19), and mood disorders (MD, 15.2%; F30–39) were most prevalent (**Supplementary Table 1**). When restricting to the 1,226,629 ED visits related to these four prevalent conditions, including overlapping cases, the majority involved individuals aged 40–64 (38.4%), women (53.9%), and those residing in urban areas (41.5% in metropolitan cities and 46.6% in cities). In the mental disorder-related ED visits among aged 0–19, the proportion living in cities was higher than in metropolitan areas (**Table 1**). Among men aged 20–39 who visited the ED for mental disorder-related reasons, the proportion residing in metropolitan cities was comparable to the proportion living in smaller cities. In contrast, for women within the same age group, the

Table 1. Characteristics of the study population with emergency department visits due to four common mental disorders from Jan 1, 2015 to Dec 31, 2021 in South Korea, the National Emergency Department Information System, stratified by sex and age

Variables	0–19 yr		20–39 yr		40–64 yr		≥ 65 yr		Total
	Men	Women	Men	Women	Men	Women	Men	Women	
No. of visits	26,202	37,532	97,716	134,656	251,847	218,817	189,337	270,522	1,226,629
Level of urbanization									
Metropolitan city	10,997 (42.0)	16,430 (43.8)	44,978 (46.0)	65,077 (48.3)	106,923 (42.5)	90,436 (41.3)	72,631 (38.4)	101,992 (37.7)	509,464 (41.5)
City	13,496 (51.5)	18,865 (50.3)	45,465 (46.5)	62,693 (46.6)	115,841 (46.0)	106,067 (48.5)	85,783 (45.3)	123,309 (45.6)	571,519 (46.6)
Rural area	1,709 (6.5)	2,237 (6.0)	7,273 (7.4)	6,886 (5.1)	29,083 (11.6)	22,314 (10.2)	30,923 (16.3)	45,221 (16.7)	145,646 (11.9)
Year									
2015–2017	11,872 (45.3)	13,401 (35.7)	43,352 (44.4)	56,661 (42.1)	117,726 (46.8)	102,879 (47.0)	76,585 (40.5)	110,615 (40.9)	533,091 (43.5)
2018–2019	8,230 (31.4)	12,502 (33.3)	30,689 (31.4)	41,570 (30.9)	79,827 (31.7)	68,141 (31.1)	58,803 (31.1)	84,326 (31.2)	384,088 (31.3)
2020–2021	6,100 (23.3)	11,629 (31.0)	23,675 (24.2)	36,425 (27.1)	54,294 (21.6)	47,797 (21.8)	53,949 (28.5)	75,581 (27.9)	309,450 (25.2)
Season									
Spring (Mar–May)	7,193 (27.5)	9,810 (26.1)	24,188 (24.8)	32,773 (24.3)	63,820 (25.3)	54,551 (24.9)	47,377 (25.0)	67,212 (24.9)	306,924 (25.0)
Summer (Jun–Aug)	6,943 (26.5)	10,424 (27.8)	26,903 (27.5)	38,042 (28.3)	67,291 (26.7)	61,019 (27.9)	49,527 (26.2)	69,936 (25.9)	330,085 (26.9)
Fall (Sep–Nov)	6,043 (23.1)	9,799 (26.1)	24,342 (24.9)	34,702 (25.8)	62,891 (25.0)	54,231 (24.8)	47,063 (24.9)	68,070 (25.2)	307,141 (25.0)
Winter (Dec–Feb)	6,023 (23.0)	7,499 (20.0)	22,283 (22.8)	29,139 (21.6)	57,845 (23.0)	49,016 (22.4)	45,370 (24.0)	65,304 (24.1)	282,479 (23.0)
Day of week									
Weekdays (Mon–Fri)	17,815 (68.0)	27,221 (72.5)	66,108 (67.7)	91,643 (68.1)	175,245 (69.6)	147,671 (67.5)	136,522 (72.1)	193,595 (71.6)	855,820 (69.8)
Weekends (Sat–Sun)	8,387 (32.0)	10,311 (27.5)	31,608 (32.4)	43,013 (31.9)	76,602 (30.4)	71,146 (32.5)	52,815 (27.9)	76,927 (28.4)	370,809 (30.2)
Mental disorders[a]									
Organic mental disorder	2,760 (10.5)	1,541 (4.1)	4,319 (4.4)	2,974 (2.2)	25,494 (10.1)	14,225 (6.5)	114,945 (60.7)	173,700 (64.2)	339,958 (27.7)
Substance use disorder	10,543 (40.2)	10,665 (28.4)	38,357 (39.3)	36,054 (26.8)	142,273 (56.5)	47,611 (21.8)	32,940 (17.4)	13,187 (4.9)	331,630 (27.0)
Mood disorder	4,747 (18.1)	12,902 (34.4)	18,107 (18.5)	36,586 (27.2)	27,625 (11.0)	42,145 (19.3)	23,932 (12.6)	39,776 14.7)	205,820 (16.8)
Anxiety disorder	9,244 (35.3)	15,165 (40.4)	42,163 (43.1)	67,932 (50.4)	70,504 (28.0)	127,756 (58.4)	29,620 (15.6)	63,548 (23.5)	425,932 (34.7)

The values in parentheses are percentage (%).
[a]Sum of ED-visits due to four mental disorders may not equal to the total number of visits due to overlapping cases.

greatest proportion of ED visits was observed during the summer season. For individuals aged 40–64, the distribution of mental disorder-related ED visits according to urbanization level, season, year, and day of the week was generally similar between men and women, showing little variation by sex. This pattern of minimal differences across sexes was also seen in the population aged 65 years and older. Most ED visits related to OMD occurred among those aged 65 years and older (84.9%; **Supplementary Table 2**). For SUD, the largest proportion was among those aged 40–64 (57.3%), with men accounting for most cases (67.6%). About one-third of MD-related visits were among those aged 40–64 (33.9%) and those aged ≥ 65 (31.0%). Women represented most MD-related visits (63.9%). Similarly, most ED visits due to anxiety disorders were seen in the 40–64 age group (46.6%) and among women (64.4%).

The overall mean ambient temperature and relative humidity during the study period were 13.2°C and 67.4%, respectively (**Supplementary Table 3**). The extremely high ambient temperature (≥ 97.5th) was 28°C, the extremely low ambient temperature (≤ 2.5th) was −5°C,

the MRT was −19.5°C, and the maximum risk ambient temperature was 34.4°C during the study period. The overall mean concentrations $PM_{2.5}$ and NO_2 over the case and control days were 22.62 μg/m^3 and 17.21 ppb, respectively.

