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Extreme ambient temperature and emergency healthcare service utilization due to substance use disorders: a systematic review and meta-analysis

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To synthesize the association between extreme ambient temperatures and the utilization of emergency healthcare services for substance use disorder (SUD). We performed a systematic literature review of original research published between 2000 and 2023 using five databases (PubMed, Embase, CINAHL, WoS, and Scopus) for literature search, and assessed study quality and risk of bias. A random-effects meta-analysis was conducted to calculate the odds ratios (OR) for SUD-related emergency healthcare service utilization during periods of extremely high or low ambient temperatures. Of 709 articles screened, eight studies met the eligibility criteria. Six studies focused on emergency department (ED) visits, while two examined on-site emergency care utilization. The risk of SUD-related ED visits was significantly higher when the mean ambient temperature was in the top 5% of the temperature distribution range (pooled OR = 1.11, 95% confidence interval [CI]: 1.07, 1.15). Conversely, the risk of SUD-related ED visits was lower when the mean temperature was in the bottom 5% of the distribution (pooled OR = 0.94, 95% CI: 0.89, 0.99). Our review showed the extremely high ambient temperature is associated with higher risk of SUD-related emergency healthcare service utilization. However, given the high heterogeneity observed across studies, these results should be interpreted with caution. Differences in study design, population characteristics, geographic region, and substance type may have contributed to this heterogeneity. Despite these differences, this finding highlights the importance of considering environmental factors in the management and prevention of SUD-related health issues.

Keywords Temperature, Heat, Cold, Substance use disorder, Emergency healthcare service, Sustainable development goals

Abbreviations
CO	Carbon monoxide
ED	Emergency department
IRR	Incidence rate ratios
IPCC	Intergovernmental Panel on Climate Change
ICD	International Classification of Diseases
NO_2	Nitrogen dioxide
OR	Odds ratio
O_3	Ozone
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RR	Relative risks
SUD	Substance use disorder

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Extreme ambient temperatures are known to have a detrimental effect on people's health, beyond just causing heat- or cold-related illnesses, such as heat cramps, heat exhaustion, heat stroke, hypothermia, frostbite, trench foot, chilblains. Severe heatwaves, droughts, and extreme cold elevate the risk of cardiovascular and respiratory fatalities, as well as admissions for mental disorders among the vulnerable population[1,2]. Additionally, heat stress from hot weather diminishes physical work capacity and cognitive function, impairing productivity across the general population[3]. According to the Intergovernmental Panel on Climate Change (IPCC) on climate change, the mean land surface air temperature has risen by approximately 1.5 °C since the period from 1850 to 1900[4]. This is accompanied by an increase in the frequency of exposure to extreme temperatures and weather in many areas of the globe. The US has experienced an increasing frequency of heatwaves since the mid-1960s[5]. European countries have seen a more than three-fold increase in the number of days experiencing severe heat and heat stress on average, with extreme heat rising by 2.3 °C from 1950 to 2018[6]. Extreme rainfall and floods have been observed in East Africa and parts of the Arabian Peninsula and intense heat has gripped large parts of Asia, disrupting daily lives[7,8]. In contrast, it has been observed that with rising temperatures, the most intense cold waves and associated ice formations in mid-latitude regions are disappearing or have already disappeared[9]. A study assessing the risks of heatwaves and cold waves in the Trentino-Alto Adige region of Italy from 1980 to 2018 found a statistically significant increase in heatwave risk and exposure, whereas cold wave risk has either remained unchanged or decreased[10]. Similarly, a study investigating heatwave and cold wave trends in Guangzhou, China, from 1951 to 2015 through the relationship between El Niño–Southern Oscillation events reported that heatwaves have become more frequent, prolonged, and intense over the past 65 years, while no significant changes have been observed in cold waves[11].

