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Association of extreme heat events with sleep and cardiovascular health: a scoping review

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Abstract

Background Extreme heat events (EHEs), driven by anthropogenic climate change, exacerbate the risk of cardiovascular disease (CVD), although the underlying mechanisms are unclear. A possible mechanism leading to heat-related CVD is disturbances in sleep health, which can increase the risk of hypertension, and is associated with ideal cardiovascular health. Thus, our objective was to systematically review the peer-reviewed literature that describes the relationship between EHEs, sleep health, and cardiovascular measures and outcomes and narratively describe methodologies, evidence, and gaps in this area in order to develop a future research agenda linking sleep health, EHEs, and CVD.

Methods A comprehensive literature search was performed in the following databases from inception–June 2023: Ovid MEDLINE, Ovid Embase, CINAHL, Web of Science, and the Cochrane Library. Studies retrieved were then screened for eligibility against predefined inclusion/exclusion criteria. Then studies were described qualitatively in relation to study design, findings, and the evidence linking the relationship between sleep health, EHEs, and CVD.

Results Of the 2035 records screened, only three studies met the inclusion criteria. In these three studies, EHE was measured as absolute temperatures (greater than 30 °C) or relative temperatures (i.e., 90th percentile daily maximum temperature within the region). Cardiovascular (CV) measures described included blood pressure (BP), heart rate (HR), and HR variability (no CVD outcomes were described), and objective and subjective measurements of sleep health outcomes included sleep duration, calmness, ease of falling asleep, ease of awakening, freshness after awakening, and sleep satisfaction. Two studies were controlled trials, and one was a cohort study. During EHEs, individuals slept for shorter periods of time and less efficiently, with greater degrees of HR variability in two of the three studies lasting at most 1–2 days; BP (both systolic and diastolic) significantly decreased during EHEs in two of the studies. No formal assessment of a mediating relationship between EHE exposure, sleep outcomes, and CV measures was undertaken.

Conclusions Few studies examine the link between CVD, sleep, and extreme heat as a possible mechanism of elevated CVD risk during EHEs, despite a strong physiological rationale. Our findings highlight an important gap in the literature that should be closely examined as EHEs become more frequent and their harmful impacts of health increase.

Keywords Extreme heat events, Heat-related sleep disruption, Cardiovascular health, Health equity

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Background

Extreme heat events (EHEs) are periods of unusually high temperatures, which are increasing in frequency, intensity, and duration as a result of anthropogenic climate change [1]. While no single definition of EHEs exists [2], since 1950, the number of heatwave days (defined as at least three consecutive days above the 90th percentile of daily maximum temperature) is estimated to have increased by 2.26 °C per decade globally, while the cumulative heat (i.e., the extra heat produced by a heatwave over a given season) increased by 2.84 °C per decade [3]. Heat exposure is associated with adverse cardiovascular (CV) events, with every 1 °C rise in ambient temperature significantly raising the risk of cardiovascular disease (CVD)-related morbidity and mortality [4]. While the heightened risk of CVD associated with EHEs is well-documented in existing literature, the underlying mechanisms contributing to heat-related CVD morbidity outcomes remain insufficiently understood [5].

Existing research hypothesizes several pathways to heat-related CVD. For example, studies have described surges in cardiac output and hyperventilation during EHEs, yet how these physiological changes during EHEs increase the risk of myocardial infarction, heart failure exacerbations, or stroke have not been fully delineated at a physiological level [6–8]. Furthermore, as EHEs become more frequent due to a changing climate, these mechanisms become more important to understand. Recently, sleep health has been recognized as a critical determinant of ideal cardiovascular health [9]. There is a well-known association between poor sleep health, and CVD, driven by a wide range of factors. Thus, a potential mechanism linking EHEs and CVD is sleep disruption. Rising temperatures have been associated with shorter sleep duration and poorer sleep quality, as has the aftermath of weather phenomena impacted by climate change like hurricanes, floods, and wildfires [10–13]. Multiple dimensions of sleep health, including insufficient sleep duration, irregular sleep schedules, and poor sleep quality, can increase cardiometabolic risk and predisposition to CVD [14]. For instance, poor sleep has been linked to a higher risk for hypertension [15, 16], obesity [17], and type 2 diabetes [18] via theorized mechanisms including inflammation [19, 20], glycemic dysregulation [21], and increased sympathetic tone via increases in nocturnal catecholamines [22]. Thus, this connection suggests a possible mechanism explaining the adverse impact of EHEs on CVD, with sleep as a mediating factor, as illustrated in Fig. 1.

