International Journal of Emergency Medicine

RESEARCH

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Association of Wet-Bulb Globe Temperature with heat-related illness hospitalizations in Japan: a time-stratified, case-crossover study

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Abstract

Background Heat-related illnesses are a serious public health concern and are exacerbated by global warming. Wet-Bulb Globe Temperature (WBGT) is widely used as a heat stress indicator, but its clinical impact remains unclear. This study aimed to investigate the association between hourly variations in WBGT and the incidence of hospitalizations for heat-related illness in Japan using a nationwide database. By incorporating individual-level clinical data and performing stratified analyses, we sought to provide a more granular understanding of how heat exposure affects the risk of heat-related illness requiring hospitalization.

Methods We conducted a time-stratified, case-crossover study using data collected from July to September in 2020 and 2021 in the Heatstroke STUDY registry. The inclusion criteria were patients registered in the Heatstroke STUDY registry, specifically hospitalized patients with heat-related illness who were transported to participating hospitals during the study period. Hourly WBGT values were assigned based on the nearest monitoring station to each hospital. Conditional logistic regression and distributed lag models were used to estimate associations between WBGT and the risk of hospitalization.

Results A total of 1,653 heat-related illness hospitalizations were analyzed. The mean patient age was 67.9 years; 67.6% were male. Each 1 °C increase in WBGT at onset (hospital arrival) was associated with a significantly increased risk of hospitalization (OR 1.10, 95% CI: 1.05–1.15). The cumulative effect over the prior six hours was also significant (OR 1.56, 95% CI: 1.50–1.62). Compared with WBGT < 25 °C, adjusted ORs were 3.39 (25–27 °C), 8.81 (28–30 °C), and 22.10 (≥ 31 °C). Stratified analyses suggested stronger associations among several subgroups; however, only patients with mental disorders showed statistically significant effect modification, whereas elevated WBGT posed a risk across all groups.

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Conclusions Higher WBGT levels were associated with an increased risk of heat-related hospitalization. Although the effect appeared greater in some subgroups, only patients with mental disorders demonstrated statistically significant effect modification, suggesting elevated WBGT confers risk broadly.

Keywords Wet-Bulb Globe Temperature, Heat stroke, Heat related illness, Global warming

Background

Heat-related illnesses represent a major global public health concern and are linked to rising global temperatures [1]. As global warming progresses, heat waves have become more frequent and severe, leading to a higher risk of hospitalization for heat-related illnesses [2]. Among heat-related illnesses, heatstroke is the most severe symptom and is associated with significantly increased intensive care unit (ICU) admissions, morbidity, and mortality [3, 4]. According to Japanese guidelines, severe heat-related illness is defined as a core temperature ≥ 40 °C combined with a Glasgow Coma Scale (GCS) score ≤ 8 [5]. Preventing progression to severe illness requires early recognition of hazardous heat conditions and timely cooling interventions [5].

Wet-Bulb Globe Temperature (WBGT), calculated from wet-bulb, black-bulb, and dry-bulb temperatures, is a widely adopted measure of heat exposure and serves as the primary metric in Japan's Heat Health Warning System [6]. WBGT, with its practicality and validated utility, is broadly used to prevent heat-related illnesses across daily activities, sports, and occupational environments [7, 8]. The occupational heat safety guidelines incorporate WBGT for permissible work intensity and required rest periods, thereby protecting workers' health in high heat environments [9].

Evidence from occupational research demonstrated that WBGT reflects physiologically meaningful heat stress and predicts reduced work capacity, heat strain, and heat-related morbidity, reinforcing its validity as an exposure indicator beyond workplace environments [10, 11]. Despite its widespread application, relatively few studies have assessed WBGT from a meteorological or population health perspective, and little is known about how fluctuations in ambient WBGT translate into clinical outcomes or how patient-level modifiers (e.g., age, comorbidities, region, illness severity) influence vulnerability [12]. Therefore, this study aimed to investigate the association between hourly variations in WBGT and the incidence of hospitalized patients with heat-related illnesses in Japan, using a large, nationwide database. Furthermore, by incorporating individual level clinical data and stratifying analyses according to patient background characteristics, we sought to provide a more detailed and comprehensive understanding of the temporal effects of heat exposure on the risk of heat-related illness requiring hospitalization.