Substance use disorder (SUD) is defined as a pattern of substance use that results in impaired physical or mental health or clinically significant impairment or distress. It is classified in DSM-5 and ICD-11 and includes pharmacological criteria such as impaired control over substance use, impaired social functioning, risky use, tolerance and withdrawal symptoms[12]. The global prevalence of SUD is estimated to be 2.2%, with higher proportion of alcohol use disorders (1.5%) compared to other drug use disorders (0.8% overall, comprising of amphetamine 0.10%, cocaine 0.06%, cannabis 0.32%, and opioid 0.29%)[13,14]. The majority of SUD has been documented in high-income countries, primarily affecting young people and men[13,15].

As episodes of extreme weather increase over time, the incidence of serious SUD events may also rise, adding additional strain to emergency healthcare services[16]. These associations can be explained by biological and sociocultural mechanisms. Amphetamine-type stimulants cause brain overheating (>40 °C) in a hot environment, which leads to blood-brain barrier damage and cellular structural abnormalities[17]. In addition, a study in the US found that homeless patients were significantly more likely to have SUDs compared to emergency department (ED) patients living in private homes[18]. In addition, given the wide range of damages caused by extreme temperature, synthesizing evidence on the potential effects of extreme ambient temperatures on the risk of SUD and related utilization of emergency healthcare services is essential for managing environmentally attributed SUD risks and preparedness of public health service. Previous studies have investigated the relationship between extreme temperature and SUD-related emergency medical use, but the findings have been inconsistent due to various reasons, such as differences in population characteristics and geographic context. To address this discrepancy, researchers have systematically synthesized existing evidence to conduct a systematic review, and perform a meta-analysis to quantify the overall effect size and explore the potential causes of heterogeneity. Therefore, the aim of this study is to review and synthesize the association between extreme ambient temperature and SUD-related emergency medical service utilization using a systematic review and meta-analysis.

Methods

Systematic search and study selection

The research was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline[19]. HJ and S-AC established a search strategy, HJ and SK ensured that all studies on extreme temperature and emergency healthcare services utilization due to substance use disorders were identified in the following databases: PubMed, Embase, CINAHL, WoS, and Scopus. The search strategy was developed using the Population, Exposure, Comparator, and Outcomes (PECO) approach to question formulation[20]. The search strategy was intentionally kept broad because this systematic review used different researchers' definitions of extreme temperature, SUD, and emergency healthcare services utilization (Supplementary Table 1). Because the summers of 1999, 2000, and 2001 were the warmest on record, we limited our search to studies published in English from 2000 to 2023, and excluded Systematic Review, Meta-analysis, and review papers. The search date was August 25, 2023, included only human studies, and had no restrictions on age or gender. We extracted the data of authors, year of publication, study design, study setting (e.g., demographics), type of substance use disorders, and definition of extreme ambient temperature from each study. The protocol registered in the International Prospective Register of Systematic Reviews (PROSPERO Registration No. CRD42023457616).

Eligibility criteria and data extraction

To ensure the consistency and reliability of the assessment results, two researchers (HJ and SK) independently reviewed and evaluated the entire set of collected studies to finalize the selection of relevant studies. The independent evaluations were then compared, and any discrepancies were discussed and resolved to achieve a consensus. This approach ensured that the selection criteria were applied uniformly across all studies. The selection method proceeded in the following order: first, selection was based on the study title, second, it was based on the abstract, and finally, it was based on the full text. In order not to exclude major papers or studies that are not often revealed in the title in the first selection, a paper that was included in the title at least one of the three keywords was selected, such as "extreme weather," "substance use disorders," and "emergency healthcare

services utilization" or similar terms. For the secondary screening, papers containing all three keywords in the abstract were selected. In the final selection, papers confirming the relationship between extreme temperature and emergency healthcare services utilization due to SUD were chosen. A hand search of the reference lists from the included studies was performed to identify additional relevant publications that may have been missed during the electronic search. The hand search was performed using the Google search function, and the keywords used in the selection method were used as search terms. Among the selected studies, information such as the title, author, publication year, country of participants, study design, age of participants, total number of participants, definition of temperature, SUD, and healthcare services utilization, types of estimates, and estimated values were extracted for meta-analysis. The exclusion criteria were applied:

- Duplicate records identified across multiple databases.
- Studies that do not meet the predefined selection criteria.
- Records where ambient temperature was not evaluated as an exposure or SUD was not examined as an outcome.
- Studies reporting different risk estimates or differing publication types that could not be synthesized.
- Records available only as an abstract.