Geographic and demographic patterns of four prevalent mental disorders

The overall mean of municipality-level incidence rate for all four mental disorders-related ED visits per 100,000 person-days was 1.16 (95% CI, 1.16–1.17), ranging from 0 to 6.05 (**Supplementary Table 4**). When stratified by sex and age, women aged ≥ 65 had the highest risk (2.59; 95% CI, 2.58–2.60), and men aged 0–19 had the lowest risk 0.24 (95% CI, 0.23–0.24). For individual disorders, SUD-related ED visits were most common among men aged 40–64 (0.67, 95% CI, 0.66–0.67), whereas risk of ED visits due to OMD (1.64; 95% CI, 1.63–1.64), MD (0.36; 95% CI, 0.36–0.36), and anxiety disorder (0.64; 95% CI, 0.63–0.64) were highest in women aged ≥ 65. The risk for different mental disorders varied across geographic regions (**Fig. 1**). OMD-related ED visits were generally comparable across non-metropolitan areas. SUD-related ED visits occurred more frequently in the northeastern

Fig. 1. Geographic distribution of the overall mean of municipality-level risk for emergency department visits related to (**A**) all four mental disorders, (**B**) organic mental disorder, (**C**) substance use disorder, (**D**) mood disorder, and (**E**) anxiety disorder by region, per 100,000 person-days, from Jan 1, 2015 to Dec 31, 2021. The results are presented in quartiles, with darker shades indicating higher risk.

regions, while MD-related and anxiety disorder-related ED visits were most common in the southwestern and central regions, respectively.

Risk of ED visits for overall and specific mental disorders by sex and age

The risk of mental disorder-related ED visits generally was higher when the ambient temperature is high. The MRT for the combination of all four conditions was –19.5°C. Compared to the MRT, the overall lag-cumulative RR of ED visits for any mental disorders was higher when the daily mean ambient temperature was ≥ 2°C (**Supplementary Fig. 2**). In the four common disorders, the risk of ED visits for SUD was consistently higher when the ambient temperature was ≥ 13°C, and the risks of MD and anxiety disorder were higher at ≥ 5°C and ≥ 2°C, respectively, while the association between ambient temperature and OMD-related ED visits did not show a clear linear pattern.

Stratified by sex and age, men aged 0–19 had higher risk of ED visits at all temperatures higher than MRT for MD and anxiety disorder (**Supplementary Fig. 3**). Similarly, higher risk of anxiety disorder-related ED visits was observed in women aged 0–19 (**Supplementary Fig. 4**), men aged 20–39 (**Supplementary Fig. 5**), and men aged 40–64 (**Supplementary Fig. 6** top panel of **Fig. 2E**). Among women aged 20–39, a higher risk was observed for SUD with ambient temperature higher than MRT (**Supplementary Fig. 7**, top panel of **Fig. 2C**). The risk of ED visits due to any of all four mental disorders was consistently higher when the ambient temperature is ≥ 0°C (top left panel of **Fig. 2A**) among men aged 40–64. A similar pattern was observed among women in the same age group, but with higher threshold ambient temperatures (**Supplementary Fig. 8**). Among individuals aged ≥ 65, the positive association between mental disorder-related ED visits and higher ambient temperatures was consistently observed for all four mental disorders, with varying threshold ambient temperatures. For example, the positive association with extremely high temperature was evident at ≥ 8°C for OMD and SUD, and at ≥ 20°C for anxiety disorder-related ED visits (**Supplementary Fig. 9**, top panel of **Fig. 2B**). On the other hand, the positive association of high ambient temperatures with OMD and SUD was not evident in women aged ≥ 65 (**Supplementary Fig. 10**).

When assessing lag-specific risk in the pairs with positive associations, higher RR for all four mental disorder-related ED visits per 1°C increase in the mean ambient temperature was noted at 0- (1.48; 95% CI, 1.33–1.65) and 1-day lags (1.10; 95% CI, 1.05–1.15), among men aged 40–64. A similar pattern was observed for OMD among men aged ≥ 65, and anxiety disorder among men aged 40–64. Among women aged 20–39, higher RRs of SUD were noted at 1- to 4-day lags, ranging from 1.00 to 1.01 (**Fig. 2**, lower panel).

When assessing the heterogeneities in the risk estimates across different sexes, we observed sex-based differences for all four groups of mental disorders. The RR of anxiety disorder-related ED visits was higher among men aged 20–39 (4.02; 95% CI, 2.77–5.85) than among women in the same age group (1.65; 95% CI, 1.17–2.32, *P* for difference < 0.001). The association between extreme heat and OMD-related ED visits was stronger in men aged 40–64 (1.49; 95% CI, 1.01–2.21) than in women of the same age group (1.29; 95% CI, 0.84–1.97, *P* for difference < 0.001). In contrast, for SUD-related ED visits, the association was more pronounced in women aged 20–39 (2.72; 95% CI, 1.85–3.99) than in men of the same age group (0.96; 95% CI, 0.66–1.39, *P* for difference = 0.009). The RR of MD-related ED visits was highest among men aged 0–19 (6.62; 95% CI, 4.04–10.86) among all age-sex strata.