To examine the prevailing literature that links sleep health, CVD, and EHEs, in this scoping review, we systematically examined the peer-reviewed literature that examined the relationship of EHEs with sleep health, CV measures, and CVD outcomes to identify gaps in the literature to develop a future research agenda.

Methods

This study was performed following the Preferred Reporting Items for Systematic reviews and Meta-Analyses-Scoping reviews (PRISMA-ScR) [23]. In adherence to this statement, a protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO; CRD42023432124).

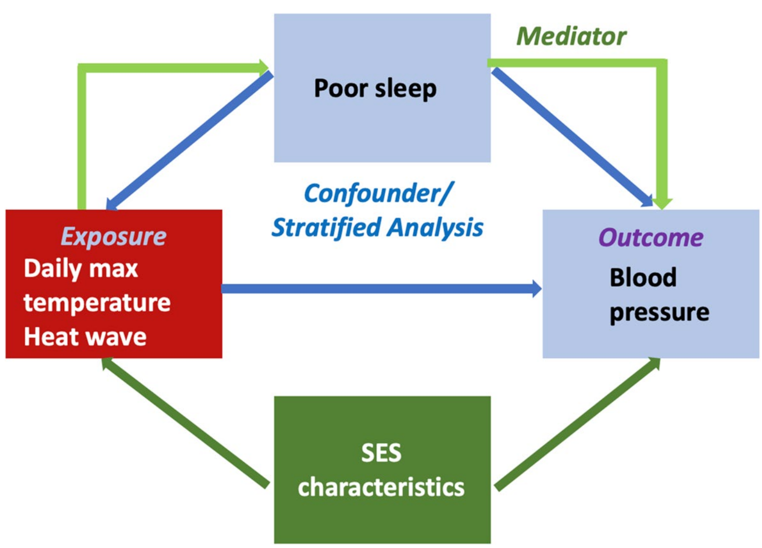

Fig. 1 Hypothesized model of relationship between EHEs, sleep quality, and CV health. Abbreviations include SES, which stands for socioeconomic status

Search strategy

A medical librarian (M. R. D.) performed comprehensive searches to identify studies that examined the effect of EHEs (heat waves) on sleep health and CVD.

Searches were completed on June 14, 2023, in the following databases: Ovid MEDLINE (ALL —1946 to present); Ovid Embase (1974 to present), CINAHL (EBSCO), Web of Science (Core Collection — Clarivate), and the Cochrane Library (Wiley). The search strategy included all appropriate controlled vocabulary and keywords for the concepts of "heat," "sleep," and "cardiovascular." The full search strategies for all databases are available in the supplement. In order to limit publication bias in our initial search strategy, there were no language, publication date, or article type restrictions on the search strategy.

Study selection

Retrieved studies were screened for inclusion using Covidence systematic review software. Titles and abstracts were reviewed against predefined inclusion/exclusion criteria by two independent reviewers. Discrepancies were resolved by consensus (N. A., S. W., R. A., M. R. D., M. C., A. K. G.). For final inclusion, the full text was then retrieved and also screened by two independent reviewers. Our inclusion criteria were articles that included the following: (1) EHEs, as defined by manuscript-specific definitions; (2) reported sleep measures: sleep health disruptions (e.g., sleep duration $\leq$7 h, irregular sleep, difficulty falling asleep, symptoms of sleep disorders, and/or daytime sleepiness); (3) CV measures (e.g., blood pressure, heart rate) and CVD events/diagnoses (e.g., diagnosis of hypertension, coronary artery disease, and peripheral arterial disease or acute CVD events such as myocardial infarction, stroke, and heart failure exacerbations); and (4) adult participants (>=18 years). Excluded studies were as follows: (1) Non-English; (2) review articles, commentaries, viewpoints, editorials, or case reports; (3) insufficient CV measures or outcomes; (4) insufficient measure of sleep defined; or (5) lack of EHE or equivalent or lack definition of EHE. For articles selected for inclusion in this study, reference lists and citing articles were pulled from Scopus (Elsevier) and also screened. The full PRISMA flow diagram outlining the study selection process is presented in Fig. 2.