Risk of bias assessment

We used the modified risk of bias rating tool developed specifically for review of environmental health studies in prior study[21]. This tool assesses various components including exposure and outcome assessment, confounding bias, selection/recruitment bias, incomplete outcome data, selective reporting, conflict of interest, and other sources of bias. For each study, we assigned a risk of bias rating of "low," "probably low," "probably high," or "high." Studies were classified as "low risk of bias" if they met the following criteria: clear and valid exposure and outcome assessment methods, appropriate control for major confounders, minimal selection bias, complete and transparent reporting, and no significant conflicts of interest. Studies were classified as "high risk of bias" if they had substantial limitations in exposure or outcome assessment, lacked proper confounder control, exhibited potential selection or reporting bias, or had conflicts of interest that could influence the findings. Those falling between these extremes were categorized as "probably low" or "probably high" based on the degree of potential bias.

Analysis

The risk estimates of SUD-related emergency healthcare service utilization, originally presented as odds ratios (OR) or incidence rate ratios (IRR), were converted to relative risks (RR) per extremely high or low ambient temperatures. Extremely high or low temperatures were defined as the 5th or 95th percentile of the temperature distribution[22–24]. Considering the different definitions of extremely high ambient temperature, the analysis used two thresholds: the 95th percentile and the 65th percentile of the temperature distribution range. We conducted a random-effects meta-analysis on literatures where the number of selected studies was three or more. If the risk estimates were provided separately by the SUD outcomes, we regarded the risk estimates for each outcome as distinct studies. If the risk estimates for SUD outcomes in three or more selected studies were treated as separate studies, heterogeneity would inevitably occur due to differences in measurement methods/definitions between outcomes. The random-effects model can statistically integrate this variability by assuming a distribution of effect sizes across studies[25]. In addition, since SUDs have various subtypes, we considered multiple outcomes within the same study as independent cases. While fixed-effects models are used to estimate a single effect under the assumption of homogeneity, random-effects models better capture the variability and heterogeneous characteristics across different populations[26,27]. Publication bias and heterogeneity in effect size were assessed by creating a forest plot using effect sizes from selected papers and confirming heterogeneity indicating differences in effect sizes. As a test for heterogeneity, chi-square tests and the I^2 statistic derived from the chi-square values were used. If I^2 exceeds 50%, it is considered heterogeneity. Meta-analysis was performed using the Review Manager 5.4 program (Cochrane Library Software, Oxford, U.K.).

Results

According to the search query, 709 articles were identified, of which 183 duplicates were removed (Fig. 1). In the total of 526 unique studies, 509 were classified as irrelevant and excluded during the title and abstract screening phase. Subsequent full text screening excluded an additional 11 references out of 17, as outcomes other than ED visit due to SUD ($n=3$), exposures other than extreme ambient temperatures ($n=3$), and risk estimates in continuous scales ($n=1$), different type of paper ($n=2$), and full-text was unavailable ($n=2$). The inclusion of hand-searched papers ($n=2$) resulted in a total of eight final studies. Among the studies, five examined the association between high temperatures and emergency healthcare services utilization, and three explored the impact of both high and low extreme temperatures.

