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REVIEW

Occupational Heat Exposure & Mental Health Outcomes: A Review and Framework Incorporating Social Determinants of Health to Guide Future Research

Stefani Florez-Acevedo[1] · Maria T. Blancas[2] · June T. Spector[1,2]

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Abstract

Purpose of Review Environmental heat exposure is associated with adverse mental health outcomes in the general population; however, the mental health effects of heat exposure in occupational populations have not been fully characterized. We sought to: (1) review primary research studies on the relationship of occupational heat exposure with mental health outcomes; and (2) synthesize the literature with a proposed framework to identify gaps and opportunities for future research, using an equity lens.

Recent Findings Ten peer-reviewed studies between 1997 and 2024 that met our selection criteria included five cross-sectional, one longitudinal, one mixed-methods, one qualitative, and two experimental/quasi-experimental studies of varying quality. Studies were conducted across five continents covering agriculture, forestry, fishing, hunting; public administration and healthcare; utilities; mining, oil and gas extraction; and glass manufacturing industries. Occupational heat exposure was associated with mental health outcomes including stress, anxiety, mental disorders and burnout in seven of ten studies.

Summary The literature on occupational heat exposure and mental health outcomes among workers is emerging. Future research should address research gaps through high-quality etiologic and solutions-oriented intervention research and should be informed by a framework that considers both upstream and downstream factors, including work psychosocial factors and social determinants of health. Research with worker populations with high current and projected occupational heat exposure and/or a high prevalence of factors associated with an increased risk of adverse mental health outcomes should be prioritized. Work equity should be addressed through partner-engaged methods and co-development of culturally appropriate products, incorporating the contexts and needs of populations at disproportionate risk of adverse mental health outcomes.

Keywords Mental health · Occupational health · Heat stress · Heat exposure · Health equity · Climate change

Introduction

Environmental heat exposure is associated with substantial morbidity, mortality, and adverse mental health outcomes in the general population; however, mental health effects of heat exposure in occupational populations have not been fully characterized. In the general population, heat exposure is associated with heat-related illnesses (HRIs), increased emergency room and hospital admittance, mortality from cardiorespiratory and other diseases, and adverse pregnancy and birth outcomes [1]. A recent systematic review of epidemiological studies reported an increased risk of suicide and hospital attendance or admission for mental illness with increases in temperature and temperature variability [2]. Among outdoor workers, heat exposure is associated with HRIs, traumatic injuries, and acute kidney injury [3], with disproportionate effects among certain worker groups, including in industries with high proportions of immigrant workers [4, 5]. However, the literature on mental health

✉ June T. Spector
spel235@lni.wa.gov

1 Safety & Health Assessment & Research for Prevention (SHARP) Program, Work Equity Research Center (WERC), Washington State Department of Labor & Industries, PO Box 44330, Olympia, WA 98504-4330, USA

2 Department of Environmental & Occupational Health Sciences, University of Washington, Seattle, WA, USA

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effects of heat exposure in occupational populations is limited.

Research in the general population on physiological mechanisms of heat exposure's effects on mental health outcomes [6, 7], and on factors affecting socioeconomic and demographic disparities in heat-related health outcomes [8], can inform plausible pathways of the effects of heat exposure on occupational mental health. Short-term neurophysiological effects during extreme heat include disrupted sleep and alterations in neurotransmitters (e.g., serotonin and dopamine) and hypothalamic-pituitary-adrenocortical (HPA) axis hormones (e.g., 'stress hormones' cortisol and adrenaline), which can lead to mood and cognitive changes [7], irritability, and emotional sensitivity, and reduced coping, motivation, and patience in interpersonal interactions [9]. Heat-induced disrupted functional brain connectivity, alterations in cerebral blood flow, temperature, and oxygen saturation, and neuro-inflammation can also affect cognition [6, 7]. Co-exposures, such as to wildfire smoke, may compound these effects through shared pathophysiological mechanisms such as inflammation [6]. The effects of extreme heat on mental health outcomes may be more pronounced for those with certain chronic diseases, sleep disorders, and those taking certain medications, including medications that affect neurotransmitters [7]. These factors, as well as pre-existing mental health, central nervous system, developmental [7], and substance use conditions [10] may lead to reduced thermoregulatory responses and behavioral adaptations [7], thus enhancing the effects of heat. Loss of family members, friends, property, and possessions and trauma from community displacement during extreme heat events may also result in longer-term mental health impacts [11].

To better inform research on occupational heat-related mental health effects, information about potential physiological mechanisms should be combined with consideration of social determinants of health (SDOH) (i.e., non-medical and non-psychiatric factors and structural conditions that impact health) [12], and modifiable workplace factors. For example, a review of disparities in heat-related health effects in the US general population considered the intersection of various socioeconomic and demographic heat vulnerability factors [8]. These factors included racial or ethnic minoritized status, lower income, lower educational attainment, poorer health, neighborhoods within urban heat islands or with less cooling opportunities, safety concerns that inhibit cooling behaviors, social and linguistic isolation, suboptimal housing, and occupations involving manual labor in hot environments [8]. In the workplace, modifiable risk factors for adverse heat health effects have been well-described, including insufficient hydration, rest, shade, and breaks, non-breathable clothing, insufficient physiological heat adaptation (acclimatization) and high work intensity and duration in the heat [13]. As workers often do not have control over their work and work environment, the most effective heat controls are systemic workplace changes that do not rely on worker behavior, such as engineering controls (e.g., air conditioning, shade) and administrative controls (e.g., cool-down rest breaks with hydration, work during cooler parts of the day, and reduced physical demands) [13]. Workplace factors associated with poor mental health outcomes at the organizational level include poor relationships with managers and co-workers, absence of leadership, poor support and lack of trust in management and institutions, weak organizational and safety culture, and work-family interference [14–17].

Vulnerability factors can combine with exposure to affect risk of mental health outcomes. Vulnerability factors can be further categorized according to whether they affect susceptibility to heat (i.e., sensitivity) or capacity to cope with heat (i.e., adaptive capacity) [18]. For example, health factors and acclimatization status may influence sensitivity while infrastructure and systems that support workplace, home, and community cooling may influence adaptive capacity. Occupational heat stress (which we heretofore refer to as 'occupational heat exposure') includes not only environmental heat exposure but also consideration of physical work duration and intensity, which produces internal body heat, and non-breathable clothing [13]. Exposure, sensitivity, and adaptive capacity factors may not be equitably distributed between and within groups of workers. These categorizations may be useful when considering potential equitable heat prevention approaches.

Average temperatures and the frequency and severity of extreme heat events are projected to increase with climate change [18]. Hundreds of millions of people are already exposed globally each year to levels of heat exposure that are associated with an increased risk of HRI [19], with particularly large population-weighted impacts of occupational heat exposure in parts of South Asia, Africa, and the Middle East [20]. Further increases in heat exposure for outdoor workers are projected with climate change, including large population-weighted impacts in South, East, and Southeast Asia [20]. The likelihood of exposure to overheated indoor environments is also increasing with climate change [21], particularly in settings that lack engineering controls such as air-conditioning and where environmental exposure is compounded by workplace point sources of heat. Further, indoor and outdoor workplace heat protections may be variable, and home and community heat exposure may also contribute to net heat exposure, making it difficult to isolate the specific effects of workplace heat exposure on mental health outcomes.

The purpose of this review is to: (1) review primary research studies on the relationship between occupational heat exposure and mental health outcomes; and (2) synthesize the literature to identify gaps and opportunities for future research with a proposed framework that takes into account SDOH, in addition to modifiable workplace physical and psychosocial factors, using an equity lens. We define equity lens as an approach that examines determinants of health inequities, or the absence of fair and just opportunities for optimal health [22], with an ultimate goal of supporting interventions and policies that reduce health inequities [23]. We used an equity lens by abstracting and describing information on potential determinants of occupational heat-related mental health inequities such as SDOH, in addition to information about study design, exposures, outcomes, and results, in our literature review. We also add to the literature by considering these factors in the development of our framework in order to help guide future research focused on developing a comprehensive understanding of the relative strengths of different mechanisms and pathways between heat exposure and mental health outcomes.