Data extraction

Data extraction was performed by team members (N. A., S. W., M. C., R. A., A. K. G., M. R. D.) independently in duplicate with predefined, standardized templates. We extracted the following information for each study: year, study location, study design, population under study, description of EHE/exposure, sleep outcome(s) evaluated, CV measure(s)/outcome(s) evaluated, and results. The studies that met our inclusion and exclusion criteria were then described and qualitatively assessed according to the definitions used for sleep health, EHEs, and CVD, and the results of these papers were described in relation to the links between EHE, CVD, and sleep health.

Results

Summary of articles

Three studies, summarized in Table 1, met the criteria for inclusion in the analysis.

Study design

Two studies were controlled trials [24, 26], while one was an observational cohort study [25]. Huang et al. recruited participants (*n*=41) into one of three intervention groups or a control group to assess the effect of these interventions (subsidies for air-conditioning, education about health and environmental heat, and use of sprinklers to cool home exteriors) on sleep quality and CV measurements during a heat wave [24]. Yan et al. performed a controlled, crossover trial, placing participants (*n*=16) in one of four room permutations, with rooms either 27 °C or 30 °C and either employing mechanical ventilation systems to circulate filtered outdoor air or not [26]. Kim et al. observed the effects of a heat wave on elderly residents of rural communities in South Korea (*n*=104) [25].

Geographies covered and study settings

The three studies analyzed here report data from China [24, 26] and South Korea [25]. One of these studies was at the regional level [25], while two were at the city level [24, 26].

Extreme heat event definitions

Definitions of EHEs varied greatly. In the Xinyi study, EHEs were defined as heat waves using the 90th percentile daily maximum temperature [24]. In the South Korean study, the criteria for heatwave were more than two consecutive days with a maximum temperature of more than 33° C [25]. Finally, the Shanghai controlled trial used indoor temperatures of 27 °C and 30 °C to model extreme heat exposure (Table 2) [26].

Sleep outcomes evaluated

Sleep outcomes used in the studies were both self-reported and objective. Subjective outcomes reported were self-assessed sleep duration [25], self-assessments of calmness, ease of falling asleep, ease of awakening, freshness after awakening, and sleep satisfaction [26]. Objective outcomes were total sleep duration (split into deep sleep duration and light sleep duration) as measured by a smart band [24] and total sleep time, sleep efficacy (ratio of time asleep to time in bed), sleep onset latency (the

