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Pregnancy and extreme heat events: A rapid review of evidence related to health outcomes, risk factors and interventions

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A R T I C L E I N F O

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A B S T R A C T

Background: Climate change is increasing the frequency and severity of extreme heat events (EHEs), resulting in increased morbidity and mortality for vulnerable populations. Pregnant people and fetuses are at risk for adverse pregnancy outcomes from EHEs.

Objective: To collate and synthesize existing evidence on the effects of EHE on pregnant people and fetuses and relevant mitigating factors and interventions to inform healthcare providers and other pregnancy-focused audiences.

Methods: A peer-reviewed search strategy was conducted in MEDLINE, EMBASE, Global Health, CAB Abstracts, SCOPUS, and ProQuest Public Health, for empirical studies and reviews published between 2009 and 2023 in English and French. The search strategy focused on terms related to EHEs, exposure, and pregnancy. Health outcomes, risk factors and interventions relating to EHEs (defined based on high ambient temperature thresholds) were reviewed and narratively reported.

Findings: Sixty-eight studies were included ($n = 16$ reviews; $n = 52$ empirical studies). Associations between both adverse fetal outcomes (e.g., pre-term birth) and maternal outcomes (e.g., severe maternal morbidities) and EHEs were identified. Pregnant people with low socioeconomic status were found to be more likely to have morbidities. Interventions such as improved clinician support have been proposed by researchers to reduce the risk of poor pregnancy outcomes.

Conclusion: There is an association between EHEs and the development of pregnancy-related morbidity and mortality, mediated by environmental, social and intrinsic individual factors. There are remaining knowledge gaps that have been identified that should be addressed, but more importantly, the synthesis of this evidence highlights the urgent need for interventions such as improved healthcare provider education, and policy interventions to mitigate the health riskscaused by exposure to heat in pregnant populations.

Statement of Significance

Problem or issue:

The increased frequency and intensity of extreme heat events (EHEs) is leading to increased rates of morbidity and mortality. Despite pregnant people being vulnerable to the heat, there is a lack of evidence-based mitigation from policymakers and clinicians

What is already known: Extreme heat is associated with poor pregnancy outcomes such as pre-term birth and severe maternal morbidities.

What this paper adds:

This review compiles and synthesizes the existing evidence to inform clinicians, policymakers and other knowledge users who support pregnant people. The synthesis of the evidence is important to further develop protective measures for pregnant people prior to and during hot weather and EHEs.

Introduction

Climate change is fueling an increase in the occurrence of extreme heat events (EHEs) and, subsequently, an increase in heat-related

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morbidity and mortality [1]. This increased risk of adverse health outcomes disproportionately impacts specific heat-vulnerable populations, such as pregnant people. Prolonged heat exposure during EHEs can result in maternal complications (e.g., cardiovascular events) [2,3], that increase the risk of developing chronic illness such as cardiovascular disease or diabetes [4,5]. Furthermore, exposure to EHEs can result in poor birth outcomes (e.g., pre-term birth) [6], which can have life-long health and developmental effects, and may result in long-term disability [7].

Extreme heat events, like many other climate threats, intensify existing inequalities. Pregnant people that are materially- or socially-marginalized face multiple risk factors that render them even more vulnerable to poor health outcomes; these risk factors include inadequate antenatal care, lack of air conditioning or well-ventilated housing [8], or substance use (i.e., nicotine and alcohol) [9].

An actionable pathway to improving perinatal health care and reducing rates of poor maternal and fetal health outcomes is to mitigate the effects of EHEs [10]. However, little is known about the current state of knowledge of policymakers and clinicians for preventing adverse health outcomes among this populationfrom heat. Moreover, future research to support heat-mitigation strategies requires a clear understanding of the existing knowledge gaps and informational needs. Thus, a rapid review of scientific literature was conducted to synthesize heat-related health outcomes, risk factors and evidence-based interventions specific to the protection of pregnant people during EHEs for an audience of clinicians, policymakers, and other knowledge-users. Through this review we sought to address the following research questions:

RQ1: What are the adverse health outcomes for pregnant people and fetuses exposed to EHEs?

RQ2: What are the protective factors and risk factors that modulate the effects of EHEs?

RQ3: What interventions have been adopted to address risk factors, and how have these been implemented?