Review of Current Evidence for the Relationship Between Occupational Heat Exposure and Mental Health Outcomes

Methods

We performed a scientific literature review in April 2024 as described in detail in Appendix 1. In brief, selected studies included primary research studies published in peer-review journals with qualitative or quantitative observational, quasi-experimental, or experimental study designs that assessed mental health and heat exposure in an occupational setting. We did not restrict the timeframe of studies or restrict to specific industries and occupations. Ten studies that met our selection criteria were included in this review. We employed an equity lens to guide our review and synthesis of the literature, focusing on determinants of occupational heat-related mental health inequities. To operationalize the equity lens, we systematically extracted and synthesized information on SDOH to assess whether and how included studies addressed social conditions impacting the mental health of heat-exposed workers. This involved abstracting study characteristics (e.g., design, exposures, outcomes), identifying determinants of inequities (e.g., education, income, work conditions), and evaluating the integration of SDOH in the research. By applying this approach, we aimed to highlight potential mechanisms and pathways linking heat exposure and mental health, contributing to a framework that informs equity-focused research and interventions. To assess the quality of quantitative studies, we used an adapted version of the Effective Public Health Project (EPHPP) tool [24]. The domains assessed included selection bias (representativeness and participation rates), confounders, and information bias (data collection methods, including both heat exposure and mental health outcomes). To assess qualitative studies we used an adapted version of the Critical Appraisal Skill Programme (CASP) checklist [25]. Domains assessed included appropriateness of design, study methods, and potential personal bias and influence on data analysis and reporting. Details of the study quality assessment are presented in Appendix 2.

Study Characteristics

Study characteristics are shown in Tables 1, 2 and 3 and Fig. 1. The majority of included studies were observational, mixed-methods, or qualitative studies ($n=8$), and only two were considered quasi-experimental [26] and experimental [27] studies (Table 1). Six of the observational studies employed a cross-sectional design, with sample sizes ranging from 179 to 40,913 individuals [28–33]. One study utilized a longitudinal design with a sample size of 184 participants [34]. Additionally, one observational study used mixed methods with a sample size of 135 participants [32]. One study was classified as a qualitative content analysis, which included in its analysis 433 articles [35]. Both quasi-experimental and experimental studies involved a small sample size of 32 and 16 participants respectively. Only half of the studies presented robust information about how their study sample was selected [29, 30, 33], and only one described the inclusion and exclusion criteria [34]. As shown in Fig. 1, we found studies conducted in countries across all five continents with representation of workers in a variety of occupations and industries, including agriculture, forestry, fishing, hunting; public administration and healthcare; utilities; mining, oil and gas extraction; and glass manufacturing (Table 3).

Social Determinants of Health (SDOH)

SDOH refer to the conditions in the environment where people are born, live, work, play, worship, and age that affect health, well-being, and quality of life outcomes [36]. SDOH are borne from structural determinants of health such as governance, policy, and cultural norms, and shape who has access to opportunities and resources to achieve physical and mental wellness and who does not [37]. Although most studies reported demographic information (e.g., age: in all studies, participants ranged in age from young adults to middle-aged adults; sex: participants were majority or only male), some studies captured more information on

Table 1 Characteristics of included studies: study design, sample size, outcomes, exposures, covariates, methods, and results

Source	Study Design & Sample Size	Outcomes & Exposures	Covariates	Analytical Methods	Effect Estimates & Key Results
Bazo-Alvarez, J. C., et al. (2022)	Cross-sectional analysis of baseline prospective cohort data 281 participants: 175 farmers, 106 non-farmers	*Outcomes*: Mental Health disorders: 12-Item General Health Questionnaire (GHQ-12): Mean ± SD Non-farmers: (1.3 ± 1.9), Farmers (3.1 ± 1.6) *Exposures*: Occupational heat stress index = WBGT: Median ± IQR farmers 28.3 ± 0.6, non-farmers = 28 ± 0 °C	• Demographics • Working hours per day: Median ± IQR = farmers 8.5 ± 1.4, non-farmers 7.8 ± 1.4 h • Use of shade during work break: 27 farmers (25.5%), 126 non-farmers (72%) • Type of contract • Time in the industry • Rest time (min) during working day: Median ± IQR = farmers 17.1 ± 30, non-farmers 30 ± 51.4) • Heavy workload: 90 farmers (84.9%), 63 non-farmers (36.0%) • Exposure to pesticide • Lifestyle covariates (tobacco, alcohol, BMI, & self-rated health)	• Primary analysis: negative binomial regression of relationship between exposure and outcome • Model 1 adjusted for monthly salary, exposure to pesticide, working hours per week, age, & work activity • Model 2: Model 1 + type of contract, time in industry, occ. heat stress, heavy workload • Secondary analysis: combined both groups to identify predictors of mental disorders	For associations with **Mental Health Disorders (GHQ-12)**: • Occupational heat stress index Unadjusted RM: 1.23 (95%CI: 0.90 to 1.68), p-value = 0.191 • Rest time in the working day, Unadjusted RM: 1.00 (95%CI: 0.99 to 1.01) P-value = 0.780 • **Shaded break**: Unadjusted RM: 0.57 (95%CI: 0.43 to 0.76), p-value < 0.001, Adjusted RM:0.73 (95%CI: 0.53 to 1.00), p-value = 0.051 • **Heavy workload**: Unadjusted RM: 1.95 (95%CI: 1.45 to 2.63), p-value < 0.001, Adjusted RM:1.68 (95%CI: 1.21 to 2.33), p-value < 0.001 • **Working hours per day**: Unadjusted RM: 1.17 (95%CI: 1.05 to 1.30), p-value = 0.004, Adjusted RM:1.13 (95%CI: 1.01 to 1.25), p-value = 0.029
Cieślak, I., et al. (2020)	Cross-sectional 578 employees of local branches of Prevention Division of municipal police agency (55.1% of all working municipal police officers in Warsaw in 2016)	*Outcomes*: Stress at Work proprietary, non-standardized questionnaire ("Do you think that occupational stress affects your health?", "Have you ever turned to a psychologist/ psychiatrist for advice?"): Municipal police officers reporting work-related stressors affected their health were more likely to consult with a psychologist/psychiatrist than those who did not (10.1% vs. 1.7%; $\chi 2$=20.152, df=2, P=0.000; V=0.19) *Exposures*: Physical conditions in the workplace proprietary, non-standardized questionnaire (Yes/No, including work at too high/low temperature, 3) contact with infectious materials, 4) physical abuse, threatening, bullying, 5) physical factors do not contribute to my stress)	Other factors evaluated: • Unpredictability at work • Need to be available at all times • Lack of resources, devices & materials • Need to work in a hurry • Organizational factors do not contribute to my stress	• Evaluated relationships between variables using $\chi 2$ Pearson test & Crammer's V effect size. Configure frequency analysis applied to assess correlations between variables	Working at **too high/low temperatures combined with**: physical abuse ($\chi 2$ = 5.2, p-value = 0.001), working in noisy environments ($\chi 2$ = 8.3, p-value = 0.000), and contact with infectious materials ($\chi 2$ = 5.5 p-value = 0.000) significantly accounted for experience of **stress** at work every day or often

Table 1 (continued)