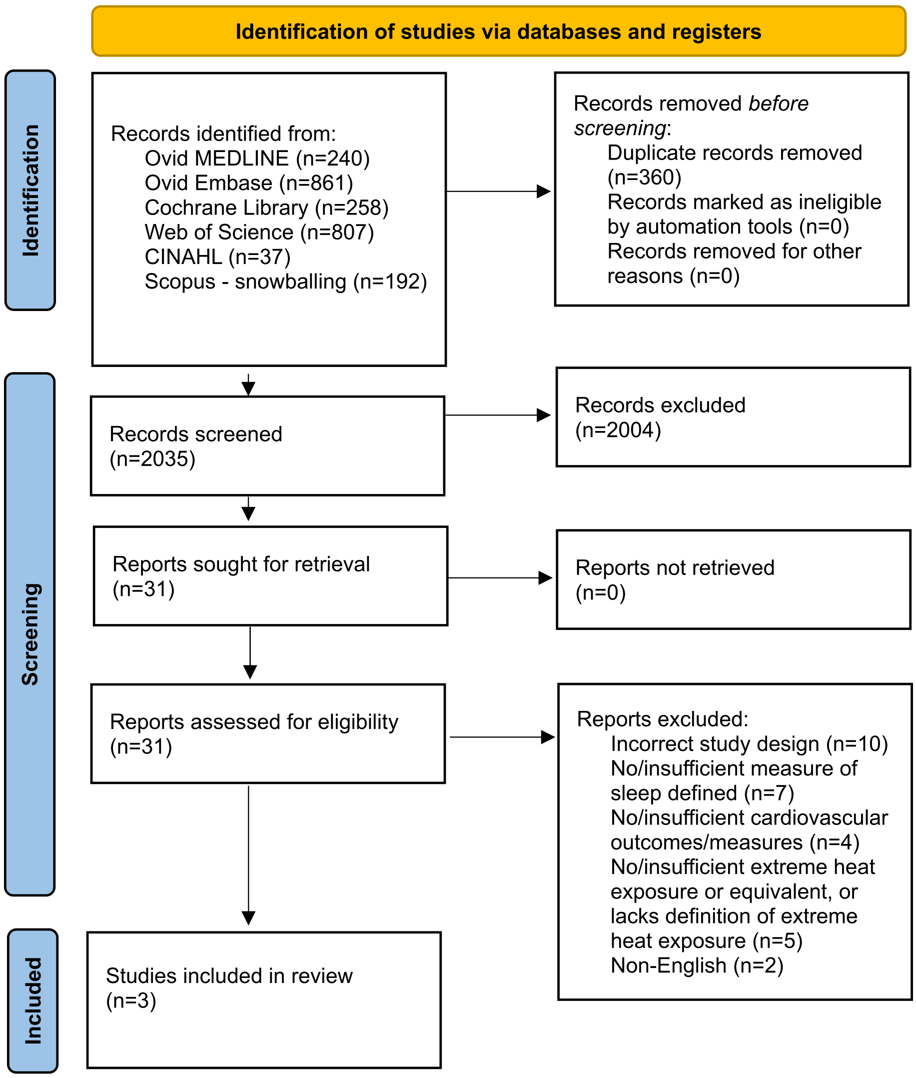

Fig. 2 PRISMA-ScR flow diagram. From Page et al. [23]. For more information, visit http://www.prisma-statement.org/

time between turning off lights and falling asleep), time awake and duration of sleep stages (NREM sleep of stages N1, N2, and N3 and REM sleep), measured using electroencephalogram (EEG), bilateral electrooculogram (EOG), and chin electromyogram (EMG) [26].

Cardiovascular measures and outcomes evaluated

No CVD outcomes were evaluated in these studies. However, CV measurements were assessed. All CV measurements were assessed with objective data. These data included systolic (SBP) and diastolic blood pressure (DBP) [24, 26, 25] measured with a sphygmomanometer and HR [24] and HR variability [26] measured with an electronic wrist monitor or ECG, respectively.

Qualitative synthesis

None of the studies included in this review directly evaluated measures of sleep health as a mediator or confounder in the relationship between EHEs and CVD or CV measures. However, indirectly, Yan et al. showed a significant mean difference (MD) in HR variability ($MD=0.7$ beats per minute [bpm]; $P=0.02$) between 27 and 30 °C room at the same time as a significant decrease in total sleep time ($MD=39.1$ min, $P=0.01$), sleep efficiency ($MD=8\%$, $P=0.01$), and REM sleep time ($MD=3.3$ min, $P=0.05$), and increase in time awake ($MD=38.1$ min, $P=0.01$) in rooms lacking mechanical ventilation (i.e., fans to bring in filtered outdoor air), as well as a decrease in sleep efficiency of 0.2% per increased bpm ($P=0.04$) and an increase in time awake of 2.39 min per increased bpm ($P=0.04$) [26].