https://doi.org/10.3346/jkms.2026.41.e25

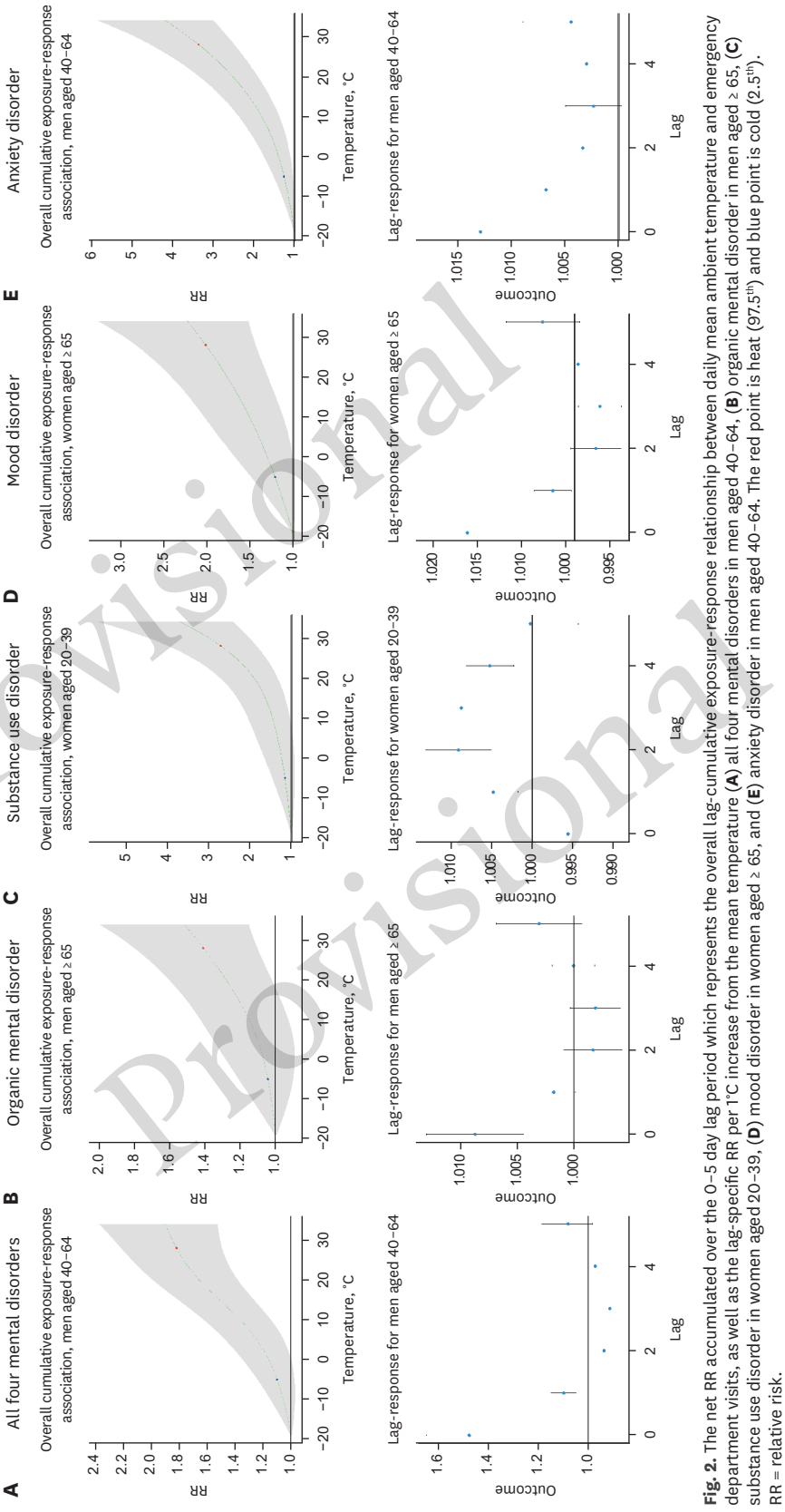

Fig. 2. The net RR accumulated over the 0–5 day lag period which represents the overall lag-cumulative exposure-response relationship between daily mean ambient temperature and emergency department visits, as well as the lag-specific RR per 1°C increase from the mean temperature (**A**) all four mental disorders in men aged 40–64, (**B**) organic mental disorder in men aged ≥ 65, (**C**) substance use disorder in women aged 20–39, (**D**) mood disorder in women aged ≥ 65, and (**E**) anxiety disorder in men aged 40–64. The red point is heat (97.5th) and blue point is cold (2.5th).
RR = relative risk.

https://doi.org/10.3346/jkms.2026.41.e25

At extreme low temperatures, lag-cumulative risk estimates were generally imprecise, although elevated RRs were observed for anxiety disorder in men 20–39 (1.41; 95% CI, 1.12–1.78) and for OMD (2.15; 95% CI, 1.53–3.01) and MD (5.14; 95% CI, 3.79–6.97) in men 0–19 (**Table 2**, **Fig. 3**). Lower risks of ED-visits were observed for OMD (0.51; 95% CI, 0.37–0.70) and MD (0.36; 95% CI, 0.28–0.46) among 0–19 year-old women.

Evaluation of the robustness of findings

A series of sensitivity analyses confirmed the robustness of our findings. First, extending the lag period to 7 days yielded similar RRs to the main analysis (**Supplementary Table 5**). Second, including individual air pollutants in the model did not alter the results, with consistent RRs for $PM_{2.5}$ (2.35; 95% CI, 1.95–2.82) and NO_2 (2.19; 95% CI, 1.83–2.63; **Supplementary Table 6**). Third, applying 8 degrees of freedom for year showed comparable results to the main analysis for all outcomes (**Supplementary Table 7**). Finally, using a constrained DLM for air pollutants did not significantly affect the direction or magnitude of the associations (**Supplementary Table 8**).

DISCUSSION

Leveraging national population data, the study found that extreme ambient temperatures, both high and low, were associated with increased risk of ED visits for specific mental disorders. We observed some positive associations between ambient temperatures and anxiety disorder-related ED visits. Notably, higher ambient temperatures were associated with higher risks for anxiety disorder, particularly among young and middle-aged men.

Table 2. Lag-cumulative relative risk and 95% confidence intervals about emergency department visit for types of mental disorder for heat and cold