Methods

Search strategy

A peer-reviewed search strategy was conducted on December 19th, 2023, in MEDLINE, EMBASE, Global Health, CAB Abstracts, SCOPUS, and ProQuest Public Health. The search was restricted to studies published between January 2009 and December 2023. A subsequent search was performed on May 2nd, 2024, to identify newly published literature. The main search concepts comprised terms related to heat, heat waves, hot weather, heat stress, pregnancy, maternal health, fetus health, obstetrics, and related-complications. Both the original and renewal search strategy are provided in the supplementary file.

The records retrieved from the initial search were imported into Covidence™ (https://www.covidence.org, Melbourne, Australia) and duplicates were eliminated using the platform's duplicate identification feature. The title and abstract of the remaining records were screened by two independent reviewers (CLM and KEW), and irrelevant articles were excluded. Full-text versions of the articles were then uploaded by the primary review (CLM) who then examined all full-text records, and the secondary reviewer (KEW) examined 25 % of the records. Any decision discrepancies were resolved through discussion between the primary and secondary reviewers.

Inclusion and exclusion criteria

Articles in English and French were eligible for inclusion. Additionally, included sources were required to i) identify pregnant people or fetuses as the study population; and ii) directly address the relationship between EHEs and maternal health, fetal health, pregnancy or birth outcomes in any stage of pregnancy. Eligible sources included literature reviews or sources based on quantitative empirical evidence. Sources were excluded if they focused on i) animal, pediatric, and/or non-pregnant study populations; ii) occupational or exercise-induced heat exposures; iii) high ambient temperature not defined as an EHE; iv) qualitative studies (i.e. those focused on subjective outcomes or responses); or v) reported non-health outcomes.

Data extraction

Data extraction was performed by two reviewers (CLM and KEW) in NVivo™ (https://lumivero.com/products/nvivo/, Denver, USA). A framework for charting (tabular) and synthesizing data from the selected sources was developed. The framework included the following categories: fetal and maternal health outcomes, risk factors (environmental, social, physiological), key developmental windows (trimesters) for outcomes, interventions, and physiological mechanisms underlying the development of morbidities in pregnant people and fetuses. In addition to the categorical charting, the following information was recorded from each source: study authors, study year, study population, sample size, Köppen-Geiger climate classification [11], EHE definition used, study design and study findings. Key outcomes, metrics and factors not identified *a priori* were added to the framework inductively. Both reviewers (CLM and KEW) discussed new additions before inclusion.

Results

Included studies

The search results are presented in a Preferred Reporting Items for Systematic Reviews and Meta-analyses for Scoping Reviews (PRISMA-ScR) flow diagram (Fig. 1) [12]. The initial search yielded 705 records, and the renewal search yielded 70 additional records. After duplicates were removed ($n = 50$), title and abstract screening was conducted on 725 records. A total of 192 full-text studies were assessed for eligibility, of which 124 were excluded for failing to meet the inclusion criteria. A total of 68 studies were included in the rapid review.

Study characteristics

The sources included 16 literature review articles and 52 articles on empirical studies (Table S1). Literature reviews included narrative ($n = 5$), scoping ($n = 3$) and systematic ($n = 8$) reviews. Tabulated summaries of the empirical studies (Table A1) and the systematic and scoping reviews (Table A2) are provided in the supplementary file. All empirical studies were epidemiological studies, which focused on pregnancies and births. Most of these studies were large cohort studies ($n = 30$). The empirical studies were set in 12 different countries, with the exception of one study that covered 14 low- and- middle-income countries [13]. Most studies were based in the United States of America (USA) ($n = 22$) and China ($n = 14$).

The geographical regions covered by the studies included 22 Köppen-Geiger climate classes [11], of which hot summer climate classes (i.e., hot summer Mediterranean, humid subtropical climate) were most prevalent ($n = 22$). Many of the studies ($n = 11$) located in the USA or China examined multiple locations across the respective countries. This allowed researchers to determine whether climate zones modulated the effects of EHEs. Two studies relied on pooled national data without distinguishing between regional sites but described the country's climatic conditions and typical temperature exposures [14,15].