Study characteristics

Six studies defined high ambient temperatures as 95% or more of temperature distribution, while two studies defined it as 65% or more (Table 1). Six studies examined ED utilization as an outcome, while two studies focused on on-site emergency care. The nationalities of the case subjects were all high-income countries including the United States ($n=4$, US), Canada ($n=2$), Germany ($n=1$), and Japan ($n=1$). While some studies investigated all age groups, others targeted adults or adolescents specifically. Four studies utilized a case-crossover design, three studies utilized time-series design, and one study adopted prospective observational study design. The outcome of interest of six studies was a single diagnosis of SUD or drug overdose. Two studies reported separate risk
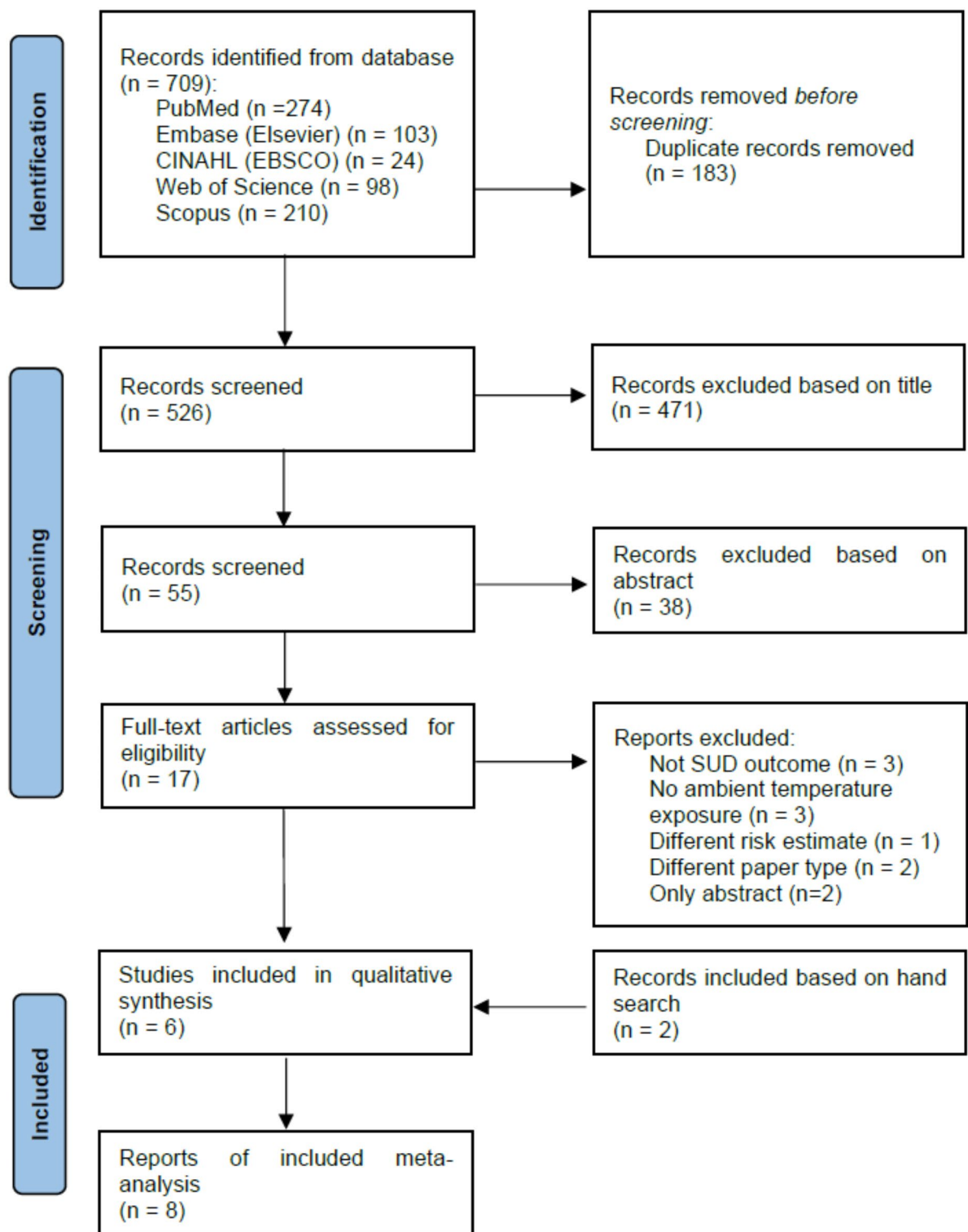
Fig. 1. PRISMA diagram of study selection.

estimates for alcohol, opioids, amphetamine, cocaine, and other psychoactive substances (sedatives or hypnotics, volatile solvents, and multiple drug use).