Mental disorders	Heat (97.5th)			Cold (2.5th)		
	Total	Men	Women	Total	Men	Women
All four mental disorders, yr	1.53 (1.39–1.69)	1.69 (1.47–1.94)	1.36 (1.19–1.55)	1.02 (0.96–1.09)	1.09 (1.00–1.18)	0.96 (0.89–1.04)
0–19	1.72 (1.36–2.18)	1.96 (1.31–2.93)	0.73 (0.50–1.08)	1.00 (0.87–1.16)	1.80 (1.41–2.30)	0.75 (0.59–0.94)
20–39	1.70 (1.46–1.98)	1.67 (1.23–2.26)	1.80 (1.35–2.41)	1.04 (0.94–1.14)	0.94 (0.78–1.13)	1.06 (0.88–1.26)
40–64	1.74 (1.49–2.04)	1.82 (1.50–2.22)	1.63 (1.31–2.03)	1.04 (0.95–1.15)	1.10 (0.98–1.24)	0.97 (0.85–1.11)
65 and over	1.37 (1.20–1.57)	1.50 (1.23–1.83)	1.29 (1.09–1.52)	1.02 (0.94–1.11)	1.06 (0.94–1.19)	1.00 (0.90–1.10)
Organic mental disorder, yr	1.16 (0.96–1.40)	1.34 (1.05–1.71)	1.07 (0.86–1.32)	0.96 (0.86–1.08)	1.06 (0.91–1.23)	0.94 (0.82–1.07)
0–19	0.70 (0.42–1.17)	0.86 (0.50–1.47)	0.65 (0.39–1.09)	1.19 (0.87–1.64)	2.15 (1.53–3.01)	0.51 (0.37–0.70)
20–39	0.33 (0.21–0.53)	0.09 (0.05–0.14)	1.28 (0.89–1.85)	0.52 (0.39–0.69)	0.96 (0.72–1.28)	0.16 (0.12–0.22)
40–64	1.44 (1.01–2.05)	1.49 (1.01–2.21)	1.29 (0.84–1.97)	1.22 (0.98–1.51)	1.22 (0.96–1.55)	1.18 (0.91–1.52)
65 and over	1.22 (1.04–1.44)	1.41 (1.11–1.80)	1.13 (0.92–1.38)	1.00 (0.91–1.10)	1.05 (0.90–1.21)	0.98 (0.87–1.10)
Substance use disorder, yr	1.53 (1.24–1.88)	1.56 (1.26–1.93)	1.40 (1.06–1.86)	1.00 (0.88–1.13)	1.06 (0.93–1.20)	0.99 (0.83–1.18)
0–19	1.47 (1.00–2.19)	1.52 (1.00–2.32)	1.32 (0.85–2.05)	1.09 (0.86–1.38)	1.01 (0.79–1.30)	1.17 (0.90–1.52)
20–39	1.46 (1.06–2.02)	0.96 (0.66–1.39)	2.72 (1.85–3.99)	0.90 (0.74–1.10)	0.74 (0.60–0.93)	1.17 (0.92–1.47)
40–64	1.43 (1.14–1.78)	1.52 (1.19–1.94)	1.35 (0.96–1.90)	1.03 (0.90–1.17)	1.08 (0.94–1.26)	0.92 (0.75–1.13)
65 and over	1.72 (1.23–2.40)	1.98 (1.38–2.86)	1.19 (0.78–1.83)	1.13 (0.92–1.39)	1.13 (0.91–1.41)	1.11 (0.86–1.44)
Mood disorder, yr	1.34 (1.02–1.75)	1.17 (0.85–1.61)	1.38 (1.06–1.81)	1.13 (0.96–1.34)	1.03 (0.85–1.25)	1.12 (0.95–1.31)
0–19	0.41 (0.27–0.61)	6.62 (4.04–10.86)	0.16 (0.10–0.25)	0.69 (0.54–0.88)	5.14 (3.79–6.97)	0.36 (0.28–0.46)
20–39	1.03 (0.74–1.43)	0.77 (0.52–1.14)	1.28 (0.89–1.85)	0.96 (0.79–1.17)	0.66 (0.52–0.83)	1.22 (0.98–1.52)
40–64	1.27 (0.93–1.74)	1.20 (0.81–1.79)	1.24 (0.87–1.77)	1.04 (0.86–1.26)	0.98 (0.77–1.25)	1.04 (0.84–1.30)
65 and over	1.70 (1.26–2.29)	1.26 (0.86–1.86)	2.00 (1.42–2.80)	1.19 (0.99–1.43)	1.14 (0.90–1.44)	1.21 (0.98–1.48)
Anxiety disorder, yr	2.25 (1.87–2.71)	2.96 (2.32–3.79)	1.68 (1.38–2.05)	1.28 (1.10–1.49)	1.21 (1.04–1.40)	0.93 (0.82–1.05)
0–19	1.66 (1.08–2.57)	2.66 (1.67–4.26)	1.25 (0.78–2.01)	1.45 (1.11–1.90)	2.29 (1.72–3.06)	1.07 (0.80–1.44)
20–39	2.38 (1.77–3.21)	4.02 (2.77–5.85)	1.65 (1.17–2.32)	1.17 (0.98–1.41)	1.41 (1.12–1.78)	1.02 (0.83–1.27)
40–64	2.33 (1.87–2.91)	3.37 (2.49–4.55)	1.86 (1.42–2.42)	1.07 (0.93–1.22)	1.26 (1.05–1.52)	0.94 (0.80–1.11)
65 and over	1.64 (1.26–2.13)	1.75 (1.22–2.51)	1.55 (1.15–2.08)	0.96 (0.82–1.13)	1.06 (0.85–1.32)	0.91 (0.76–1.09)

Adjusted for relative humidity, $PM_{2.5}$, NO_2, seasonal, and day of week. All relative risks were calculated using a consistent minimum risk ambient temperature across all four mental disorders, as well as across different age and sex groups. Lag period was 0–5 days for ambient temperature, relative humidity, $PM_{2.5}$, and NO_2.