Methods

Study design

This study employed a time-stratified, case-crossover design, a case only variant of the crossover study, which is particularly well suited for assessing the acute effects of transient exposures [13]. In this design, exposure levels preceding the event of interest were compared with those during control periods in which no event occurred. Control periods were matched to the case period by day and time of the week and calendar month to control for temporal confounding.

Our study was approved by the Okayama University Ethics Committee (K2403-025). The requirement for written informed consent was waived because of the retrospective study design. The study adheres to Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Study population and data collection

This study utilized data from the Heatstroke STUDY, a prospective registry organized by the Heatstroke and Hypothermia Surveillance Committee of the Japanese Association for Acute Medicine (JAAM). The study protocol was approved by the ethics committees of participating institutions, including Teikyo University (approval no. 17-021-5). Data collection for the Heatstroke STUDY registry is conducted annually from July to September in the emergency departments of tertiary and regional secondary hospitals (165 institutions participated in 2020 and 2021). The registry includes hospitalized patients with heat-related illness who were transported to participating hospitals during the study period. Patients were identified by the attending physicians according to the 2015 JAAM Heatstroke Guidelines based on clinical symptoms such as hyperthermia, dehydration, dizziness, myalgia, headache, nausea, altered consciousness, or convulsions and a documented history of exposure to high environmental temperatures [14].

Medical records documented by attending physicians and emergency medical services were integrated and prospectively registered as patient data. Registry data were anonymized at each participating institution, entered into a password-protected secure electronic database, and subsequently provided to the research group as encrypted, de-identified datasets. Hospitals were assigned encrypted identification codes, and a separate correspondence file linking these codes to specific facilities was made available to the investigators. The

research team accessed this mapping file only for analytical purposes to confirm facility information, and all data were handled under appropriate information governance procedures. The collected data included demographic characteristics (age, sex, region, location [outdoor or indoor], medical history), time of hospital arrival, clinical findings at hospital arrival (vital signs, axillary or core temperature, kidney injury (serum creatinine > 1.2 mg/dL) or liver injury (total-bilirubin > 1.2 mg/dL) based on Sequential Organ Failure Assessment score, disseminated intravascular coagulation (DIC) score based on JAAM-DIC [15], severity of heat-related illness, use of mechanical ventilation and disposition (general ward admission, ICU admission, or death in the outpatient setting), patient outcomes (ICU mortality, in-hospital mortality, length of ICU stay or hospitalization).

Severity of heat-related illness was classified according to the 2024 Heat Illness Guidelines into four levels, from I (mild) to IV (most severe) [5]. Patients with a core temperature ≥ 40.0 °C and a GCS score ≤ 8 were defined as IV. If core temperature was not measured, surface body temperature was used as a proxy, and patients with a surface body temperature ≥ 40.0 °C and a GCS score ≤ 8 were classified as S-IV. Patients who did not meet those criteria were classified as III or lower. We classified region as follows: Northern Japan (Hokkaido and Tohoku regions), Eastern Japan (Kanto-Koshin, Hokuriku, and Tokai regions), and Western Japan (Kinki, Chugoku, Shikoku, and Kyushu regions), according to the regions defined by the Japan Meteorological Agency.