Risk of bias assessment

For the key components of risk of bias, most studies were assigned "probably low risk" or "low risk". All obtained the temperature data in all included studies from official meteorological data of monitoring stations, ensuring the reliability of the measurement of exposure. Most studies ($n = 8$) assessed the outcome of SUD based on

Author	Study Setting	Type of substance	Study design	Study population age	Time period of data collection	Study population size	Risk estimates	Definition of extreme temperature	Definition of healthcare services utilization	The main findings
Chang[23]	US	Amphetamine use	Case-crossover	All	2005–2019	1,496,401	OR	Comparing the 95th percentile and 50th percentile of daily mean temperature	Emergency department visit	People who use stimulants and opioids may be a subpopulation sensitive to short-term higher ambient temperature
		Cocaine use				518,256				
		Opioid use				890,265				
Hensel[22]	Germany	Alcohol	A prospective observational study	All	January, 2010–December, 2014	604	Risk difference	Mild (10–20 °C) vs. high (over 20 °C)	On-site emergency care	Continuously increasing probability of occurrence of severe acute poisoning by alcohol and drugs with rising temperature
								Mild vs. low (less 10 °C)		
		Opioids				295		Mild vs. high		
								Mild vs. low		
		Sedatives or hypnotics, volatile solvents, and multiple drug use and use of other psychoactive substances				636		Mild vs. high		
								Mild vs. low		
Lavigne[28]	Canada	Psychoactive substance use	Case-crossover	All	March 1st, 2004–December 31st, 2020	9,958,759	OR	Heat (97.5% temperature in each health area)	Emergency department visit	The impacts of heat on mental and behavior disorders emergency department visits may vary across different vulnerability factors.
								Cold (2.5% temperature in each health area)		
Niu[29]	US	Not Specified	Case-crossover	12–17	2005–2011	2,385	OR	Higher than 95% of the daily minimum temperature distribution for June-August	Emergency department visit	Elevated ambient temperatures were associated with acute mental health ED or hospital encounters across childhood, adolescence and young adulthood
				18–25		14,505				
Nori-Sarma[30]	US	Not specified	Case-crossover	≥18 years	2010–2019	2,243,395	IRR	More than 95% of the region's population-weighted average daily maximum temperature between May and September	Emergency department visit	Days of extreme heat were associated with higher rates of mental health related ED visits
Roy[31]	Japan	Not specified	Time-series study	≥15 years	2010–2014	12,937	RR	Values at the maximum RR point based on a 1% value of the daily average temperature distribution	On-site emergency care	An increase in daily mean temperature was associated with increased drug overdose risk
Wang[24]	Canada	Not specified	Time-series study	All	2002–2010	73,050	RR	Values at the 99% of the daily average temperature distribution	Emergency department utilization	Extreme temperature poses a risk to the health and wellbeing for individuals with mental and behavior illnesses
Yoo[32]	US	Not specified	Time-series study	All	2009–2016	2,893,794	RR	Values at the 97.5% of the daily average temperature distribution	Emergency department utilization	Positive association between short-term exposure to extreme heat and increased ER visits for total mental disorders