https://doi.org/10.3346/jkms.2026.41.e25

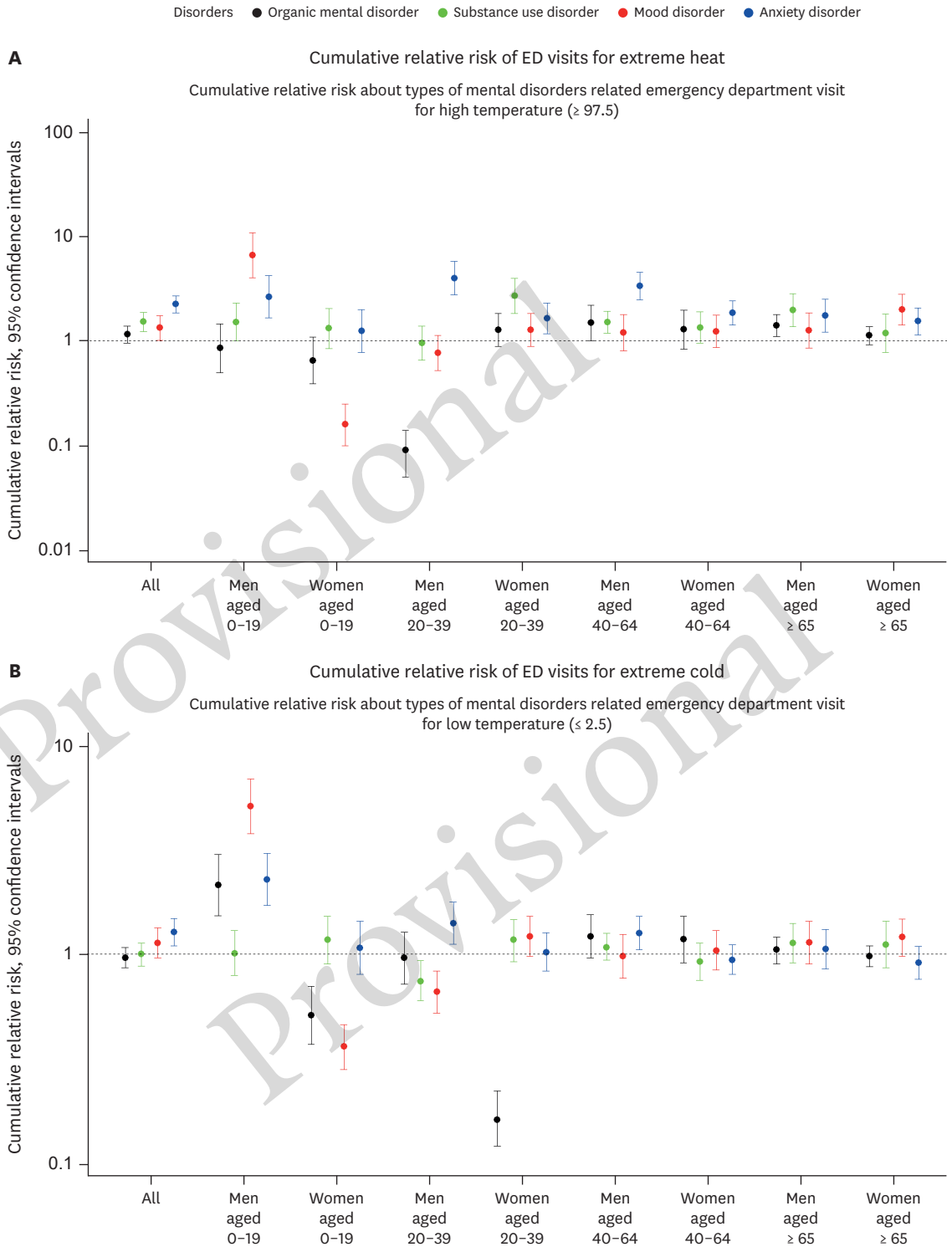

Fig. 3. Relative risk about four mental disorders-related emergency department visits for (**A**) extremely high (97.5%) and (**B**) low (2.5%) ambient temperatures, compared to the minimum risk ambient temperature.
ED = emergency department.

https://doi.org/10.3346/jkms.2026.41.e25

While the impact of extremely low ambient temperatures was less pronounced, young and middle-aged men still a high-risk group for anxiety disorder. These findings underscore the importance of considering the varying impact of climate change on mental health and developing more tailored strategies to effectively mitigate these risks.

The positive association between high ambient temperatures and ED visits for all four mental disorders generally aligns with previous research. For instance, a Canadian study linked exposure to extreme heat to increased risks of SUDs, dementia, neurotic disorders, and schizophrenia.[27] Another studies found higher risks for SUD, MD, schizophrenia, and dementia.[34,36] However, while these studies generally concur, they diverge in terms of the association with extremely low ambient temperatures and age or sex-specific vulnerabilities. This discrepancy may be attributed to differences in ambient temperature distribution, emergency healthcare systems, and study population characteristics. The average daily ambient temperature in our study (13.2°C) was higher than that of Canadian (6.0°C), US (9.3°C), and China (12.1°C) studies. Additionally, while there was a finding that extremely low ambient temperatures increased the risk of ED visits due to a 14-lag day,[34] there was also a finding that the number of psychiatric patients visiting the ED decreased in extremely low ambient temperatures.[37] Our study replicates the positive association between extremely low ambient temperatures and ED visits for anxiety disorder. A study of Toronto residents observed an increase in ED visits due to anxiety disorder at extremely low ambient temperatures.[38]

The positive associations between extremely high ambient temperatures and mental disorder-related ED visits may reflect thermoregulatory vulnerability caused by psychotropic medications. Medications such as antipsychotics, anticholinergics, antidepressants, tranquilizers, and mood stabilizers used to treat conditions such as anxiety disorders are drugs that cause patients to sweat or increase heat production.[39] People who regularly take opioids have found that their efficacy decreases in warmer weather, and they are more likely to take higher doses on hot days, which may lead to more ED visits due to SUD.[40] High temperatures affect the levels and balance of serotonin and dopamine, neurotransmitters in the brain that play a role in mood, cognitive function, and performing complex tasks, and heat exposure can cause significant neuroinflammatory responses and neuronal cell death in the hippocampus of the brain. This may explain the increased ED visits for acute events related to mood disorders and dementia.[41] These disease characteristics may explain why they have been shown to increase the risk of ED visits during extreme heat. However, findings on vulnerability across sex, age, and mental disorder types were inconsistent. Regarding the short-term impact of ambient temperature on mental disorder hospitalizations, a study in Lisbon, Portugal, found that women were more vulnerable than men.[42] In Shanghai, China, the association between high ambient temperature and mental disorder hospitalizations was observed only in women and for those aged > 44 years.[43] An Australian study observed more pronounced effect of high ambient temperature among men aged > 75 years, especially with schizophrenia, schizotypal, and delusional disorders.[39] This inconsistency reflects variations in the epidemiology of mental disorders and gender-specific factors influencing the exacerbation of these disorders across different countries. SUD-related ED visits were more frequent for men than for women at any age group, while MD-related ED visits were more common among women.[44] In general, however, women are more likely to visit ED due to mental problems than men.[45] Sex differences in mental disorders have been generally observed with varying prevalence by sex, particularly when categorized into internalizing and externalizing disorders.[46] The incidence of mental disorders generally decreases in older age groups, contributing to the difference in the pattern of association between ambient temperature and mental disorders.[47]

https://doi.org/10.3346/jkms.2026.41.e25

The mechanism underlying sex-specific vulnerability to extreme heat remains unclear. Biological differences between men and women, including hormonal status, may explain sex-based differences in ambient temperature regulation and heat stress response. For example, the women reproductive hormone estrogen alters thermoregulation, promoting heat dissipation and tending to lower body temperature, providing a protective effect against heat stress.[48,49] On the other hand, heat stress increases testicular temperature and interferes with testosterone synthesis, which can negatively affect male fertility.[50] Social gender roles can further exacerbate these vulnerabilities. Many men may be at higher risk of death from heatstroke because they tend to have outdoor jobs or engage in more physical activities that expose them to extreme ambient temperatures.[51] Women often spend time in indoor spaces without adequate air flow, which exposes them to more heat than men, making them more vulnerable to heat stress.[52] Understanding these mechanisms will aid in developing more effective preventive strategies to address extreme ambient temperatures for both men and women.

This study has several limitations. First, due to the case-based nature of the data, individual-level analysis was not possible because the same person was recognized as a different person even if they visit on different days. However, by analyzing the municipality-level incidence that include individual-level information such as sex and age, the potential bias attributed to ED visit by the same individual would have been minimized.[53] Second, we could not take into account of the severity of mental disorders. Nonetheless, our study focusing on ED visits provides a robust measure of acute exacerbations requiring immediate treatment. Third, detailed information on specific subtypes of mental disorders was lacking. However, our classification still provides valuable insight into the differential impact of ambient temperature on major mental disorders. Lastly, to determine the effects of extremely low temperatures, long-term exposure to extremely low temperatures would be desirable, but since we only examined short-term effects, there is a possibility that the effects of extremely low temperatures may be inaccurate.[54] However, looking at short-term effects of extremely low temperatures can also provide important insights and serve as a basis for future related research.

Both extremely high and low ambient temperatures were associated with increased risk of mental disorder-related ED visits. Specifically, extremely high ambient temperatures were associated with higher risk of anxiety disorder in young and middle-aged men. Developing tailored climate change adaptation strategies that account for the differential vulnerabilities of different population groups, particularly those with specific mental health conditions would be necessary.