Meteorologic data

We assigned hourly WBGT values as the measurement recorded at the monitoring station nearest to each patient. WBGT is measured at a total of 841 stations throughout Japan; we obtained hourly WBGT values as well as the locations of each station from the Heat Illness Prevention Information website managed by the Ministry of the Environment. Geographic coordinates of the stations were obtained by cross-referencing station names with the Japan Meteorological Agency's Automated Meteorological Data Acquisition System. Because precise locations where heat-related illnesses occurred were unavailable, we used the location of the hospital to which each patient was transported and time of transport as a proxy for the site of occurrence. Hospital location data were obtained from 2020 National Land Numerical Information. We then spatially linked each hospital to its nearest WBGT observation station using vector-based Geographic Information System analysis using Quantum Geographic Information System version 3.40.4 to construct the dataset. A total of 88 WBGT observation stations were linked to hospitals (Supplement Fig. 1). All spatial data were standardized to the 2011 Japan Geodetic Datum.

Statistical analysis

Descriptive statistics summarize all patient demographics with continuously measured variables reported as mean ± standard deviation (SD) for normally distributed data. We first performed descriptive analyses, followed by conditional logistic regression to assess the association between a 1 °C increase in WBGT and heat-related illnesses. We adjusted for national holidays and estimated adjusted odds ratios (ORs) and corresponding 95% confidence intervals (CIs). To evaluate the temporal effects of exposure, we used a distributed lag model with up to six hours of lag time. The six-hour lag was selected, as it aligns with continuous segments of daily living, including morning, afternoon, and evening periods [16].

We further evaluated the associations between categorized WBGT exposure levels at the time of the case event (0 h) and the heat-related illnesses. WBGT values were categorized according to the heat illness prevention guidelines for sports activities issued by the Japan Sports Association [17]. These guidelines classify WBGT into five categories: <21 °C, 21–24 °C, 25–27 °C, 28–30 °C, and ≥ 31 °C. However, given the low incidence of ambulance transports for heat-related illness at WBGT < 21 °C during the summer in Japan, the < 21 °C and 21–24 °C categories were combined into a single < 25 °C category. Consequently, WBGT values were classified into four categories (< 25 °C, 25–27 °C, 28–30 °C, and ≥ 31 °C), with < 25 °C used as the reference group.

We also stratified the patients according to the following factors: age (7–64, and ≥ 65 years old); medical history (cardiovascular disease, mental disorder, other disorders), onset of timing (10:00–17:00, 18:00–9:00); region (Northern or Eastern, Western), and severity of heat-related illness (≤ III, S-Ⅳ or Ⅳ). Patients < 7 years old and those from Okinawa were excluded from the age and region analyses, respectively, due to small sample sizes. To assess effect modification, we tested the interaction between WBGT and each stratification variable by including interaction terms in the conditional logistic regression model. Statistical significance was assessed using the Wald test. A p-value < 0.05 was considered statistically significant.

To assess the robustness of our findings, we conducted three sensitivity analyses. First, we excluded death in the outpatient setting, as these patients may differ in clinical characteristics or data accuracy from hospitalized patients. Second, we excluded patients that occurred indoors, as WBGT primarily reflects outdoor environmental conditions and may not accurately represent indoor heat exposure. Third, we performed a distributed lag model with up to twelve hours of lag time.

All statistical analyses were conducted using Stata SE, version 18 (StataCorp, College Station, TX, USA).

Results

Of the 1,742 patients, 1,653 were included in the final analysis after excluding those with unknown time of hospital arrival ($n = 88$) and unknown hospital name ($n = 1$) (Fig. 1).

Table 1 presents baseline characteristics of the participants and meteorological conditions during the study period. The mean age was 67.9 ± 20.9 years, and 1,118 (67.6%) were men. The mean core body temperature was 39.1 ± 2.1 °C. Regarding severity of heat-related illness, 1,366 patients (82.6%) were classified as ≤ III, 76 (4.6%) as S-IV, and 133 (8.0%) as IV. Overall, 1,099 (66.5%) developed heat-related illness requiring hospitalization between 10:00 and 17:00, and 981 (59.3%) were from Eastern Japan. Mean WBGT and globe temperature during transport were 28.1 ± 3.4 °C and 39.3 ± 9.4 °C, respectively. Mechanical ventilation was required in 197 patients (11.9%), with a mean duration of 0.9 ± 5.6 days. Patient outcomes included 918 patients (55.5%) admitted to a general ward, 553 (33.5%) to ICU, and 37 (2.2%) who died in the outpatient setting (Table 2).