Table 1. Characteristics of studies included in qualitative synthesis and meta-analysis. *OR* odds ratio, *IRR* incidence rate ratio, *RR* relative risk.
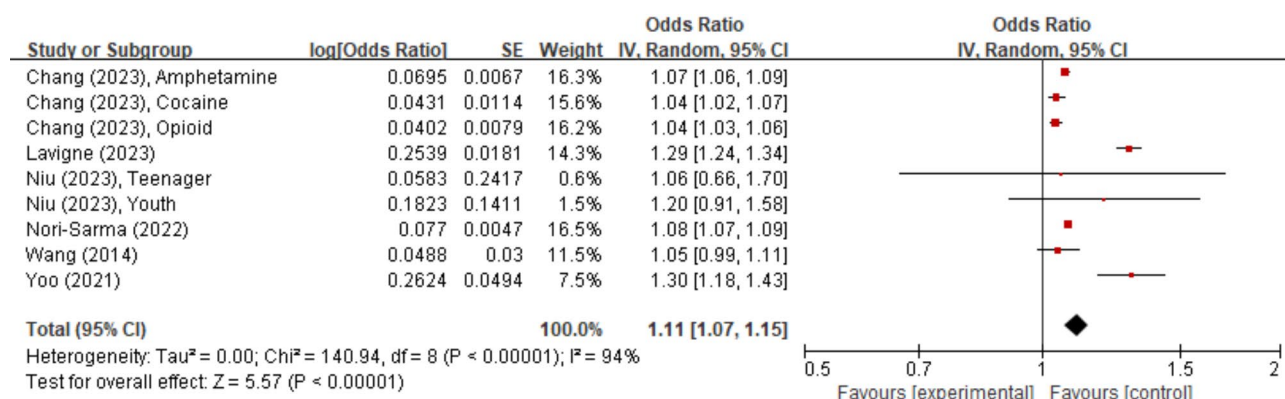
Fig. 2. Forest plot of the association between extremely high ambient temperature (95% of the temperature distribution range or higher) and substance use disorder (SUD)-related emergency department (ED) visit.
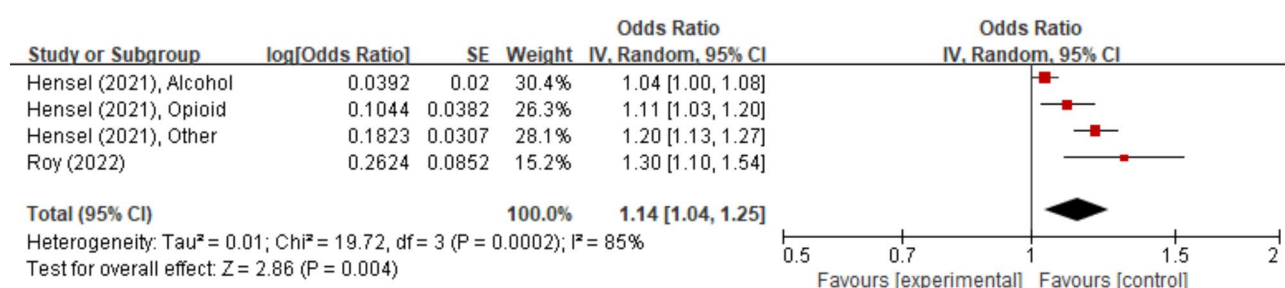
Fig. 3. Forest plot of the association between extreme high ambient temperature (65% of the temperature distribution range or higher) and on-site emergency care for substance use disorder.

the International Classification of Diseases (ICD) diagnosis codes. We assigned 'probably high' for outcome assessment to one study which used the diagnosis of 'drug overdose' recorded on the emergency ambulance dispatch data. Among these studies, seven studies adjusted for the relative humidity, seasonal and long-term trends, and days of the week that are likely to change and introduce bias when examining short-term health effects of extreme temperature exposure. Five studies included long-term trends of the temperature in the model. One study adjusted for the confounding effects of air pollution including nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3). Risk of selection bias was assessed to be 'probably high' in one study where the 'drug overdose' outcomes were identified among the suicide attempt cases. Otherwise, the risks of bias were assessed to be 'low' or 'probably low' (Supplementary Table S1).