Source	Study Design & Sample Size	Outcomes & Exposures	Covariates	Analytical Methods	Effect Estimates & Key Results
Gelaye, K. A., et al. (2021)	Cross-sectional 950 seasonal migrant farmworkers	*Outcomes*: Common Mental Disorders (CMD) self-reported questionnaire (SRQ-20): CMD prevalence 23.05% (219/950) [95% CI: 20.47–25.84] *Exposures*: Pretested & structured questionnaires. Heat stress: YES 757 (79.68%); HRI: YES 572 (60.21%)	Work hours per day: pretested and structured questionnaire: 8+responses 691 (72.74%)	• Multivariable logistic regression	• **Seasonal farmworkers suffering from HRI** 1.6x more likely to have **CMDs** than those who did not have HRI (AOR = 1.60, 95% CI: 1.11, 2.30) • Perceived stress levels, average daily income, receipt of health information, & longer farm stays also significantly associated with CMDs
Keeney et al. (2023)	Mixed methods: quantitative (cross- sectional), qualitative (open-ended questionnaires, key informant interviews) *Quantitative*: 135 participants: farmers (n = 18) & farmworkers (n = 117) *Qualitative*: 12: farmers (n = 6), and farmworkers (n = 6)	*Outcomes*: Self-reported depression symptomology: Center for Epidemiologic Studies depression screening scale for farmers (CES-D), 20-item instrument: Above cutoff score of 16: Total = 47 (40.2%), males 19 (30.6%), females 27 (49.1%) *Exposures*: Migrant Farmworker Stress Inventory (MFWSI) for farmworkers Farmer stressors: 4-point Likert scale (1 = no stress, 4 = severe stress) from Farm Stress Survey (FSS): Mean (SD) farmers: government regulations & policies 3.39 (0.778), weather 2.50 (0.924), debt load 2.50 (0.924)	Mean (SD) Farmworker stressors: not getting enough sleep 3.10 (1.13), weather 3.09 (1.20), work long hours 3.02 (1.21), Air at work is not clean 2.91 (1.28)	o *Quantitative*: Bivariate analyses to examine associations between demographic variables (e.g., gender, farm role) & mental health risk scores. Simple logistic regression to examine how attribute variables predicted scores of clinical concern o *Qualitative*: Cross-case analysis to identify themes that cut across all cases in both farmer & farmworker groups	o Quantitative: No reported significant effects for farmers and farmworkers between weather & depressive symptoms o Qualitative: Farmers & farmworkers experienced concerns associated with farmworker injury & illness. Farmworkers expressed concerns for lack of comprehensive health insurance o Weather, high temperatures was a cross-cutting stressor for farmers & farmworkers. Farmworkers cited working in extreme temperatures and rain o Long working hours, fatigue, & the physical nature of the work were viewed as factors that impacted farmers' & farmworkers' personal lives

Table 1 (continued)

Source	Study Design & Sample Size	Outcomes & Exposures	Covariates	Analytical Methods	Effect Estimates & Key Results
Mirzaei, E., et al. (2024)	Longitudinal observational 184 workers who worked in teams for >the last 12 mo, were literate, & were not diagnosed with musculoskeletal disorders	*Outcomes*: Mental Stress: Validated (Iran) NASA Workload Index, six subscales measured on a scale of 0-100: Mean ± SD mental stress 80.8 (±9.9), physical pressure 85.1 (±8.8), time pressure 83.5 (±9.2), performance 84.6 (±11.1), attempt & effort 74.1 (±13.3), frustration 58.4 (±15.8) *Exposures*: • WBGT Mean ± SD = 32.01 ± 1.7 °C • Heat Stress: Validated temperature stress screening checklist: Six parameters including *air temperature* (Score + 2: 79.9% of work station; Score + 1: 20.0% of work stations), *humidity* (Score + 1: 100% conditions), *radiant temperature* (Score + 2: 27.4% of work stations; Score + 1: 72.6% of work stations), *air flow* (Score + 2: 21.7% of work stations; Score + 1: 78.3% of work stations), *workload*: (Score + 2: 79.9% of work stations; Score + 1: 20.1% of work stations), *clothing* (Score + 3: 100% conditions), and *worker's opinion* (Undesirable (+3): 75.5% of people, Being desirable (+1): 24.5% of people)	• Age • Height • BMI • Level of education • Work experience	• Comparison between summer & winter seasons • Logistic Regression Modeling • Pearson correlation coefficients • Independent and dependent t tests	• More **mental stress** (Mean differences= -3.64, t (183) = -7.6, $p < 0.001$) and frustration (Mean differences= -7.83, t (183) = -5.8, $p < 0.001$) during the **winter compared to the summer.** • No adjusted estimates presented
Liu, J., et al. (2019)	Cross-sectional 179 (89.95%) participants (initial sample 199)	*Outcomes*: Psychological well-being: Multidimensional SCL-90-R scale: 22 (12.3%, 95% CI 7.4–17.1%) had a positive indication of a psychological problem, defined as a total SCL-90-R score of ≥160 points, ≥43 positive items, or a score≥2 on any subscale *Exposures*: Pressure, relative humidity, temperature (testo480, Testo, AG, Germany); total γ radiation dose-rate (AT1123, ATOMTEX, Belarus); & oxygen concentration: Temperature increased from 11.9 °C at 60 m depth to 28.8 °C at 1470 m depth • Adverse factors in the deep-underground: study-specific questionnaire 1. Negative impression of ambient conditions: 97.2% 2. Worried about safety while working: 75.9% 3. >1 adverse factor caused discomfort while working, including moisture (74.9%), heat (33.5%), poor ventilation (32.4%), dim light (26.8%), and narrow space (18.9%) 4. More than 1 self-reported negative physical symptom while working, including being easily tired (30.7%), thirst (25.7%), headache (17.9%), nasal obstruction & breathing difficulties (11.7%), & cold sweats (9.5%)	• Insomnia • Longest continuous staying time in underground • Number of adverse factors • Number of physical symptoms • Depth	Multivariable analyses to identify significant predictors of SCL-90-R scores	• **More than 1 perceived adverse factor in the deep underground** was a significant predictor of high **SCL-90-R** scores (β = 0.8, p-value = 0.001) • **Continuously spending > 8 h in the deep-underground space** was a significant predictor of high **SCL-90-R** scores (β = 0.6, p-value = 0.001)

Table 1 (continued)

Source	Study Design & Sample Size	Outcomes & Exposures	Covariates	Analytical Methods	Effect Estimates & Key Results
Smith, D. L., et al. (1997)	Experimental (pre/post) 16 firefighters: hot condition/experimental group ($n=7$, with 1 not included in analysis), neutral condition/control group ($n=8$)	*Outcomes*: • Trait anxiety: 20-item Trait Anxiety Inventory (baseline): Mean = 32.4 (SD 8.4) • State Anxiety: Validated & modified 10-item version of State Anxiety Inventory (before, immediately after, & 10 min after task) *Exposures*: • Simulated firefighting task: drill that simulated a ceiling overhaul while inside a 2-story, concrete training building. 16-min task divided into two, 8-min segments • Participants randomly assigned to perform task under one of two conditions: (1) neutral (13.7 ± 1.6℃, with no fire) condition; (2) hot & hostile condition (89.6 ± 16.6℃, with a fire), with temperatures measured at three different locations using thermocouples mounted ~ 107 cm from the floor • For both conditions (neutral, hot), subjects wore standard firefighting turnout gear, including 8.5 oz PBI shell with Gortex barrier, quilted liner, Servus bunker boots, Nomex hood with full gauntlet, Fire Grip gloves, Cairns helmet, and a self-contained breathing apparatus (SCBA). The total weight of ensemble averaged 22. 5 (±2.1) kg for both conditions		Separate repeated measures analyses of variance (ANOVA) for each dependent measure, repeated over time	• **State anxiety increased significantly following the hot condition** whereas there was little change following the neutral condition • Repeated measures ANOVA: significant Condition*Time interaction [$F(2,26) = 4.90$, $p = 0.02$]. Whereas state anxiety was reduced in both conditions following the 10-min recovery period, state anxiety remained significantly elevated from baseline following the hot condition
Tetzlaff, E. J., et al. (2024)	Qualitative (systematized review & content analysis) 433 articles from the broader study data set ($n=2909$) that included content related to workers/workplace settings were identified as information-rich cases for this secondary analysis	*Outcomes*: Occupational Burnout, including exhaustion, cynicism, professional efficacy *Exposures*: • Job demands, including work overload, emotional demands, physical demands, work-home interference • Job resources, including autonomy, social support, relationship with supervisor, performance feedback		Development of a working codebook of concepts, positive indicators, & textual examples inductively. Codebook was circulated to all authors for review & agreement	• During the heat dome, work overload, emotional demands & physical demands are significant factors contributing to burnout among employees • Elements in Composite Narratives: Workload: All professions mentioned experiencing a surge in demands and calls due to the extreme heat event. Emotional demands: prolonged periods of intense work, time pressures, resource depletion, & emotional strain • Physical demands: carried out physically demanding tasks such as rescuing individuals, standing or walking for prolonged periods, & performing life-saving measures while donning heavy protective gear and equipment

Table 1 (continued)