Results from the distributed lag models are shown in Fig. 2. For all patients hospitalized for heat-related illness, the OR for each 1 °C increase in WBGT was highest at 0 h before hospital arrival, with an OR of 1.10 (95% CI: 1.05–1.15), and the associations were slightly attenuated for 0 to six hours. Moreover, the total cumulative OR for heat-related illness over the 0 to six hour lag period was 1.56 (95% CI: 1.50–1.62). Table 3 shows the association between categorized WBGT levels and heat-related illness requiring hospitalization at 0 h before hospital arrival. Compared with WBGT < 25 °C, the adjusted ORs were 3.39 (95% CI: 2.73–4.22) for 25–27 °C, 8.81 (6.85–11.33) for 28–30 °C, and 22.10 (16.38–29.81) for ≥ 31 °C.

In subgroup analyses, higher WBGT levels were associated with an increased risk of heat-related hospitalization across all subgroup (Table 4). The association was notably stronger among patients with mental disorders, and this subgroup showed statistically significant effect modification (interaction $p = 0.02$).

The results did not change substantially in sensitivity analyses excluding either death in an outpatient setting or indoor patients (Supplemental Figs. 2 and 3, See Supplementary Tables 1 and 2). Furthermore, although elevated WBGT remained associated with hospitalization risk, the magnitude of the association progressively declined over the 12-hour lag window (Supplemental Fig. 4).

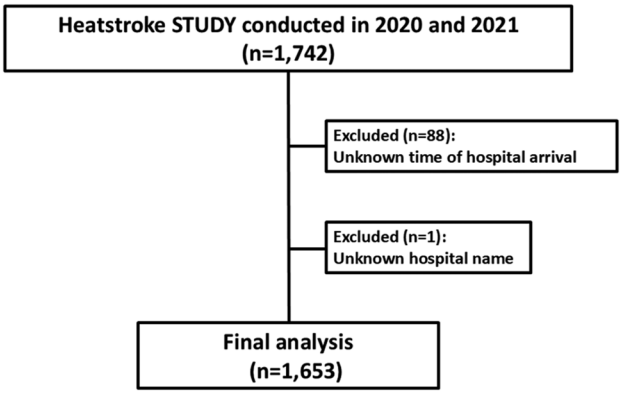

Fig. 1 Flowchart of study population

Discussion

In this national case-crossover study, higher WBGT levels were significantly associated with increased odds of hospitalization for heat-related illness, with the strongest effect observed at the time of presentation. Vulnerability appeared more pronounced among patients with mental illness, although these findings warrant cautious interpretation due to potential residual confounding.

WBGT may serve as a more sensitive and clinically relevant index than air temperature alone for predicting heat-related hospitalization risk [18]. Unlike air temperature, WBGT integrates multiple environmental stressors—humidity, radiant heat, and wind—providing a more comprehensive assessment of thermal burden [7]. In our study, WBGT at the time of onset showed a strong and dose-dependent association with the risk of hospitalization, with a 1 °C increase leading to a 10% increase in odds. These findings are consistent with prior research from South Korea, which demonstrated that WBGT-defined heatwaves were associated with a markedly higher risk of heat disorder–related hospitalization than temperature-based definitions [19]. Our findings, which showed that higher WBGT levels were associated with an increased risk of death in the outpatient setting, are consistent with previous research reporting that elevated WBGT also increases the risk of in-hospital mortality [20].