Evidence synthesis using meta-analysis

Chang's and Hensel's study were analyzed in three parts each for the type of substance, and Niu's study was analyzed in two parts according to age, so these studies were considered independent studies according to the results. High ambient temperature was consistently associated with higher risk of SUD-related ED visit regardless of the threshold. Combining the risk estimates for different types of SUDs of two studies[23,29], the total number of studies analyzed for extremely high temperatures (≥95%) was nine. The risk of SUD-related ED visit was higher when mean ambient temperature was 95% of the temperature distribution range or higher (pooled OR = 1.11, 95% CI: 1.07, 1.15, Fig. 2). Heterogeneity testing revealed significant heterogeneity among the studies ($I^2 = 94\%$).

Combining the risk estimates for different types of SUDs from one study[22], the total number of studies analyzed for extreme temperatures as high as ≥65% was four. The pooled OR of SUD-related ED visit was 1.14 when the mean ambient temperature was 65% of the distribution range or higher (95% CI: 1.04, 1.25, Fig. 3). Heterogeneity testing revealed significant heterogeneity among the four studies ($I^2 = 85\%$).

Three studies reported the association between extremely low temperature and SUD. Because one study separately reported three types of SUD's, the included risk estimates in the analysis of extremely low temperature were five. The risk of SUD-related ER visit was lower when the mean ambient temperature is as low as ≤5% of the temperature distribution range (pooled OR = 0.94, 95% CI: 0.89, 0.99, Fig. 4). Heterogeneity testing revealed significant heterogeneity among the studies ($I^2 = 78\%$).

Discussion

We found a consistent positive association between high ambient temperatures and an increased risk of SUD-related emergency healthcare services utilization, such as ED visit and on-site emergency care. Extremely low
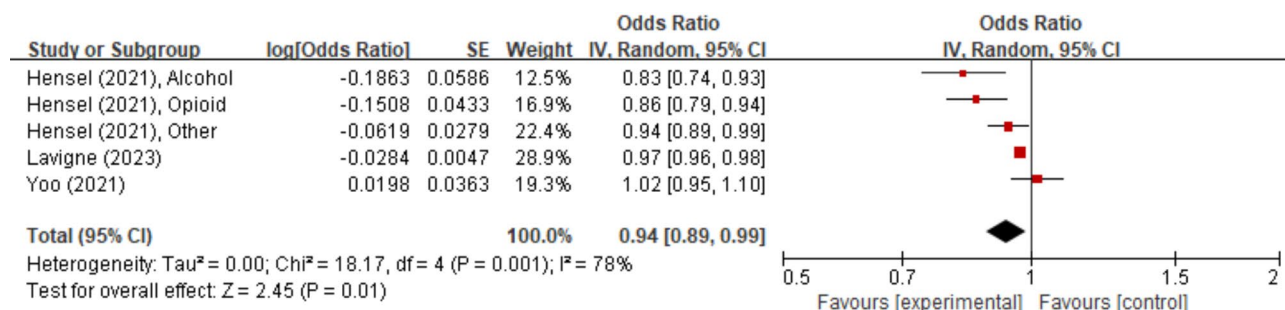
Fig. 4. Forest plot of the association between extreme low ambient temperature (5% of the temperature distribution range or lower) and emergency healthcare services utilization for SUD patients.

temperatures were associated with a decreased risk of SUD-related emergency healthcare services utilization. However, given the high heterogeneity observed across studies, caution is warranted in the interpretation of these findings. Variations in study design, population characteristics, geographic regions, and type of substance may have contributed to this heterogeneity. Despite these differences, our findings provide evidence for the needs in predicting medical demands that attributed to extreme temperatures.