Table 1 Summary of studies

First author, year	Geographic region	Study design	Population	Description of extreme heat event	Objective sleep outcomes	Subjective sleep outcomes	CV measures/outcomes	Results	Comments
Huang, 2022 [24]	Xinyi, Xuzhou, China	Randomized controlled trials	$n=41$; 60% female, mean age = 58.8 years	Participants were split into three groups of 10 and one of 11, one control, and three experimental. Baseline health metrics were taken on a normal-temperature day. For 5 days during a subsequent heat wave, three groups each received one of the following interventions: education about health during heat waves, subsidies for electricity costs of running an AC or fan, or daytime water spraying of homes in an attempt to cool interior temperatures	Use of an unspecified smart band that measured TSD, DSD, and LSD. The paper did not specify how the smart band measured these durations	None	A wrist blood pressure monitor measured DBP and SBP and HR of participants. Both metrics were measured three times every morning for the 5-day study period	In the control group, DBP and SBP elevated from baseline during the heat wave, with SBP increasing significantly on days 1 and 2 by 5.33 mmHg (95% *CI*: 3.38–7.30; $P=0.01$) and by 4.92 mmHg (95% *CI*: 2.74–7.09; $P=0.02$), respectively HR elevated from baseline and on day 1 and lowered to near baseline by day 5. DSD decreased significantly in the first 3 days by −0.48 h (95% *CI*: −0.61, −0.34; $P=0.00$), −0.36 h (95% *CI*: −0.51, −0.21; $P=0.01$), and −0.25 h (95% *CI*: −0.37, −0.12; $P=0.05$), respectively In the cooling-spray group, SBP increased significantly on day 1 by 3.18 mmHg (95% *CI*: 1.73, 4.63; $P=0.03$) and on day 2 by 3.34 (95% *CI*: 1.76, 4.93; $P=0.04$) before gradually declining and returning to baseline. DSD was reduced significantly on day 2 by −0.21 h (95% *CI*: −0.31, 0.11; $P=0.05$)	The experimental group interventions were not fully described. Information on occupation and AC use was not collected in an initial questionnaire, nor was information on ability to pay for AC, which would shed light on the efficacy of subsidies

Table 1 (continued)

First author, year	Geographic region	Study design	Population	Description of extreme heat event	Objective sleep outcomes	Subjective sleep outcomes	CV measures/ outcomes	Results	Comments
Kim, 2020 [25]	Rural areas in southern South Korea: Gijang, Busan; Imsil, Jeollabuk-do; Gwangyang, Jeollanam-do; and Namhae, Gyeongsangnam-do	Cohort study	$n = 104$; 72.1% female, mean age = 79.6 years	All participants were exposed to the 2018 heat wave in South Korea (August 1–19). Indoor temperature and relative humidity were measured twice a day (morning and afternoon) for 3 days. Outdoor temperature and relative humidity were retrieved from the Korean Meteorological Administration website for each study area, with average values between 9 AM through 12 PM used as morning data and 1 PM through 5 PM used as afternoon data	None	Number of hours of sleep during the prior night was self-reported to investigators on days in which temperature, relative humidity, and health measures were taken	Body temperature measured by infrared thermometer; DBP and SBP measured twice (morning and afternoon) per day using a sphygmomanometer	DBP decreased significantly ($P < 0.001$) in subjects with hypertension, with a 1 °C increase in indoor temperature decreasing DBP by 0.44 mmHg (95% *CI*: 0.04–0.84 mmHg). The association between indoor temperature and SBP was positive but not significant. Number of hours of sleep decreased with indoor temperature by 0.036 h (95% *CI*: −0.138, 0.067 h); however, this result did not reach statistical significance	No analysis was performed to determine if subjects who reported fewer hours slept had significant differences in BT, DPB, or SBP

Table 1 (continued)