Previous studies have commonly examined the association between heat-related illnesses and daily maximum or minimum WBGT values, rather than assessing the impact of WBGT at the time of onset [21]. This limited temporal resolution has made it unclear whether WBGT levels at specific time points directly influence the incidence of heat-related illnesses. To our knowledge, few studies have evaluated WBGT exposure at an hourly scale in relation to the precise timing of patient presentation or ambulance transport [22]. Notably, a recent study on traumatic injuries founded that elevated WBGT levels were associated with an increased incidence of occupational injuries beginning one hour before the event, suggesting that heat exposure may exert effects even prior to onset [23]. Our findings provide novel insights into

Table 1 Patient characteristics of study population

	Patients (*n* = 1,653)
Age (year) ± SD	67.9 ± 20.9
Sex, n (%)	
Men	1,118 (67.6)
Women	524 (31.7)
Missing	11 (0.7)
Vital signs	
Surface body temperature (℃) ± SD	38.0 ± 2.3
Core body temperature (℃) ± SD	39.1 ± 2.1
GCS, n (%)	
3–8	384 (23.2)
9–13	328 (19.8)
14–15	857 (51.8)
Missing	84 (5.1)
sBP (mmHg) ± SD	125 ± 31
HR (beats/min) ± SD	105 ± 30
RR (breaths/min)) ± SD	24 ± 9
Severity, n (%)[a]	
≤III	1,366 (82.6)
S-IV or IV	209 (12.6)
Missing	78 (4.7)
Medical history	
Cardiovascular disease, n (%)	
Yes	111 (6.7)
No	1,478 (89.4)
Missing	78 (3.9)
Mental disorder, n (%)	
Yes	189 (11.4)
No	1,400 (84.7)
Missing	64 (3.9)
Other disorders, n (%)	
Yes	1,501 (90.8)
No	89 (5.4)
Missing	63 (3.8)
Onset, n (%)	
10:00–17:00	1,099 (66.5)
18:00–9:00	554 (33.5)
Region, n (%)[b]	
Northern Japan	227 (13.7)
Eastern Japan	981 (59.3)
Western Japan	422 (25.5)
Okinawa	23 (1.4)
Location, n (%)	
Outdoor	821 (49.7)
Indoor	802 (48.5)
Missing	30 (1.8)
Weather	
WBGT (℃) ± SD	28.1 ± 3.4
Tg (℃) ± SD	39.3 ± 9.4
Organ dysfunction on arrival	
Kidney injury, n (%)	968 (58.6)
Missing	49 (3.0)
Liver injury, n (%)	495 (29.9)

Table 1 (continued)

	Patients (*n* = 1,653)
Missing	91 (5.5)
Coagulopathy, n (%)	198 (12.0)
Missing	53 (3.2)
Admission, n (%)	
General ward	918 (55.5)
ICU	553 (33.5)
Death in the outpatient setting	37 (2.2)
Missing	145 (8.8)
Procedure	
Mechanical ventilation, n (%)	197 (11.9)
Missing	182 (11.0)
Duration of mechanical ventilation (day) ± SD	0.9 ± 5.7

GCS, Glasgow coma scale; HR, heart rate; ICU, intensive care unit; sBP, systolic blood pressure; RR, respiratory rate; SD, standard deviation; Tg, globe temperature; WBGT, Wet-Bulb Globe Temperature

a Patients with core temperature ≥ 40.0 °C and GCS ≤ 8 were classified as grade IV; if core temperature was unavailable, surface temperature ≥ 40.0 °C with GCS ≤ 8 was defined as S-IV. All others were classified as grade III or lower

b Japan was divided into three regions for analysis: Northern Japan (Hokkaido and Tohoku), Eastern Japan (Kanto-Koshin, Hokuriku, and Tokai), and Western Japan (Kinki, Chugoku, Shikoku, and Kyushu)

Table 2 Patient outcomes of study population

	Patients (*n* = 1,653)
Outcome	
Length of ICU stay (day) ± SD	1.9 ± 4.7
Length of hospitalization (day) ± SD	10.9 ± 14.8
ICU mortality, n (%)	72 (4.4)
Missing	277 (16.8)
In-hospital mortality, n (%)	106 (7.4)
Missing	219 (13.2)