EHE exposures

Researchers defined EHEs according to typical or expected meteorological conditions rather than temperature thresholds for population-wide morbidity and mortality. However, the thresholds used to define EHEs reflected what would be considered "extreme" high temperatures

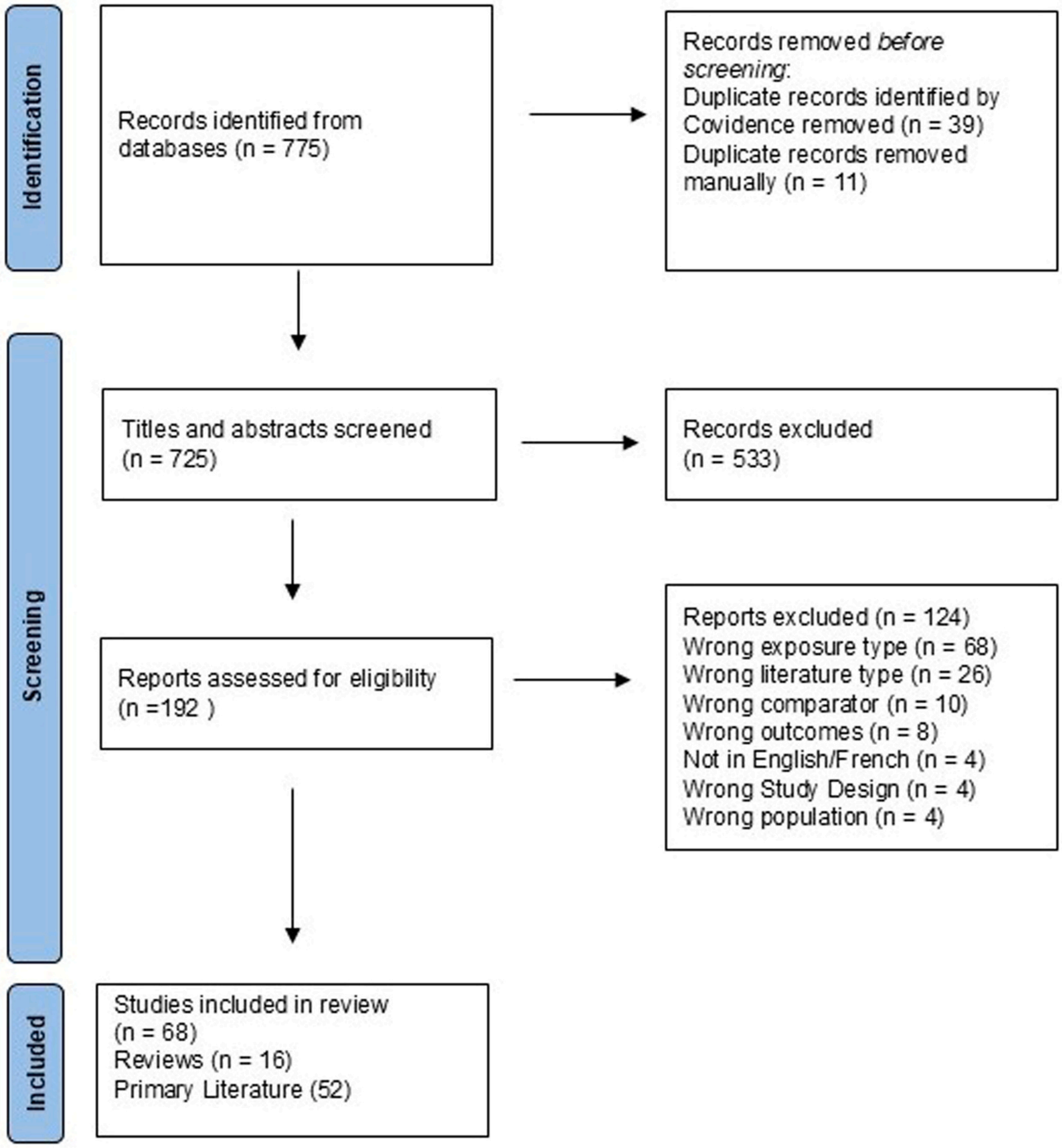

Fig. 1. Study selection process, PRISMA flow diagram. Page M J, McKenzie J E, Bossuyt P M, Boutron I, Hoffmann T C, Mulrow C D et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews *BMJ* 2021; 372:n71 doi:10.1136/bmj.