Source	Study Design & Sample Size	Outcomes & Exposures	Covariates	Analytical Methods	Effect Estimates & Key Results
Tawatsupa, B., et al. (2010)	Cross-sectional 24,907 workers whose job type was known & who did not make non-thermal work hazard complaints in secondary analysis from the Thai Cohort Study Initial analysis group included 40,913 full-time workers for overall heat stress analyses	*Outcomes*: Psychological distress: 3 anxiety-oriented questions from the standard Kessler 6 psychological distress questions: 8% of workers, reported by 20% of those with 3–5 other work hazards Self-reported poor overall health, from 1st question of the Medical Outcomes short form instrument (SF8). Nearly 5% of workers reported poor overall health, 9% of those with 3–5 other work hazards *Exposures*: Heat Stress: One question '*During the last 12 months, how often have you experienced at work high temperatures which make you uncomfortable?'*, dichotomized into often or not often for analysis. Experience high temperature: Often = Male (22.5%), Female (14.9%); Sometimes = Male (34.1%), Female (28.5%); Rarely = Male (26.1%), Female (29.8%); Never = Male (17.3%), Female (26.8%)	• Sex • Age • Job location • Job type • Education • Income • Other work hazards	• Multivariable logistic regression • Stepwise logistic regression included only significant confounders & heat stress interaction terms	• For **psychological distress**, the corresponding final adjusted ORs of **heat stress** were significant & similar for females and males: females 2.21 ($P < 0.001$ for $n = 40{,}913$) and males 2.17 ($P < 0.001$ for $n = 24{,}907$) • Cohort members who experienced **heat stress** at work had higher odds of **poor overall health** (crude OR = 1.67, P-value < 0.001; adjusted OR = 1.49, P-value < 0.001)
Vangelova, K., et al. (2002)	Quasi-experimental 32 participants: Experimental group in workplaces with heat exposure ($n = 16$); Control group in workplaces without heat exposure ($n = 16$)	*Outcomes*: Psychosocial Factors: Self-reported questionnaire (5 subscales with 80 items): Mean ± SD subscales included *working conditions* Experimental 9.72 ± 2.54, Control: 8.60 ± 2.64, *job content* Experimental: 9.35 ± 2.36, Control: 8.00 ± 2.23, *job control* Experimental: 6.10 ± 2,17, Control: 6.10 ± 1.96, *social support* Experimental: 3.75 ± 1.48, Mean 3.66 ± 1.44, *health complaint* Experimental: 9.24 ± 4.06, Control: 10.1 ± 3.63 Excretion rates of cortisol, adrenaline and noradrenaline: Radioimmunoassay (RIA) kit. Urine samples collected at 3 h intervals *Exposures*: WBGT: Mean (range) WBGT for Experimental group: 36.9 (29.3–41.7 °C)		One-way analysis of variance (ANOVA)	• No significant differences in the psychosocial factors between the two groups • **Higher cortisol values in heat exposed operators vs. control group** (F = 20.344, $p = 0.002$ and F = 9.927, $p = 0.0037$ for period 1 & period 2, respectively) • **Adrenaline excretion** significantly higher during period 1 in the heat exposed operators (F = 7.269, $p = 0.0135$) & increased during period 2 in both groups, but increase in heat exposed group was greater & with significantly higher adrenaline values (F = 23.502, $p = 0.0000$) • **Noradrenaline excretion** followed the same trend. Higher noradrenaline values measured during period 1 (F = 3.735, $p = 0.06$) & significantly higher during period 2 (F = 1 6.344, $p = 0.0003$) in the exposed group

BMI (Body Mass Index); Common Mental Disorders (CMD); Confidence Interval (CI); Odds Ratio (OR); Ratio of Means (RM); Standard Deviation (SD); Wet-Bulb Globe Temperature (WBGT); Statistically Significant Associations are **Bolded**

SDOH while others captured less (Table 2), and few studies addressed SDOH as covariates in their analyses or the interaction of SDOH with other variables (Table 1). Although relevant, it was beyond the scope of this review to identify studies that focused solely on examining the direct effects of SDOH on occupational mental health outcomes.

Among studies that reported information about SDOH, there were differences in educational attainment of participants depending on the occupation. Studies in agriculture indicated that farmworkers had lower levels of educational attainment compared with non-farmworkers [28, 30, 32]. Likewise, in the mining industry, most miners had less than a high school education [31]. Studies with workers in multiple industries revealed that female workers who enrolled in distance learning programs had higher professional educational attainment than male workers [33]. Studies in agriculture, forestry, fishing, and hunting industries were conducted in rural areas [28, 30, 32]. Two studies mentioned that their participants were migrant farmworkers coming from other regions or countries [30, 32]. Studies related to public

Table 2 Characteristics of included studies: study context, population, industry, occupation, demographics, and SDOH

Source	Study Context	Population/Industry/Occupation Characteristics	Demographics (Age and Sex) & SDOH
Bazo-Alvarez, J. C., et al. (2022)	• Rural farms in N. Peru • Minimal or non-existent mental healthcare in rural areas in Peru • Sugarcane farmworkers were subcontracted & paid by the piece	Sugarcane industry • farmworkers: cane cutters, seeders, & seed-cutters; • non-farmworkers: management, logistics, quality assessment, & supervisory activities • Time of work in the industry (years), median ± IQR: (farmers: 10 ± 13, non-farmers: 11 ± 14)	• Age: Mean (SD, range) 41.4 (11.2, 18–60) yrs • Sex: 100% male • Race/Ethnicity: Latinos, Peruanos • Language: Spanish • Education: <7 yrs (20.6%) (farmers: 40.6%, non-farmers: 8.6%) • Marital Status: married/cohabiting (farmers: 77.4%, non-farmers: 65.1%); divorced/separated/single (farmers: 22.6%, non-farmers:34.9%) • Monthly salary: High (farmers: 32.1%, non-farmers: 40%); Low (farmers: 67.9%, non-farmers: 60%)
Cieślak, I., et al. (2020)	• Apr.-Sept. 2015 in Warsaw, Poland • Prevention Division: Largest & most numerous municipal police structure • Main task: to protect public order & to ensure peace in Warsaw	Police officers • Prevention Division included: Senior Inspector 118 (20.4%), Municipal Police Officer 94 (16.3%)	• Age: Mean ± SD 43 ± 8.5 yrs • Sex: Male 419 (72.5%) • Education: Primary 21 (3.6%) Secondary 317 (54.8%) Higher 240 (41.5) • Seniority ≤3 yrs 11 (1.9%), 4–7 yrs 75 (13.0%), 8–11 yrs 153 (26.5%), 12–15 yrs 75 (13.0%), > 15 yrs 264 (45.7%) • Marital Status: Married 401 (69.4%) • Having children: Yes (78%), No (22%)
Gelaye, K. A., et al. (2021)	• West Gondar zone in Ethiopia • Data collected Feb.-Mar. 2019 • Large populations of seasonal migrant farmworkers • Temperature range 22–43 °C	Seasonal migrant farmworkers coming mostly from central Amhara region • Working time > 8 h a day 691 (72.7%)	• Age: Median (IQR, range) 25 (20–29, 13–67) yrs • Sex: Male 943 (99.3%) • Religion: Orthodox Christian 932 (98.0%) • Rural residents 832 (87.6%) • Married 243 (25.6%) • Education: Primary 406 (42.8%), Secondary and higher: 97 (10.2%) • Daily Income: > 5 USD = 538 (56.6%) • Migration more than twice to the study region 772 (81.3%) • Access to health information 566 (60%)
Keeney et al. (2023)	• Imperial County, CA • Data collected Mar. 2020-Aug. 2021, during COVID-19 pandemic • High number of Hispanic/Latino agriculture, forestry, and fishing workers, poverty, & poor health in Imperial County • About 1/2 of farmworker population travels from Mexico • 30.1% of general population born outside the US • Most farmers in Imperial County are white (95%), male (81%), and > 35 yrs (90%)	Farmers (owners or operators of farms) & farmworkers (employed by farms to work in the field)	• Age: Mean (SD) Total 46.7 (13.5); Farmers 47 (15.4); Farmworkers 46.6 (13.3) yrs • Sex: Male: Farmers 16 (89%); Farmworkers 62 (53%) • Spanish language: Farmers 2 (11%); Farmworkers = 117 (100%) • Ethnicity: Latino/Hispanic: Farmer 1 (6%); Farmworker 117 (100%) • Farm role: Farmer 18 (13.3%); Farmworker 117 (86.7%) • Education: No school: farmworkers (3%); Elementary-Middle School: farmworkers (48%); High School: farmers (22%), farmworkers (35%); Higher education: farmers (78%), farmworkers (14%)
Mirzaei, E., et al. (2024)	• Iran • Hot and dry summer weather • Data collected starting in 2021 during a summer & winter season (same yr)	• Workers on rescue & disaster teams at Shiraz Water & Sewerage Company • Work Experience in current job: Mean ± SD 8.77 ± 4.60 years • Work hours per day: Mean ± SD 12.07 ± 0.43 • Number of working days per week: Mean ± SD 4 ± 0	• Age: Mean ± SD (range) 35.8 ± 6.11 (25–59) yrs • Sex: 100% males