ACKNOWLEDGMENTS

This research used the National Emergency Department Information System (NEDIS) data (N20235021111) provided by the National Medical Center of Korea.

SUPPLEMENTARY MATERIALS

Supplementary Table 1

Eleven subgroups of mental, behavioral and neurodevelopmental disorders (ICD-10 codes of F01–F99)

Supplementary Table 2
Characteristics of the study population with emergency department visits due to three common mental disorders from Jan 1, 2015, to Dec 31, 2021 in South Korea, the National Emergency Department Information System

Supplementary Table 3
Daily concentration of ambient temperature, relative humidity, and air pollutants of emergency department visit cases for types of mental disorder from 2015 to 2021

Supplementary Table 4
Overall mean district-level incidence rate of mental disorder-related emergency department visits per 100,000 person-days, stratified type of mental disorders, sex, and age

Supplementary Table 5
Sensitivity analysis for lag-cumulative relative risk of emergency department visits due to different mental disorders under extreme heat and cold, with lag lengths of 0–7 days

Supplementary Table 6
Sensitivity analysis for lag-cumulative relative risk of emergency department visits for anxiety disorder under extreme heat and cold, when adjusting for single air pollutant ($PM_{2.5}$, or NO_2)

Supplementary Table 7
Sensitivity analysis for lag-cumulative relative risk of emergency department visit due to different mental disorders under extreme heat and cold, when applying 8 degree of freedom for year

Supplementary Table 8
Sensitivity analysis for lag-cumulative relative risk of emergency department visits due to different mental disorders under extreme heat and cold, when applying a constrained distributed lag linear model for air pollutants.

Supplementary Fig. 1
Directed acyclic graph for the causal relationship between variables.

Supplementary Fig. 2
Results of the analysis on the association between ambient temperature and emergency department visits presented as relative ratios: all three mental disorders (far left), organic mental disorders (second from left), substance use disorder (third from left), mood disorder (fourth from left), and anxiety disorder for total population. The top row of panels displays the net risk relative to –19.5°C cumulated in the lag period 0–5 days as overall cumulative exposure–response associations. The red point indicates extreme heat (97.5th) and the blue point presents extreme cold (2.5th). The bottom row of panels shows instead the full exposure-lag-response associations, represented as the bi-dimensional risk surface.

Supplementary Fig. 3
Results of the analysis on the association between ambient temperature and emergency department visits presented as relative ratios: all three mental disorders (far left), organic mental disorders (second from left), substance use disorder (third from left), mood disorder (fourth from left), and anxiety disorder (far right) for men aged 0–19. The top row of panels

displays the net risk cumulated in the lag period 0–5 days as overall cumulative exposure–response associations. The red point indicates extreme heat (97.5th) and the blue point denotes extreme cold (2.5th). The bottom row of panels shows instead the full exposure-lag-response associations, represented as the bi-dimensional risk surface.

Supplementary Fig. 4

Results of the analysis on the association between ambient temperature and emergency department visits presented as relative ratios: all three mental disorders (far left), organic mental disorders (second from left), substance use disorder (third from left), mood disorder (fourth from left), and anxiety disorder for women aged 0–19. The top row of panels displays the net risk cumulated in the lag period 0–5 days as overall cumulative exposure–response associations. The red point indicates extreme heat (97.5th) and the blue point denotes extreme cold (2.5th). The bottom row of panels shows instead the full exposure-lag-response associations, represented as the bi-dimensional risk surface.

Supplementary Fig. 5

Results of the analysis on the association between ambient temperature and emergency department visits presented as relative ratios: all three mental disorders (far left), organic mental disorders (second from left), substance use disorder (third from left), mood disorder (fourth from left), and anxiety disorder for men aged 20–39. The top row of panels displays the net risk cumulated in the lag period 0–5 days as overall cumulative exposure–response associations. The red point indicates extreme heat (97.5th) and the blue point denotes extreme cold (2.5th). The bottom row of panels shows instead the full exposure-lag-response associations, represented as the bi-dimensional risk surface.

Supplementary Fig. 6

Results of the analysis on the association between ambient temperature and emergency department visits presented as relative ratios: all three mental disorders (far left), organic mental disorders (second from left), substance use disorder (third from left), mood disorder (fourth from left), and anxiety disorder for men aged 40–64. The top row of panels displays the net risk cumulated in the lag period 0–5 days as overall cumulative exposure–response associations. The red point indicates extreme heat (97.5th) and the blue point denotes extreme cold (2.5th). The bottom row of panels shows instead the full exposure-lag-response associations, represented as the bi-dimensional risk surface.

Supplementary Fig. 7

Results of the analysis on the association between ambient temperature and emergency department visits presented as relative ratios: all three mental disorders (far left), organic mental disorders (second from left), substance use disorder (third from left), mood disorder (fourth from left), and anxiety disorder for women aged 20–39. The top row of panels displays the net risk cumulated in the lag period 0–5 days as overall cumulative exposure–response associations. The red point indicates extreme heat (97.5th) and the blue point denotes extreme cold (2.5th). The bottom row of panels shows instead the full exposure-lag-response associations, represented as the bi-dimensional risk surface.

Supplementary Fig. 8

Results of the analysis on the association between ambient temperature and emergency department visits presented as relative ratios: all three mental disorders (far left), organic mental disorders (second from left), substance use disorder (third from left), mood disorder

(fourth from left), and anxiety disorder for women aged 40–64. The top row of panels displays the net risk cumulated in the lag period 0–5 days as overall cumulative exposure–response associations. The red point indicates extreme heat (97.5th) and the blue point denotes extreme cold (2.5th). The bottom row of panels shows instead the full exposure-lag-response associations, represented as the bi-dimensional risk surface.

Supplementary Fig. 9

Results of the analysis on the association between ambient temperature and emergency department visits presented as relative ratios: all three mental disorders (far left), organic mental disorders (second from left), substance use disorder (third from left), mood disorder (fourth from left), and anxiety disorder for men aged ≥ 65. The top row of panels displays the net risk cumulated in the lag period 0–5 days as overall cumulative exposure–response associations. The red point indicates extreme heat (97.5th) and the blue point denotes extreme cold (2.5th). The bottom row of panels shows instead the full exposure-lag-response associations, represented as the bi-dimensional risk surface.