ICU, intensive care unit; SD, standard deviation

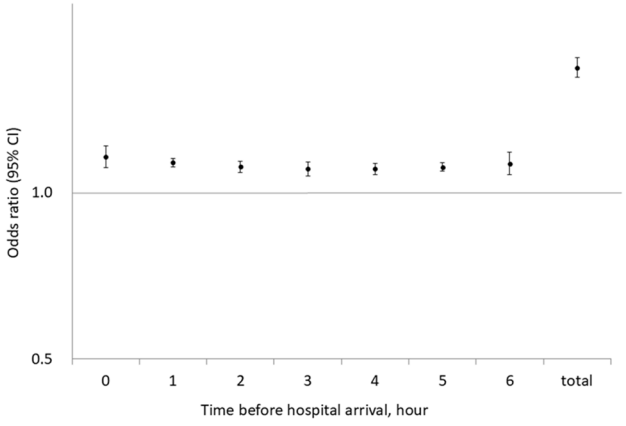

Fig. 2 Adjusted odds ratios and 95% CI for heat-related hospitalization per 1 ℃ increase in WBGT, evident even six hours before hospital arrival. WBGT, Wet-Bulb Globe Temperature; CI, confidence interval

the short-term temporal dynamics between heat exposure and clinical events, indicating that elevated WBGT can increase the risk of heat-related illness requiring hospitalization, even before development of symptoms.

Table 3 Association between WBGT category and incidence of hospitalized patients with heat-related illnesses at 0 h before exposure

Variables	Adjusted OR (95% CI)
WBGT category (℃)	
< 25℃	Reference
25–27℃	3.39 (2.73–4.22)
28–30℃	8.81 (6.85–11.33)
≥ 31℃	22.10 (16.38–29.81)

Adjusted for holidays

CI, confidence interval; WBGT, Wet-Bulb Globe Temperature

The observed lag effect of WBGT may be influenced by comorbidities and changes in living arrangements. Moreover, considering the cumulative effect of elevated WBGT across the entire exposure window, rather than at each individual hour, revealed a greater overall impact on hospitalization risk [24, 25]. This finding indicates that the health burden of heat exposure accumulates over several hours and that restricting analyses to a single time point may underestimate its true effects. Inappropriate indoor temperature regulation and poor adherence to medication could further delay the recognition of early symptoms, thereby contributing to the preceding intervals observed before hospitalization.

A recent systematic review demonstrated that seasonal heat acclimatization is commonly induced under summer conditions where the mean WBGT is approximately 25 °C, with physiological adaptations such as reduced resting core temperature, lower heart rate, and increased sweat rate observed in healthy adults [26]. Heat-related illnesses result from an imbalance between heat production and heat dissipation during physical exertion or exposure to high environmental temperatures. Based

Table 4 Association between WBGT category and hospitalized patients with heat-related illnesses: stratified analysis of adjusted odds ratio