Table 2 (continued)

Source	Study Context	Population/Industry/Occupation Characteristics	Demographics (Age and Sex) & SDOH
Liu, J., et al. (2019)	• Jiapigou Minerals Limited Corporation of China National Gold Group Corporation workers • Study conducted Jan.-Apr. 2018 • Median longest continuous time spent in deep-underground space: 8 (IQR: 8–8; range: 4–60) hrs • Median hrs per week spent in deep-underground space: 56 (IQR: 8–56; range: 1–72) • Temperature increased from 11.9 °C at 60 m depth to 28.8 °C at 1470 m depth. Relative Humidity increased from 30.3% at 60 m depth to 99% at 1470 m depth	Underground miners • Median length of employment at mine: 15 years (IQR: 8–20; range: 1, 33 years)	• Age: Mean (SD, range) 44.2 (7.3, 21–57) yrs • Sex: 100% male • Education: Junior middle or lower: $n=111$; Senior middle or higher: $n=68$
Smith, D. L., et al. (1997)	• April 1993 • Ambient temperatures for 2 days of testing 14.4–16.7 °C with relative humidity 50–97%	Career & volunteer firefighters attending a Breathing Apparatus Specialist course at University of Illinois Fire Service Institute	• Age: Mean 29.8 (5.2) yrs • Sex: 100% male
Tetzlaff, E. J., et al. (2024)	• Canada during the 2021 Heat Dome identified between Jun. 1, 2021-Feb. 26, 2022 • Histories from workers in British Columbia, Alberta, Saskatchewan, and Manitoba	First respondents including: Paramedics ($n=243$ articles), Firefighters ($n=139$ articles), Police Officer ($n=133$ articles), Dispatcher ($n=94$ articles)	N/A
Tawatsupa, B., et al. (2010)	• Thai Cohort Study (began in 2005)	Thai workers • Workers in Bangkok: Male (17.2%), Female (21.8%); urban areas outside Bangkok: Male (42.3%), Female (39.3%); rural areas: Male (40.5%), Female (38.9%) • Job Type: Office: Male (81%), Female (85.2%); Physical: Male (19%), Female (14.8%) • Other Work Hazard Complaints aside from high temperatures: No Other complaints Male (69.8%), Female (72.4%); 1–2 more complaints Male (24.4%), Female (24.2%); 3–5 other complaints Male (5.8%), Female (3.4%)	• Age range: 15–87 yrs • Sex: Male (44.7%), Female (55.6%) • Education: University Male (29%), Female (30.4%); Diploma Male (27%), Female (36.1%); High School Male (44%), Female (33.5%) • Monthly Income (Baht/mo): 20,001 + Male (14.1%), Female (8.5%); 10,001–20,000 Male (35%), Female (25.7%); 7,001–10,000 Male (28.2%), Female (29.1%); <7,000 Male (22.7%), Female (36.7%)
Vangelova, K., et al. (2002)	Glass manufacturing, during a hot period of the year	• Workplaces with heat exposure: mean (range) air temperature 38.9 (32.7–47.3) °C, air velocity 0.8 (0.3–2.3) m/s, relative humidity of 17.5 (12.8–22.2)%. Workplaces without heat exposure: mean (range) air temperature 31.4 (29.0–32.7)°C, air velocity 0.37 (0.09–0.60) m/s, relative humidity 22.7(17.6–26)% • Four consecutive early morning shifts (6.30–14.30), two days off, four afternoon shifts (14.00–22.00), followed by two days off with moderate workload (both groups)	• Age: Mean ± SD Experimental group 35.9 ± 11.3; Control group 35.9 ± 11.5 yrs • Length of Service: Experimental group: 15.9 ± 11.4 yrs. Control group: 20.3 ± 12.5 yrs

Interquartile Range (IQR); Standard Deviation (SD); Social Determinant of Health (SDOH)

administration and healthcare industries were conducted in metropolitan areas, and those with workers in multiple industries were similarly distributed in urban and rural areas [33]. Studies in industries such as utilities, mining, and glass manufacturing did not specify if their location and workers belonged to rural or metropolitan areas [26, 31, 34].

In addition to the geographical and climate conditions (Fig. 1 & Table 2, study context column), including hot

Table 3 Study industries and occupations

Industry	Occupation	Study
Agriculture, forestry, fishing, hunting	Sugarcane industry farmers & non-farmers	Bazo-Alvarez 2022
	Seasonal migrant farmworkers	Gelaye 2021
	Farmworkers & farmers	Keeney 2023
Public administration & healthcare	Municipal police officers	Cieślak 2020
	Firefighters	Smith 1997
	First responders	Tetzlaff 2024
Utilities	Water & sewage workers	Mirzaei 2024
Mining, quarrying, oil, & gas extraction	Miners	Liu 2019
Manufacturing	Glass manufacturing workers	Vangelova 2002
Multiple (population-based study)	Multiple (population-based study)	Tawatsupa 2010

and dry environments mentioned in several studies [30, 34], work conditions such as long working hours and high work demands can increase the risk for negative physical and mental health outcomes [38] and magnify the health disparities that historically marginalized workers (including low-wage workers, immigrant workers, women, people with disabilities, etc.) endure [39, 40]. Farmworkers, miners, water and sewage workers, and public administration and healthcare workers reported being exposed to long working hours and heavy work [28, 30, 31, 32, 34, 35]. Workers in outdoor spaces reported less access to shade and resting time [35] and being exposed to polluted air most of the workday [32]. Indoor workers reported working in small spaces with poor ventilation and high humidity [30, 34] and reported other concerns about their work conditions aside from being exposed to high temperatures [33].

Occupational Heat Exposure and Mental Health Outcomes

Occupational heat exposure was assessed in all studies, per our study inclusion criteria. However, there were inconsistencies in how researchers assessed heat exposure, and we observed variability in the levels of heat exposure assessed. Three studies [26, 28, 34] used the wet-bulb globe temperature (WBGT), a combined metric that takes into account air temperature, humidity, solar radiation, and wind speed and is associated with HRI risk [13].