First author, year	Geographic region	Study design	Population	Description of extreme heat event	Objective sleep outcomes	Subjective sleep outcomes	CV measures/ outcomes	Results	Comments
Yan, 2022 [26]	Shanghai, China, in controlled hospital bedroom setting	Controlled, crossover trial	$n=16$, 50% female, mean age 72 years	Each participant was assigned to one of four experimental conditions established in a 2×2 experimental design: hospital-based bedrooms were heated to either 27° or 30° C and used or did not use a mechanical ventilation system to provide the room with filtered outdoor air. Participants spent five nonconsecutive nights (one adaptive and four observed) sleeping in their assigned room, with a 3-day interval between experimental nights	Total sleep time, sleep efficacy, sleep onset latency, time awake and duration of sleep stage, measured using EEG, bilateral EOG, and chin EMG	Questionnaire each morning measuring calmness of sleep, ease of falling asleep, ease of awakening, freshness after awakening, and sleep satisfaction on 5-point scales	Heart rate and heart rate variability measured by ECG; DBP and SBP measured before and after sleep using a sphygmomanometer	Compared to 27 °C, individuals at 30 °C had a significantly increased time awake (*MD* = 15.9 min in MV setting, *MD* = 38.1 min in NMV setting, $P=0.01$), less total sleep time (*MD* = 14.5 min in MV setting, *MD* = 38.1 min in NMV setting, $P=0.01$), less sleep efficiency (*MD* = 3% in MV, 8% in NMV, $P=0.01$), and less REM sleep (*MD* = 7.4 min in MV setting, *MD* = 3.3 min in NMV setting, $P=0.05$); heart rate variable significantly differed (*MD* = 0.7 bpm in MV setting; 0.7 bpm in NMV setting, $P=0.02$), and DBP ($P=0.01$) and SBP ($P<0.001$) significantly decreased with increases in duration of deep sleep defined by REM	Rigorously designed experimental study

Abbreviations: *AC*, air-conditioning; *TSD*, total sleep duration; *LSD*, light sleep duration; *REM*, rapid eye movement; *DBP*, diastolic blood pressure; *HR*, heart rate; *SBP*, systolic blood pressure; *EEG*, electroencephalogram; *EOG*, electrooculogram; *EMG*, electromyogram; *MV*, mechanical ventilation; *NMV*, nonmechanical ventilation; *MD*, mean difference

Table 2 Study definitions of extreme heat events

Study	Definition
Huang, 2022 [24]	The 90th percentile daily maximum temperature as a relative threshold to define a heat wave
Kim, 2020 [25]	More than two consecutive days with a maximum temperature of more than 33 °C
Yan, 2022 [26]	Indoor temperatures of 27 °C or 30 °C with exposure over five nights, with a 3-day interval between any two consecutive nights

Kim et al. [25] present findings suggestive of a relationship between extreme heat and both sleep and CV measures; however, these neither reached statistical significance nor implied that sleep played a mediating role between EHEs and CV measures. DBP decreased significantly ($p < 0.001$) in subjects with hypertension, with a 1 °C increase in indoor temperature decreasing DBP by 0.44 mmHg (95% *CI*: 0.04–0.84 mmHg). The association between indoor temperature and SBP was positive but not significant. The number of hours of sleep decreased with indoor temperature by 0.036 h (95% *CI*: −0.138, 0.067 h); however, this result did not reach statistical significance [25].

Similarly, Huang et al. [24] show an association between EHEs and both sleep and CV measures, though no causal mechanisms can be inferred. In the control group, DBP and SBP elevated from baseline during the heat wave, with SBP increasing significantly on days 1 and 2 by 5.33 mmHg (95% *CI*: 3.38–7.30; $P = 0.01$) and by 4.92 mmHg (95% *CI*: 2.74–7.09; $P = 0.02$), respectively. HR elevated from baseline and on day 1 and lowered to near baseline by day 5. Deep sleep duration decreased significantly in the first 3 days by −0.48 h (95% *CI*: −0.61, −0.34; $P = 0.00$), −0.36 h (95% *CI*: −0.51, −0.21; $P = 0.01$), and −0.25 h (95% *CI*: −0.37, −0.12; $P = 0.05$), respectively [24].

Discussion

This scoping review identified three articles examining the relationship between EHEs, sleep, and CV health. These papers, while not elucidating a causal mechanism linking EHEs to worsening CV measures or CVD, examined associations between these three factors.

Importantly, our review highlighted several current research gaps linking EHEs, sleep health, and CVD health. First, the studies reviewed suggest but do not rigorously examine causal links between heat, sleep, and CVD through physiological mechanisms. Second, while duration and quality of sleep were examined, future research could evaluate multiple dimensions of sleep health and their relationship to EHEs and CVD. Sleep health is a multidimensional process that constitutes important subjective and objective measures [27]. Utilizing these multiple measures, as well as alternative definitions of EHEs (including absolute measures and relative measures) that both represent different aspects of thermal comfort [2], is critical to understanding the relationship between EHEs, sleep health, and CVD. Third, studies lacked the inclusion of participants from at-risk populations including low-income individuals or other socioeconomically vulnerable groups prone to both CVD risk and heat-related illness. Research including these populations could offer perspective on ways to aid those most vulnerable to harm in a warming climate.