Supplementary Fig. 10

Results of the analysis on the association between ambient temperature and emergency department visits presented as relative ratios: all three mental disorders (far left), organic mental disorders (second from left), substance use disorder (third from left), mood disorder (fourth from left), and anxiety disorder for women aged ≥ 65. The top row of panels displays the net risk cumulated in the lag period 0–5 days as overall cumulative exposure–response associations. The red point indicates extreme heat (97.5th) and the blue point denotes extreme cold (2.5th). The bottom row of panels shows instead the full exposure-lag-response associations, represented as the bi-dimensional risk surface.

REFERENCES

1. Weilnhammer V, Schmid J, Mittermeier I, Schreiber F, Jiang L, Pastuhovic V, et al. Extreme weather events in europe and their health consequences - a systematic review. *Int J Hyg Environ Health* 2021;233:113688. PUBMED | CROSSREF
2. Ebi KL, Capon A, Berry P, Broderick C, de Dear R, Havenith G, et al. Hot weather and heat extremes: health risks. *Lancet* 2021;398(10301):698-708. PUBMED | CROSSREF
3. Lavigne E, Gasparrini A, Wang X, Chen H, Yagouti A, Fleury MD, et al. Extreme ambient temperatures and cardiorespiratory emergency room visits: assessing risk by comorbid health conditions in a time series study. *Environ Health* 2014;13(1):5. PUBMED | CROSSREF
4. Nori-Sarma A, Sun S, Sun Y, Spangler KR, Oblath R, Galea S, et al. Association between ambient heat and risk of emergency department visits for mental health among US adults, 2010 to 2019. *JAMA Psychiatry* 2022;79(4):341-9. PUBMED | CROSSREF
5. Basu R, Gavin L, Pearson D, Ebisu K, Malig B. Examining the association between apparent temperature and mental health-related emergency room visits in California. *Am J Epidemiol* 2018;187(4):726-35. PUBMED | CROSSREF
6. Monti K, Bachi K, Gray M, Mahajan V, Sweeney G, Oprescu AM, et al. Data mining-based clinical profiles of substance use-related emergency department utilizers. *Am J Emerg Med* 2022;53:104-11. PUBMED | CROSSREF
7. Oyama O, Paltoo C, Greengold J. Somatoform disorders. *Am Fam Physician* 2007;76(9):1333-8. PUBMED
8. Meade RD, Akerman AP, Notley SR, McGinn R, Poirier P, Gosselin P, et al. Physiological factors characterizing heat-vulnerable older adults: a narrative review. *Environ Int* 2020;144:105909. PUBMED | CROSSREF
9. Bernstein AS, Sun S, Weinberger KR, Spangler KR, Sheffield PE, Wellenius GA. Warm season and emergency department visits to US children's hospitals. *Environ Health Perspect* 2022;130(1):17001. PUBMED | CROSSREF

10. Montes J, Serrano C, Pascual-Sanchez A. The influence of weather on the course of bipolar disorder: a systematic review. *Eur J Psychiatry* 2021;35(4):261-73. CROSSREF
11. Park J, Kim A, Bell ML, Kim H, Lee W. Heat and hospital admission via the emergency department for people with intellectual disability, autism, and mental disorders in South Korea: a nationwide, time-stratified, case-crossover study. *Lancet Psychiatry* 2024;11(5):359-67. PUBMED | CROSSREF
12. Folkerts MA, Bröde P, Botzen WJW, Martinius ML, Gerrett N, Harmsen CN, et al. Sex differences in temperature-related all-cause mortality in the Netherlands. *Int Arch Occup Environ Health* 2022;95(1):249-58. PUBMED | CROSSREF
13. Park JS, Lee BK, Ko SK, Ro YS. Recent status of sudden cardiac arrests in emergency medical facilities: a report from the National Emergency Department Information System (NEDIS) of Korea, 2018-2022. *Clin Exp Emerg Med* 2023;10(S):S36-41. PUBMED | CROSSREF
14. Oh M, Lee JH, Jeon BU, Jeong TO, Heo T, Lee S. Usage patterns of emergency medical services in Korea: analysis of patient flow. *Chin Med J (Engl)* 2019;132(3):259-68. PUBMED | CROSSREF
15. Yoon H, Yoon S, Lee J, Lee T, Kwon Y, Kim J. *Emergency Medical Center Evaluation Report*. Seoul, Korea: National Emergency Medical Center & Ministry of Health and Welfare; 2015.
16. Niu L, Girma B, Liu B, Schinasi LH, Clougherty JE, Sheffield P. Temperature and mental health-related emergency department and hospital encounters among children, adolescents and young adults. *Epidemiol Psychiatr Sci* 2023;32:e22. PUBMED | CROSSREF
17. Korean Statistical Information Service (KOSIS). Korean Statistical Information Service. https://kosis.kr/eng/. Updated 2024. Accessed September 30, 2024.
18. Ibebuchi CC, Lee CC, Silva A, Sheridan SC. Evaluating apparent temperature in the contiguous United States from four reanalysis products using Artificial Neural Networks. *J Geophys Res Mach Learn Comput* 2024;1(2):e2023JH000102. CROSSREF
19. Korea Meteorological Administration. Observation Network. https://www.kma.go.kr/eng/biz/observation_01.jsp. Updated 2024. Accessed September 30, 2024.
20. Buoli M, Grassi S, Caldiroli A, Carnevali GS, Mucci F, Iodice S, et al. Is there a link between air pollution and mental disorders? *Environ Int* 2018;118:154-68. PUBMED | CROSSREF
21. Lee W, Seo D, Myung W, Prifti K, Kang C, Jang H, et al. Association of long-term exposure to air pollution with chronic sleep deprivation in adults from 141 urban communities in South Korea: a community-level longitudinal study, 2008–2016. *Epidemiol Psychiatr Sci* 2021;30:e57. CROSSREF
22. Kim Y, Oh J, Kim S, Kim A, Park J, Ahn S, et al. Relationship between short-term ozone exposure, cause-specific mortality, and high-risk populations: a nationwide, time-stratified, case-crossover study. *Environ Res* 2024;261:119712. PUBMED | CROSSREF
23. Min J, Lee W, Kang DH, Ahn S, Kim A, Kang C, et al. Air pollution and acute kidney injury with comorbid disease: a nationwide case-crossover study in South Korea. *Environ Res* 2024;260:119608. PUBMED | CROSSREF
24. Ahn S, Kang C, Oh J, Yun H, Ahn S, Kim A, et al. Heterogeneous associations between short-term ambient ozone exposure and morbidities from infants to seniors: a nationwide case-crossover study in South Korea. *Journal of Hazardous Materials Advances* 2025;17:100531. CROSSREF
25. Deng X, Brotzge J, Tracy M, Chang HH, Romeiko X, Zhang W, et al. Identifying joint impacts of sun radiation, temperature, humidity, and rain duration on triggering mental disorders using a high-resolution weather monitoring system. *Environ Int* 2022;167:107411. PUBMED | CROSSREF
26. Gasparrini A. The case time series design. *Epidemiology* 2021;32(6):829-37. PUBMED | CROSSREF
27. Lavigne E, Maltby A, Côté JN, Weinberger KR, Hebbern C, Vicedo-Cabrera AM, et al. The effect modification of extreme temperatures on mental and behavior disorders by environmental factors and individual-level characteristics in Canada. *Environ Res* 2023;219:114999. PUBMED | CROSSREF
28. Fujibe F. Day-of-the-week variations of urban temperature and their long-term trends in Japan. *Theor Appl Climatol* 2010;102(3-4):393-401. CROSSREF
29. Lawrence EN. Urban climate and day of the week. *Atmos Environ* 1971;5(11):935-48. CROSSREF
30. Simmonds I, Keay K. Weekly cycle of meteorological variations in Melbourne and the role of pollution and anthropogenic heat release. *Atmos Environ* 1997;31(11):1589-603. CROSSREF
31. Sun Y, Milando CW, Spangler KR, Wei Y, Schwartz J, Dominici F, et al. Short term exposure to low level ambient fine particulate matter and natural cause, cardiovascular, and respiratory morbidity among US adults with health insurance: case time series study. *BMJ* 2024;384:e076322. PUBMED | CROSSREF
32. Kim S, Byun G, Lee JT. Association between non-optimal temperature and cardiovascular hospitalization and its temporal variation at the intersection of disability. *Sci Total Environ* 2023;904:166874. PUBMED | CROSSREF