WBGT in these studies ranged from a median of 38 °C on sugarcane farms [28] to a mean of 42 °C in a glass manufacturing setting [26]. None of these studies simultaneously assessed all elements of occupational heat exposure -- environmental heat exposure (e.g., WBGT), workload, and clothing -- as they relate to mental health outcomes [26, 28]. In addition to WBGT, one study in a gold mine used a digital meter to measure temperature and relative humidity

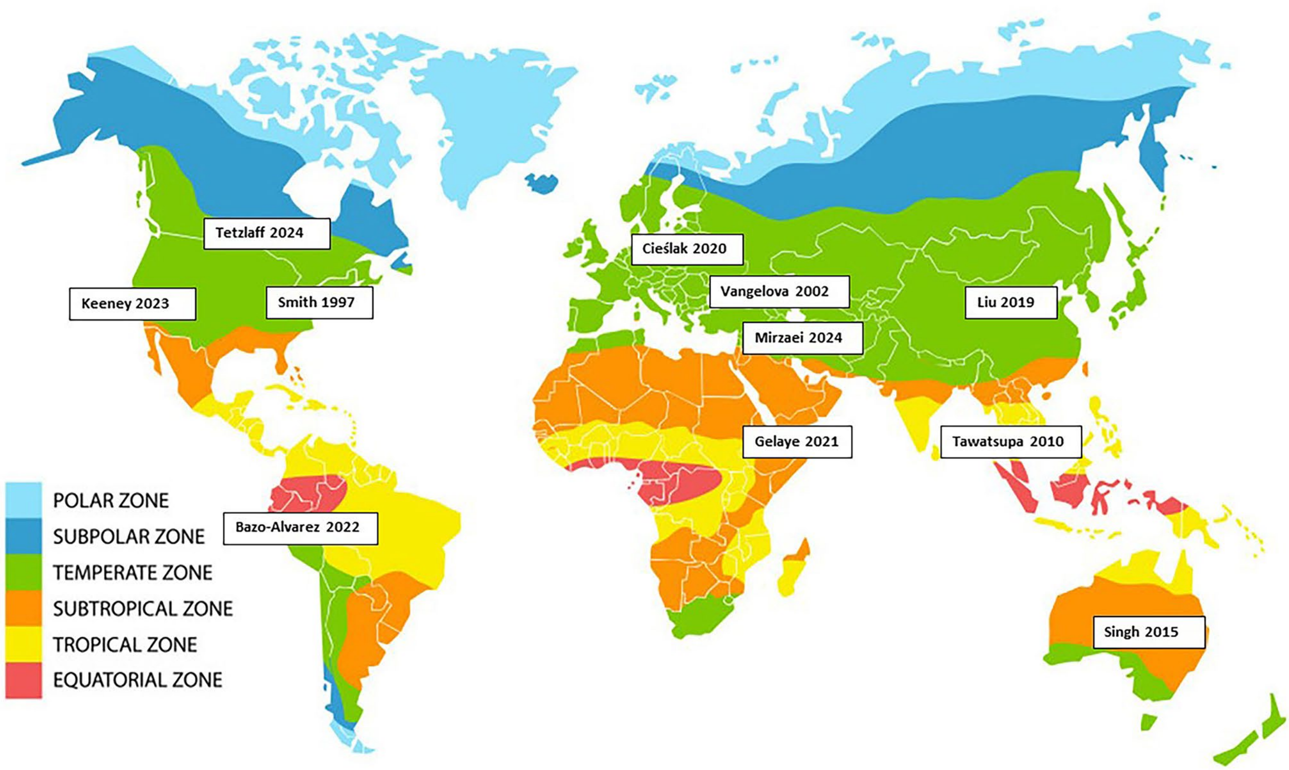

Fig. 1 Geographical distribution of studies by climate zone. Locations are not exact. Map image credit: iStock.com/SiberianArt

[31]. In the experimental study, firefighters were exposed for 16 min to 90 °C versus 14 °C conditions, assessed using a thermocouple device [27]. Other studies did not measure heat exposure, but rather used validated scales [32, 34] or non-standardized questionnaires [29, 30, 33]. These scales and questionnaires focused on different self-reported aspects related to heat exposure including weather [32], occupational heat exposure elements (e.g., temperature, humidity, radiant temperature, air flow, workload, clothing) [34], high/low temperature [29], heat stress [30], and uncomfortable high work temperatures. The content analysis study did not directly assess heat exposure but rather selected histories for analysis that focused on the 2021 extreme 'heat dome' event in Canada [35].

Mental health encompasses a wide range of disorders and conditions, and there was inconsistency among researchers in the terminology used to conceptualize mental health. Results showed that three studies assessed symptoms of depression [28, 32] and anxiety [27]. In contrast, the remaining studies assessed occupational stress [29], mental illness [30], mental stress [34], psychological distress [33], psychological problems [31], occupational burnout [35], and psychosocial factors [26]. To measure these constructs, most of the studies employed different standardized metrics, including the General Health Questionnaire, the Generalized Anxiety Disorder Scale, the Patient Health Questionnaire-9, the Symptoms Cheklist-90-Revised, the Trait Anxiety Inventory, and the State Anxiety Inventory. However, two studies utilized non-standardized and self-reported questionnaires [29, 32]. In general, a substantial proportion of workers screened poor in mental health in each industry (Table 1, outcomes column). Studies in agriculture showed that farmworkers reported poor mental health [28] and higher perceived stress [30], and that female farmworkers scored higher in depressive symptoms than males [32]. Likewise, studies in utilities and mining reported high scores in mental stress [34] and psychological problems [31]. Interestingly in the glass industry, although there were no statistically significant differences in the distribution of psychosocial factors that affected mental health between workers exposed to heat and those who were not, working conditions (e.g. working pose, lighting, noise, vibrations, humidity, dust, odor) and job content (cyclical work, monotony, intense concentration, organization of work, safety concerns) were prominent factors for those exposed to heat [26].

Effect Estimates and Results

Occupational heat exposure was statistically significantly associated with mental health outcomes in seven of ten studies (Table 1). Workers in multiple industries who experienced heat exposure at work had 2.21 higher odds of psychological distress and 1.67 odds of poor health compared to those workers who were not exposed [33]. Similarly, in the agriculture industry, farmworkers exposed to heat were 1.6 times more likely to have common mental disorders (CMDs) than those who were not [30]. Qualitative analyses reported that high temperatures were a cross-cutting stressor for farmers and farmworkers, negatively impacting their quality of life [32]. Workers exposed to high temperatures along with other adverse occupational factors, such as noisy environments, physical abuse, contact with infectious materials [29], or long shifts underground [31], experienced significantly poorer psychological well-being ($\beta = 0.8$, p-value $= 0.001$) in the mining industry [31] and greater occupational stress in the public administration and healthcare industries [35]. High temperatures were also significantly associated with state anxiety for firefighters [F [2, 26] = 4.9, p-value = 0.02] [27]. Additionally, qualitative analyses revealed that working in high temperatures exacerbates factors contributing to burnout, such as work overload and emotional and physical demands placed on workers, in the public administration and healthcare industries [35].

Three studies did not report any association between occupational heat exposure and mental health. One study in the agriculture industry measured occupational heat exposure and mental health disorders but did not examine the direct relationship between these two constructs [28]. In the utility industry, a study found that workers experienced more mental stress (Mean difference: -3.64, t (183) = -7.6, $p < 0.001$) and frustration (Mean difference: -7.83, t(183) = -5.76, $p < 0.001$) during the winter than in the summer [34]. Finally, in the glass manufacturing industry, although workers exposed to high temperatures had higher levels of stress-related hormones such as cortisol, adrenaline, and noradrenaline, there were no statistically significant differences in psychosocial factors compared to workers who were not exposed to heat [26].

Study Quality

Both representativeness of the study population and participation rates were evaluated to assess selection bias for quantitative studies. Two studies [29, 30] included participants who were likely to be representative of the target population. Six studies [27, 28, 31–34] were not fully clear on recruitment processes or implications for workers in the same industry/occupation. One study [26] did not describe selection criteria. Half of the studies [26, 27, 31, 32, 34] did not describe participation rates. Four studies [28–30, 33] reported participation between 60 and 79%. No studies presented characteristics of participants that were not included, compared to included participants.

Our assessment of confounders identified two studies [27, 30] that addressed a large proportion of the relevant confounders in the design or analysis. Four studies addressed a moderate proportion of relevant confounders [26, 28, 31, 33], and three studies addressed a smaller proportion of confounders [29, 32, 34]. Seven of the quantitative studies used valid and reliable measurements for outcomes [27, 28, 30, 31, 32, 33, 34]. For the two remaining quantitative studies, one [29] used a valid but not a reliable tool for outcome measurement, and the other [26] did not use a valid or reliable outcome measure. Most of the studies [26, 29, 30, 33, 34] used a valid but not a reliable method for exposure assessment. Two studies [27, 28] used valid and reliable exposure assessment methods, and two studies [31, 32] did not.

For the two studies that used qualitative methods, we found that the research design of one study was appropriate to address the aims of the research [35] while the other study did not justify the methods and used different approaches for their two participant groups of interest [32]. We found that recruitment and sample size were justified in one study [32], while in the other study, although there was limited description of how the researchers developed the composite of their narratives, there was a rigorous co-coding process [35]. Researchers did not report examining their own role, potential bias, or influence during the analysis and presentation of results for either qualitative study. Detailed quality ratings for each study are provided in Appendix 2.