Furthermore, the existing studies were limited in their geographic reach and lacked standardization of key terminology such as the EHE definition. Given that all of the studies reviewed were conducted in East Asia, our analysis underscores the need for a broader geographic representation in research on this subject. Further analyses may show important regional variation: given that the impacts and manifestations of climate change are so variable, associations between EHEs, sleep, and CVD should be investigated in different settings to inform interventions and policy, and research conducted in specific countries may find an association between EHEs, sleep, and CVD more likely, particularly where CVD outcomes are more prevalent [28]. The need for a uniform characterization of what constitutes an EHE or heat wave is also important in order to promote coherence and comparability between studies [2]. This would facilitate a more nuanced understanding of the broader implications of EHEs on health on a global scale and allow comparisons across regions and countries. Without such standardization, the heterogeneity in EHE definitions across studies complicates direct comparisons of findings, potentially hindering the development of a cohesive research approach. This inconsistency challenges efforts to draw generalized conclusions about EHEs' health impacts and may impede the formulation of effective, evidence-based strategies for mitigating CVD risks associated with extreme heat.

Interestingly, the role of air-conditioning (AC) as a potential confounder in the relationship between EHEs, sleep health, and CVD is likely an area for further study. In the studies conducted by Huang [24] and Yan [26], a significant emphasis is placed on the role of interior room temperature, positing it as a more important critical determinant of health outcomes than external temperature. Their findings suggest that regulating indoor temperatures may enhance both sleep quality and CV health, potentially mitigating some of the adverse effects of EHEs. Notably, Huang's research delineates that daytime exposure to heat does not suffice to induce elevated SBP, suggesting that nocturnal temperature levels particularly may play a pivotal role — an area of future research [29].

Although we conducted a comprehensive review, the final number of results is very small. We argue that this underscores the early stage of research in this area, highlighting the need for more extensive and in-depth studies to build a robust body of evidence that seeks to understand the physiological mechanisms linking the impact of sleep health on CVD through EHEs. Only then can potential interventions be used to address the clear association between CVD and heat-related health risk, not just today but into the future as EHEs become more frequent.

We describe two limitations to our work. First, we did not include non-English literature and therefore may have missed important peer-reviewed manuscripts. This is particularly noteworthy because of the three studies that met inclusion criteria, and all were from countries outside the English-speaking regions. Second, we did not consider gray literature. However, given the nuanced nature of our research question and the conceptual framework we examined (Fig. 1), the peer-reviewed literature is the most likely source of empirical studies on this topic.

Conclusion

In conclusion, this scoping review examined the 7v-reviewed literature that described the relationship between EHEs, sleep health, and CV health to better understand the mechanisms linking CVD with EHEs. The existing literature, though limited, suggests associations between sleep health, CVD, and EHEs, but more rigorous studies that can causally examine the links are required. Understanding these dynamics and their causal links, if found to hold true, may lead to better health-related measures that mitigate the threat of EHEs on cardiovascular health and overall well-being in general.

Abbreviations

AC	Air-conditioning
BP	Blood pressure
CV	Cardiovascular
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
EEG	Electroencephalogram
EHE	Extreme heat event
EMG	Chin electromyogram
EOG	Bilateral electrooculogram
HR	Heart rate
MD	Mean difference
PRISMA-ScR	Preferred Reporting Items for Systematic reviews and Meta-Analyses-Scoping reviews
SBP	Systolic blood pressure

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13643-024-02742-7.

Additional file 1. Search strategies.

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Not applicable.

Authors' contributions
AG and NA determined the focus of the review, reviewed articles, and were major contributors in writing and editing the manuscript. MD conducted the search and was a major contributor in writing the " Methods " section. SW, MC, and RA reviewed articles. NM, PT, and RN contributed writing and edits. OK contributed significant revisions. All authors read and approved the final manuscript.

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Data availability
All data generated or analyzed during this study are included in this published article and its supplementary information files.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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