The positive association between exposure to extremely high temperatures and exacerbation of SUD is consistent with prior studies on heat exposure and mental disorders[33]. Prior studies have found that high ambient temperatures can lead to psychological distress and likelihood of risky behaviors to relieve the stress such as substance use[21,34]. Extreme heat exposure is associated with physical and psychological fatigue, and studies have shown that high temperatures directly increase hostility and indirectly enhance aggression through aggressive thinking[35]. Positive associations of high temperatures with violent behavior, homicides, and suicides were observed[36]. Although the biological or sociocultural mechanisms of these associations are not fully understood, emerging evidence suggests a complex interplay between temperature, neurotransmitter activity, and behavioral responses[37]. Considering the significant heterogeneity in SUD contexts, the underlying mechanisms may differ by substance type, demographic group, and geographic setting. For instance, stimulant use could intensify heat-related risks through synergistic disruptions in thermoregulation, while amphetamines may boost metabolic heat production and reduce the body's capacity to dissipate heat[38]. Sociodemographic factors, such as homelessness or lack of access to air conditioning, may increase vulnerability to heat-related substance use exacerbations[39]. Longitudinal and experimental studies are needed to confirm our findings and explore potential causal mechanisms.

An interesting finding was the inverse association between extreme cold and a slight increase in ED healthcare services utilization. Although a limited number of empirical studies are available, the direction of association was consistent. We can postulate several socio-behavioral mechanisms: colder weather typically reduces outdoor activities and social interactions, leading to fewer opportunities for substance use and related emergencies[40]. On the other hand, the risk of opioid overdose death was higher in the cold weather[41]. This inconsistency may be explained by the method of outcome measurement: a higher proportion of SUD cases attributed to extreme cold may result in mortality rather than emergency healthcare services utilization, thus appearing as a lower risk of SUD-related emergency healthcare services utilization. Many countries are trying to prevent increased demand for emergency medical care due to extreme cold. The Cold Wave Plan, which was implemented in the UK in 2012, is a policy to warn about and prevent major avoidable health impacts during extreme cold periods. Health and social care providers are positive about the policy and it was cost-effective in some scenarios, while there are many challenges to overcome[42]. Toronto, Canada, implemented the Toronto Cold Weather Program in 1996 to protect people from extreme weather conditions. Some results show that the program is not effective in reducing cold-related mortality and morbidity[43]. While we observed some indication of a reduced risk of SUD-related ED visits, the current evidence for the combined impact on the mortality and morbidity attributed to the extreme cold remains inconclusive.

Several prediction models for forecasting emergency medical services demand have incorporated special days and analyzed demand patterns across various time intervals—hours, days of the week, months, seasons—as well as spatial components[44–46]. However, many of these models did not account for specific medical conditions or the strength of their associations with demand. Our findings indicate that ambient temperatures in the 65th to 95th percentiles are associated with an 11–14% increase in SUD-related ED visits. This insight can enhance the predictive power of existing models and improve resource planning for emergency services.

The findings of this study need caution in interpretation. First, all analyses displayed significant heterogeneity ($I^2 > 78\%$), indicating substantial variation in study design, populations, and outcome measures. To generalize the findings, further studies with standardized approaches would be necessary. Second, while most studies included in this review employed case-crossover or time-series designs, which have been widely used for similar research question[47], inclusion of just one prospective study may limit the ability to infer a causal association[22]. Third, potential heterogeneities in the risk estimates based on the specific SUD and age group were not fully explored in the study due to the limited number of studies. As more reports are accumulated, future reviews will be able to assess variations in the effects in greater detail, potentially utilizing subgroup analyses. Exploring

specific vulnerabilities of different age groups and types of substance using subgroup analyses would be also needed.

Conclusion

In conclusion, our findings indicate a significant association between high ambient temperatures and an increased risk of SUD-related emergency healthcare services utilization. Conversely, extremely low temperatures were associated with a decreased risk. These results underscore the importance of considering environmental factors in the management and prevention of SUD-related health issues.

Data availability

All data generated or analysed during this study are included in this published article.

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Declarations

Competing interests

The authors declare no competing interests.

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