Synthesis of the Relationship Between Occupational Heat Exposure and Mental Health Outcomes: Proposed Framework and Research Gaps

Although current evidence suggests an association in the general population between heat exposure and mental health outcomes [2] and plausible mechanisms for this effect [6, 7], the literature on occupational heat exposure and mental health outcomes among workers is still emerging. Existing studies raise the possibility of an association between occupational heat exposure and adverse mental health effects, but variability in the working populations studied, study design, setting, heat exposure assessment, outcome assessment, study quality, and limited consideration of SDOH present a challenge for global interpretation of this relatively small body of literature, in the absence of further study. A framework could help guide future research and interpretation of results.

Framework Elements

We propose a working framework of the relationship between occupational heat exposure and mental health outcomes that incorporates: (1) existing research findings and considerations arising from review of primary research studies and the broader literature; and (2) occupational health & safety (OHS) conceptual models that include SDOH and workplace factors associated with poor mental health outcomes, in addition to other concepts such as workplace physical hazards and individual characteristics. We incorporated multiple sources to ensure that the framework encompasses components from our review that are grounded in evidence and also broader gaps and areas for future investigation. The purpose of the framework is to: (1) assist researchers in broadly considering what relevant variables and domains to assess and what role these variables may play in studies of occupational heat-related mental health outcomes; and (2) outline different potential pathways in the relationship of heat exposure and mental health that researchers may wish to study to determine their relative strengths. The framework is intended to be a working framework that is modified as new research emerges and is not intended to suggest which pathways are dominant until the quality and quantity of research increases.

As occupational heat exposure disproportionately affects certain worker groups [4, 5], our framework draws heavily from Lipscomb et al.'s OHS model of work and health disparities [41]. This model considers workplace physical and psychological exposures, healthcare and other benefits, home and community factors, and other structural factors such policies and regulations, economic context, and discrimination that may interact to impact workers' well-being, as illustrated in the description of our framework below. Our framework additionally considers work equity by incorporating modifiable factors that may ultimately inform equitable prevention and intervention approaches. Work equity is the intersection of: (1) health equity, or the assurance of conditions that enable all individuals to attain their full potential for well-being; and (2) workplace equity, which supports equal rights to safe and healthy work environments, OHS policies, and labor laws, regardless of individual, job, employment, or occupational characteristics. Work equity exists when a person's occupation and work environment can no longer predict injury or illness [42].

Proposed Framework

Our proposed framework (Fig. 2) broadly includes mental health outcomes that have been studied in the context of heat exposure in both the general population and occupational health literature, including depression & anxiety [27, 32], occupational stress & burnout [29, 35], and suicide & suicidal behavior [2]. However, other relevant mental health outcomes may emerge over time with further study such as Post-Traumatic Stress Disorder (PTSD). Heat exposure is defined broadly to capture the different definitions of heat

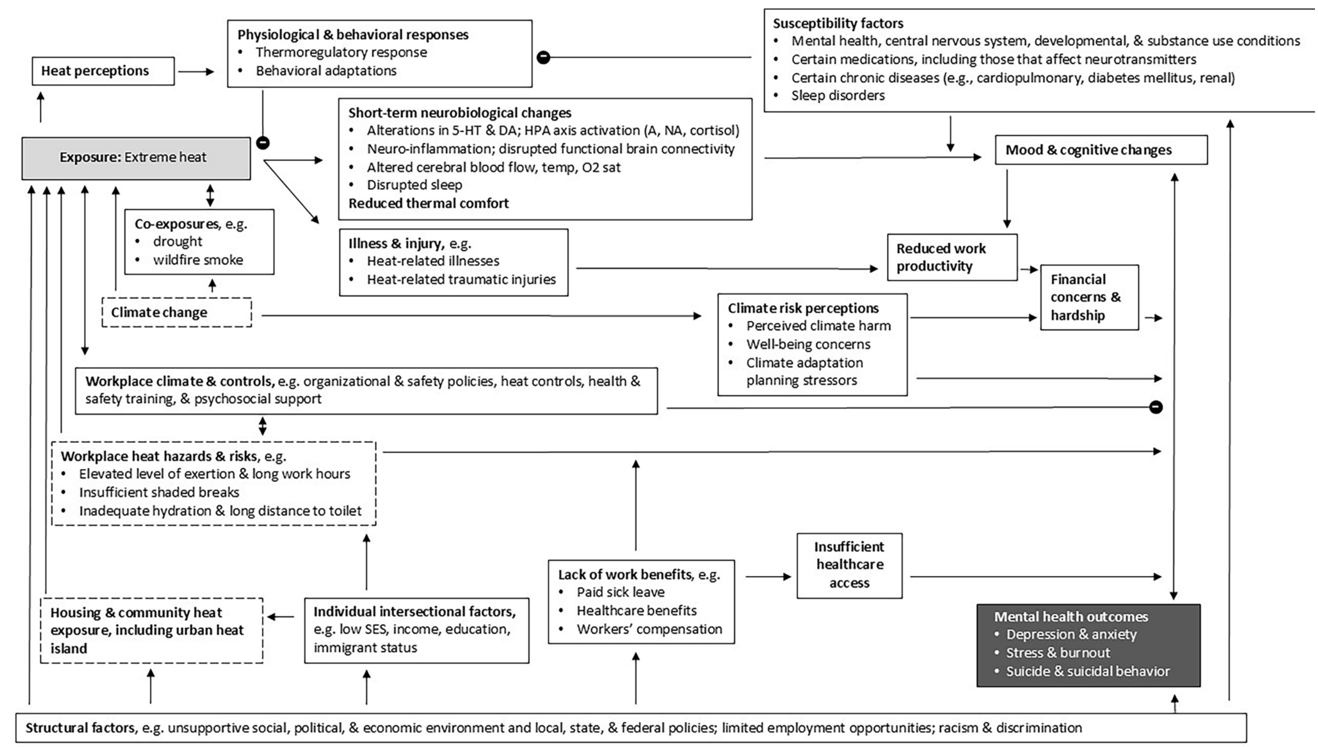

Fig. 2 Framework with potential elements to consider in future studies of the relationship between occupational heat exposure and mental health. The dark gray box indicates mental health outcomes, and the light gray box indicates heat exposure. Boxes with dotted lines indicate factors that directly influence or enhance the effects of heat exposure. Lines indicate that: (1) the factor at the arrow tail may influence or enhance the effects of the factor at the arrow head; (2) the factor at the arrow tail may inhibit the factor at the black circle with white minus sign; or (3) factors on either side of the line may positively or negatively influence each other (double-headed arrow). The framework is intended to be a working framework that is modified as new research emerges, integrates established findings and emerging evidence, and aids in identifying areas for future investigation. It is not intended to be fully comprehensive or suggest which pathways are dominant until the quality and quantity of research increases

exposure used in the literature to date [2, 26, 27, 28, 35, 44]. Intermediate outcomes include mood & cognitive changes [2, 27, 32], which are associated with heat-related neurobiological changes [26] and thermal comfort [6, 7, 31, 33]. Mood and cognitive changes, HRIs, and heat-related traumatic injuries may reduce work productivity [1, 43, 45] and generate financial strain and hardship [30, 32] that contribute to mental health outcomes. Perceived harm from climate change, well-being concerns and stressors related to climate adaptation may also be associated with financial strain and hardship [44]. In our framework, heat exposure is conceptualized not only in relationship to occupational heat exposure factors (i.e., ambient exposure, physical exertion, non-breathable clothing, hydration, breaks, and incentives to work longer and harder such as payment for the amount of work performed [28, 31, 34, 46, 47]), but also outside of work within housing [48] and the community, which comprise additional sources of cumulative heat exposure that workers experience. Effective workplace heat controls, policies, training, supportive psychosocial climates, and organizational and safety cultures may mitigate exposure and mental health effects [29, 35, 49]. Co-exposures, including drought and wildfire smoke, which may share pathophysiological mechanisms with heat [6, 44], are also included in the framework. Heat perceptions stimulate physiological (e.g., thermoregulatory) responses & behavioral adaptations, which can mitigate the effect of heat exposure on neurobiological changes, HRIs, and heat-related injuries [1]. Thermoregulatory responses and behavioral adaptations may, in turn, be reduced by certain susceptibility factors (e.g., certain medications, substances, mental health conditions, chronic diseases, and sleep disorders) [7].