33. Arbuthnott K, Hajat S, Heaviside C, Vardoulakis S. Changes in population susceptibility to heat and cold over time: assessing adaptation to climate change. *Environ Health* 2016;15 Suppl 1(Suppl 1):33. PUBMED | CROSSREF
34. Yoo EH, Eum Y, Roberts JE, Gao Q, Chen K. Association between extreme temperatures and emergency room visits related to mental disorders: a multi-region time-series study in New York, USA. *Sci Total Environ* 2021;792:148246. PUBMED | CROSSREF
35. Sun CF, Lin Y, Pola A, Kablinger A, Trestman R. Benzodiazepine prescription for anxiety disorders increase the risk of substance use disorders: a retrospective cohort study. *Eur Psychiatry* 2023;66(Suppl 1):S324. CROSSREF
36. Niu Y, Gao Y, Yang J, Qi L, Xue T, Guo M, et al. Short-term effect of apparent temperature on daily emergency visits for mental and behavioral disorders in Beijing, China: a time-series study. *Sci Total Environ* 2020;733:139040. PUBMED | CROSSREF
37. Brandl EJ, Lett TA, Bakanidze G, Heinz A, Bermpohl F, Schouler-Ocak M. Weather conditions influence the number of psychiatric emergency room patients. *Int J Biometeorol* 2018;62(5):843-50. PUBMED | CROSSREF
38. Wang X, Lavigne E, Ouellette-kuntz H, Chen BE. Acute impacts of extreme temperature exposure on emergency room admissions related to mental and behavior disorders in Toronto, Canada. *J Affect Disord* 2014;155:154-61. PUBMED | CROSSREF
39. Hansen A, Bi P, Nitschke M, Ryan P, Pisaniello D, Tucker G. The effect of heat waves on mental health in a temperate Australian city. *Epidemiology* 2008;116(10):1369-75. PUBMED | CROSSREF
40. Parks RM, Rowland ST, Do V, Boehme AK, Dominici F, Hart CL, et al. The association between temperature and alcohol- and substance-related disorder hospital visits in New York State. *Commun Med (Lond)* 2023;3(1):118. PUBMED | CROSSREF
41. Liu J, Varghese BM, Hansen A, Xiang J, Zhang Y, Dear K, et al. Is there an association between hot weather and poor mental health outcomes? A systematic review and meta-analysis. *Environ Int* 2021;153:106533. PUBMED | CROSSREF
42. Almendra R, Loureiro A, Silva G, Vasconcelos J, Santana P. Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon. *Sci Total Environ* 2019;647:127-33. PUBMED | CROSSREF
43. Peng Z, Wang Q, Kan H, Chen R, Wang W. Effects of ambient temperature on daily hospital admissions for mental disorders in Shanghai, China: a time-series analysis. *Sci Total Environ* 2017;590-591:281-6. PUBMED | CROSSREF
44. Brathwaite D, Waller AE, Gaynes B, Deselm TM, Bischof JJ, Tintinalli J, et al. Age and sex trends among mental health-related emergency department visits in North Carolina. *Healthcare Analytics* 2022;2:100056. CROSSREF
45. Bowden N, Hedquist A, Dai D, Abiona O, Bernal-Delgado E, Blankart CR, et al. International comparison of hospitalizations and emergency department visits related to mental health conditions across high-income countries before and during the COVID-19 pandemic. *Health Serv Res* 2024;59(6):e14386. PUBMED | CROSSREF
46. Boyd A, Van de Velde S, Vilagut G, de Graaf R, O'Neill S, Florescu S, et al. Gender differences in mental disorders and suicidality in Europe: results from a large cross-sectional population-based study. *J Affect Disord* 2015;173:245-54. PUBMED | CROSSREF
47. Plana-Ripoll O, Momen NC, McGrath JJ, Wimberley T, Brikell I, Schendel D, et al. Temporal changes in sex- and age-specific incidence profiles of mental disorders-a nationwide study from 1970 to 2016. *Acta Psychiatr Scand* 2022;145(6):604-14. PUBMED | CROSSREF
48. Charkoudian N, Stachenfeld N. Sex hormone effects on autonomic mechanisms of thermoregulation in humans. *Auton Neurosci* 2016;196:75-80. PUBMED | CROSSREF
49. Wong BJ, Hollowed CG. Current concepts of active vasodilation in human skin. *Temperature* 2016;4(1):41-59. PUBMED | CROSSREF
50. Ko SH. Effects of heat stress-induced sex hormone dysregulation on reproduction and growth in male adolescents and beneficial foods. *Nutrients* 2024;16(17):3032. PUBMED | CROSSREF
51. World Health Organization. *Gender, Climate Change and Health.* Geneva, Switzerland: World Health Organization; 2014.
52. Otto IM, Reckien D, Reyer CP, Marcus R, Le Masson V, Jones L, et al. Social vulnerability to climate change: a review of concepts and evidence. *Reg Environ Change* 2017;17(6):1651-62. CROSSREF
53. Elliott P, Wartenberg D. Spatial epidemiology: current approaches and future challenges. *Environ Health Perspect* 2004;112(9):998-1006. PUBMED | CROSSREF
54. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *Lancet* 2015;386(9991):369-75. PUBMED | CROSSREF