	N	WBGT < 25 °C	WBGT: 25–27℃ (95% CI)	WBGT: 28–30℃ (95% CI)	WBGT ≥ 31℃ (95% CI)	*P* values for interaction
Age group (years)						0.37
7–64	535	Reference	3.25 (2.29–4.63)	7.56 (4.92–11.62)	19.90 (11.73–33.77)	
≥65	1,107	Reference	3.46 (2.62–4.57)	9.28 (6.78–12.70)	23.04 (15.96–33.28)	
Severity of heat-related illness[a]						0.20
≤III	1,366	Reference	3.22 (2.55–4.08)	7.84 (5.98–10.28)	19.53 (14.14–26.97)	
S-IV or IV	209	Reference	4.55 (2.24–9.25)	17.40 (7.48–40.44)	52.29 (19.96–136.9)	
Medical history						
Cardiovascular disease						0.84
Yes	111	Reference	3.74 (1.58–8.89)	7.19 (2.65–19.51)	31.70 (9.99–100.5)	
No	1,478	Reference	3.26 (2.60–4.10)	8.57 (6.58–11.16)	20.16 (14.71–27.63)	
Mental disorder						0.02
Yes	189	Reference	7.41 (3.34–16.47)	22.28 (9.05–54.84)	71.62 (25.40-201.9)	
No	1,400	Reference	2.97 (2.36–3.74)	7.59 (5.81–9.92)	17.96 (13.06–24.71)	
Other disorders						0.26
Yes	1,501	Reference	4.89 (1.26–19.06)	28.78 (6.62–125.2)	64.59 (12.74–327.5)	
No	89	Reference	3.22 (2.57–4.03)	7.97 (6.15–10.34)	19.78 (14.45–26.89)	
Onset						0.11
10:00–17:00	1,099	Reference	3.21 (2.29–4.51)	8.70 (6.22–12.18)	20.84 (14.35–30.26)	
18:00–9:00	554	Reference	3.52 (2.64–4.68)	7.95 (5.04–12.53)	80.44 (21.32–303.5)	
Region[b]						0.53
Northern or Easten Japan	1,208	Reference	3.69 (2.86–4.75)	9.64 (7.18–12.95)	25.69 (18.06–36.55)	
Western Japan	422	Reference	2.62 (1.70–4.02)	6.40 (3.94–10.42)	14.24 (8.00-25.32)	

Adjusted for holidays

CI, confidence interval; WBGT, Wet-Bulb Globe Temperature

a Patients with core temperature ≥ 40.0 °C and GCS ≤ 8 were classified as grade IV; if core temperature was unavailable, surface temperature ≥ 40.0 °C with GCS ≤ 8 was defined as S-IV. All others were classified as grade III or lower

b Japan was divided into three regions for analysis: Northern Japan (Hokkaido and Tohoku), Eastern Japan (Kanto-Koshin, Hokuriku, and Tokai), and Western Japan (Kinki, Chugoku, Shikoku, and Kyushu)

on this evidence, we defined WBGT < 25 °C as the reference category in our analysis, representing a physiologically meaningful threshold below which the risk of severe heat-related illness is considered to be lower. Collectively, these findings support the use of WBGT as a more effective metric for identifying high-risk environmental conditions and informing real-time public health interventions.

Patients with mental disorders is the association between rising WBGT and heat-related hospitalization. Several mechanisms may explain this vulnerability: reduced awareness of heat risk, impaired judgement, maladaptive behaviors, and social isolation may limit protective actions [27]. Psychotropic medications can further impair thermoregulation, compromising heat tolerance [28]. Furthermore, socioeconomic disadvantage, unstable housing, and higher rates of comorbid physical illness increase susceptibility [27]. These mechanisms are consistent with our finding that mental illness modified the effect of WBGT on heat-related hospitalization.

Strength & limitations

A major strength of this study is the use of a case-crossover design, which allowed for adjustment within individual confounding factors such as underlying diseases and lifestyle habits other than temporal changes. Furthermore, the availability of individual level data enabled stratified analyses to assess effects according to personal risk factors and background characteristics. In addition, the use of a large, nationwide, multi-center data set allowed for comprehensive analyses across diverse regions and patient backgrounds. Additionally, all populations included in the study were diagnosed with heat-related illness by attending physicians, ensuring a clear definition. Moreover, the use of hourly exposure data enabled a more detailed evaluation of the impact of WBGT fluctuations on the risk of heat-related illness.

Nevertheless, several limitations should be acknowledged. First, because the exact locations where the patient occurred were unknown, we assigned exposure based on the hospital to which each patient was transported. This approach may not fully reflect individual level exposure conditions. However, by spatially linking WBGT data from the observation station closest to each