In addition to workplace hazards and risks, benefits associated with work (e.g., paid sick leave, healthcare benefits, and workers' compensation) and healthcare access (e.g. behavioral and mental health services) are included in our framework, following the Lipscomb et al. model [41]. Without these supports, workers may experience additional stressors related to working while ill or losing their income if they are unable to access timely healthcare in order to recover and work [28, 30, 41]. High cognitive load and family & community stressors, particularly stigma [50] and isolation [8], may exacerbate the effect of heat exposure on mental health outcomes. We used an asset-based approach rather than focusing solely on ways in which structures harm workers by considering community, family, and individual resilience factors, which could help mitigate the effects of heat exposure on mental health [8]. We importantly include structural factors (e.g., social, political, economic, policy, and racism & discrimination), which influence many of the other included concepts (e.g., housing, community, workplace, healthcare, and health factors) [51, 52]. Though not directly modifiable, we account for individual factors (e.g., low SES, income, educational attainment, immigrant status) which may intersect to influence the risk of mental health outcomes.

Gaps in Occupational Heat-Related Mental Health Research

When compared with our framework (Fig. 2), the reviewed occupational heat-related mental health literature exhibits multiple gaps. Though one study evaluated the relationship between heat exposure and hypothalamic-pituitary-adrenocortical (HPA) axis activation among glass manufacturers [26], no other occupational studies that we identified have investigated potential neurobiological or behavioral mechanisms underlying the relationship of occupational heat exposure with mental health outcomes. Our review did not identify any studies examining the association of occupational heat exposure with PTSD, though studies in the general population have examined PTSD as an outcome among people exposed to other extreme weather events [53]. Female agricultural workers have been reported to experience a higher prevalence of work psychosocial risk factors including work-family conflict and supervisor support [54], but our review identified gaps in research on heat exposure and mental health among female workers. Although studies have shown how social connections with family, friends, and community members have an impact on mental health outcomes [55], no studies that we identified examined how non-workplace exposures or family or community stressors or assets influence occupational heat-related mental health outcomes. No studies included heat exposure assessments both at work and at home or in the community to investigate how work and home or community exposures may interact to influence occupational health outcomes. We were not able to identify any recent occupational studies that have incorporated information about workplace benefits, healthcare access, or other structural factors when examining the relationship between occupational heat exposure and mental health outcomes. None of the included studies specifically documented the longitudinal course: from heat exposure or co-exposures; to HRIs, heat-related traumatic injuries, or other outcomes; to subsequent mental health outcomes, via mechanisms such as reduced productivity and financial hardship. We also did not identify any intervention studies evaluating the effectiveness of heat prevention approaches on mental health outcomes. Finally, we found that although some studies described certain SDOH, there appears to have been limited subsequent incorporation of this information into analyses or other application of this information.

Implications and Future Directions

Our review, characterization of research gaps, and framework provide a foundation for research recommendations for future studies of occupational heat exposure and mental health. This is the first published review of occupation heat exposure and mental health that we are aware of that explicitly included consideration of non-medical factors and structural conditions that may impact health of diverse working populations. In a recent call-to-action paper highlighting work-related psychosocial hazards associated with adverse mental health disorders, increased etiologic, intervention, and implementation research and increased translation of research findings into guidance for workers and employers were recommended [45]. Investigations of mental health effects of occupational heat exposure may benefit from similar recommendations, along with partner-engaged development of research questions and research designs and co-development of culturally appropriate communication and research products to address work equity by incorporating the unique contexts and needs of populations at disproportionate risk.

Research should prioritize worker populations that are, and are projected to be, exposed to occupational heat (e.g., large working populations in global low-latitude areas and hot climate zones projected to experience substantial increases in exposures [20]) and/or that are characterized by a high prevalence of factors associated with an increased risk of adverse mental health outcomes (see Fig. 2, including SDOH and workplace factors). Future studies should capture information related to SDOH to determine how these non-medical factors and structural conditions may combine with heat and other factors to impact workers' mental health outcomes. Consideration should also be given to new research within geographies, industries, and occupations (e.g., warehouse workers, transportation & material handling, construction trade workers, emergency responders, and disaster clean-up workers) that have not yet been studied, as well as confirmatory studies among high-risk populations with whom research has already been initiated (Fig. 1; Table 3).

Our review additionally identified gaps in research methods that should be addressed in future studies. Future research should include clear justification of the study design based on the research question, articulation of selection criteria and representativeness of the study population, use of culturally sensitive validated instruments [56, 57], articulation of the geography and weather characteristics of the study area, and acknowledgment of potential researcher bias. Quantitative etiological studies should clearly and consistently define occupational heat exposure and mental health outcomes and address confounders in the design or analysis (including consideration of factors such as workplace benefits, healthcare access, and structural factors as outlined in Fig. 2). Studies should systematically characterize indoor and outdoor heat exposure intensity, duration, clothing, and workload, define occupational and non-occupational heat exposure, and depending on the research question, consider assessing both measured heat exposure and thermal comfort, which influences behavior. Epidemiologic studies could investigate how workplace psychosocial factors and non-workplace, community, sleep, family, financial and other factors may interact with occupational heat exposure to affect mental health [9]. Future longitudinal studies, qualitative, and mixed methods studies could further elucidate mechanisms, including neurobiological and behavioral mechanisms, of the relationship between heat exposure and mental health outcomes. Qualitative studies could gather information about potentially promising practical prevention solutions, tailored to at-risk populations.

Our working framework should be refined by future research results that confirm the effects of risk factors and elucidate which pathways and mechanisms most strongly link heat exposure to occupational mental health outcomes. This information could support prioritization of specific pathways for practitioners to intervene on to prevent these outcomes. For example, if research confirms that certain SDOH to interact more strongly with heat exposure than other factors to affect mental health outcomes, interventions should be prioritized that address the former factors. Future intervention research should include practical solution-oriented intervention research, including participatory action research focused on practical workplace safety solutions, guidance, safety and health programs, and mental health support, that engages multidisciplinary teams, including mental health professionals and occupational health and safety experts [58]. Qualitative work should form the foundation for potential practical solutions. Following identification of opportunities for intervention using the refined framework, additional models could be employed to support considerations of audience, development, implementation, and evaluation of interventions. For example, the social-ecological model could be used to conceptualize different or multiple target intervention levels and audiences (e.g., policy, workplace, community), taking into account SDOH at different levels [59]. Worker-facing interventions should be co-developed with target audiences to ensure they are tailored to the specific audience (e.g., workers, supervisors, managers who have different levels of control and authority in the workplace than employers) and are linguistically and culturally appropriate. This research will require funding support and training and development of occupational mental health equity researchers.

Conclusions

The literature on occupational heat exposure and mental health outcomes among workers is emerging. Of ten peer-reviewed studies of varying quality published between 1997 and 2024 that met our inclusion criteria, occupational heat exposure was associated with mental health outcomes including stress, anxiety, mental disorders, and burnout in seven studies in several different industries. We proposed a working framework to guide future high-quality research among high-risk populations that includes work-related psychosocial factors and structural and SDOH. SDOH should be further characterized in future studies to better understand how and to what degree these factors interact with heat exposure to affect heat-related mental health outcomes. Refinement of the framework should be made as new research emerges on the relative strength of different mechanisms and pathways of occupational heat-related mental health outcomes, in order to inform prioritization of prevention efforts. This work is urgently needed, as mental health disorders are increasing in background prevalence in the working-age population [45], and the frequency and severity of extreme heat events are projected to increase in the future with climate change [18].

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Human and Animal Rights This article does not contain any studies with human or animal subjects performed by any of the authors.

Competing Interests The authors declare no competing interests.

Conflict of Interest Stefani Florez-Acevedo declares that she has no conflict of interest. Maria Blancas declares that she has no conflict of interest. June Spector declares that she has no conflict of interest.

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