hospital with high accuracy, we were able to improve the validity of our exposure assessment. Moreover, although outdoor meteorological indices may not fully capture indoor environmental conditions or the use of air conditioning, our sensitivity analysis excluding indoor patients showed results consistent with the main analysis, suggesting that this limitation had minimal impact on our findings. Second, because the precise time of onset was not available, we used time of hospital arrival as a proxy. Given the well-developed emergency transport system in Japan and the generally short interval between onset and hospital arrival, the impact of this limitation is likely to be minimal. Third, although our study focused on WBGT as the primary exposure index, a direct comparison with ambient air temperature was beyond the scope of our research questions. Future research comparing its performance with air temperature could provide further insights into WBGT's relative sensitivity as a heat indicator. Finally, some limitations exist regarding external validity and generalizability. Our study population was limited to patients who were transported and hospitalized in secondary and tertiary emergency hospitals and thus did not include mild cases or those treated in primary care settings. Furthermore, climatic conditions, healthcare access, and population behaviors in Japan may differ from those in other countries; therefore, extrapolation to regions with distinct environments, healthcare systems, or sociocultural contexts should be made with caution. Nonetheless, because the observed associations were consistent across multiple severity strata and patient backgrounds, our findings remain informative for populations requiring hospitalization for heat-related illness, although broader generalizability warrants further investigation in different settings.

Conclusions

WBGT at onset was associated with heat-related hospitalization, and this risk remained detectable up to six hours beforehand, highlighting the importance of short-term heat exposure. Although mental disorder significantly modified the magnitude of this association, elevated WBGT posed a risk across all patient groups.

Abbreviations

CI	Confidence interval
DIC	Disseminated intravascular coagulation
ICU	Intensive care unit
JAAM	Japanese Association for Acute Medicine
OR	Odds ratio
SD	Standard deviation
WBGT	Wet-Bulb Globe Temperature
SD	Standard deviation

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12245-025-01112-x.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3: Supplemental Figure 1: Mapping of locations of the 88 WBGT observation stations nearest to hospitals where patients were transported. WBGT, Wet-Bulb Globe Temperature

Supplementary Material 4: Supplemental Figure 2: Sensitivity analysis: Adjusted odds ratios and 95% CI for heat-related hospitalization per 1°C increase in WBGT, evident even six hours before hospital arrival, excluding patients who died in the outpatient setting. WBGT, Wet-Bulb Globe Temperature; CI, confidence intervals

Supplementary Material 5: Supplemental Figure 3: Sensitivity analysis: Adjusted odds ratios and 95% CI for heat-related hospitalization per 1°C increase in WBGT, evident even six hours before hospital arrival, excluding indoor patients. WBGT, Wet-Bulb Globe Temperature; CI, confidence interval

Supplementary Material 6: Supplemental Figure 4: Sensitivity analysis: Adjusted odds ratios and 95% CI for heat-related hospitalization per 1°C increase in WBGT, evident even twelve hours before hospital arrival. WBGT, Wet-Bulb Globe Temperature; CI, confidence interval

Acknowledgements

The Heatstroke STUDY was supported by the Environment Research and Technology Development Fund JPMEERF25S12450 of the Environmental Restoration and Conservation Agency, provided by the Ministry of the Environment of Japan. We thank Christine Burr for editing the manuscript.

Author contributions

TH and YY contributed equally to this work and share first authorship. YY and TH conceived the study, designed the trial, and obtained research funding. TY, KT, TO, TN, HN, and AT supervised the conduct of the trial and data collection. JK and SY undertook recruitment of participating centers and patients and managed the data, including quality control. FS and TY provided statistical advice on study design and analyzed the data. YY and TH drafted the manuscript, and all authors contributed substantially to its revision. TH takes responsibility for the paper as a whole.

Funding

This work was financially supported by the Chugoku Occupational Health Association.
Acknowledgements.

Data availability

The datasets from this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study conforms to the principles outlined in the Declaration of Helsinki and was approved by the Okayama University Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences and Okayama University Hospital Ethics Committee (ID: K K2403-025). Patient consent was waived.

Consent for publication

Consent for publication was waived.

Competing interests

The authors declare no competing interests.

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Received: 31 October 2025 / Accepted: 25 December 2025
Published online: 05 January 2026

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