[16]. Most studies used a minimum of 90th percentile of the daily mean temperature or daily maximum temperature to define an EHE, which was also the most prevalent exposure found in the literature [17–19]. Three studies originating from the USA used the Heat Index to quantify EHEs [8,20,21]. The Heat Index is a standardized metric that combines the effects of humidity and temperature and is posited to more accurately reflect a person's perception of temperature [22]. Within the reviewed studies, the EHE's ranged from one [23] to seven days [21]. To account for the lack of an accepted definition for an EHE, many researchers used more than one intensity (percentiles) or more than one duration to define EHEs, with up to 18 metrics used [24]. This also allowed for an investigation into whether EHEs defined conservatively (i.e., with a higher intensity or longer duration) have stronger associations with morbidities than those not [25,26]. Possible dose-dependent effects of the heat have been identified in the literature [25,27–29] and were investigated as a secondary outcome in two studies [30,31].

Fetal morbidities and mortality

Most studies examined fetal outcomes ($n = 56$), including 94 % of the literature reviews ($n = 15$). Although fetal morbidities were occasionally identified in the literature as neonatal morbidities—since they are first observed and recorded after birth—all morbidities identified developed *in utero*. The key fetal morbidities included congenital disorders, low birth weight, and pre-term birth. Empirical studies also examined the effect of EHEs on fetal mortality ($n = 7$) either before 20 weeks of gestation (miscarriage) or 28 weeks of gestation (stillbirth) [8,13,32–35].

Congenital disorders

Seven studies examined the association between EHEs and the development of congenital disorders. One empirical study and a systematic review of 13 studies found that the association between EHEs and congenital disorders were strongest for congenital heart defects [7, 36].Further, Yu *et al.* found that the risk of developing congenital heart defects was compounded by increasing intensity and duration of EHEs as assessed during the first two to eight weeks of gestation [37]. For other common congenital disorders, neither neural tube defects nor cranio-facial defects have a significant link to EHEs [30,38,7].

Low birthweight

Five studies reported a negative relationship with a child's birth-weight and EHEs [39–43]. Studies reported a mean decrease in birth-weight between 55 [39] and 97 [43] grams associated with EHEs. However, in two studies, the relationship was only present among the most extreme temperature thresholds or particular populations of pregnant people [40]. Some preliminary work has investigated how extreme heat affects fetal growth, which sheds some light on birthweight outcomes. For instance, Wulayin *et al.* investigated whether the placenta mediated the effects of extreme heat on low birthweight. The authors theorized that placental function is compromised by extreme heat as maternal blood flow would be diverted away from the placenta to peripheral tissue to facilitate thermoregulation [43]. Through ultrasound measurements, they found that placental weight and volume were reduced in association with EHE exposure in low birthweight neonates, indicating reduced placental efficiency *in utero*. Li et al., also suggested that restrictions in overall fetal growth can also result in a neonate that is small for gestational age, which can present similarly to a neonate that has a low birthweight [44]. Being small for gestational age has also been linked to EHE exposure, but investigations into the association have been more limited than those related to birthweight [17,44].

Pre-term birth

Pre-term birth was the most extensively investigated outcome ($n = 37$), and many studies demonstrated an association between pre-term birth and EHEs. In both Belgium and Texas, USA, the risk of pre-term birth was found to increase over 15 % after an EHE [45,46], while another study based on multiple sites in China found that avoiding heat during an EHE would prevent up to 17 % of all pre-term birth [47]. Conversely, a study in Sweden demonstrated an association between pre-term birth and EHEs, but it was not statistically significant, and associations were weak in northern, colder regions [15]. A systematic review found clear dose-response associations between EHEs and pre-term birth based on the meta-analysis of 6 studies, with more intense or longer durations of EHEs resulting in higher incidences of pre-term birth [28]. Two studies reported the association between pre-term birth and EHEs was stronger at higher temperature thresholds and longer EHE durations [24,26]. Two studies found a possible (but non-significant) association between extreme pre-term births and EHEs [15,40]. Both spontaneous pre-term birth [9] and pre-term births induced for medical indications [23] were investigated for links with EHEs. However, more studies refined their focus to spontaneous pre-term birth ($n = 8$) and only a few investigated both subtypes ($n = 3$). All other studies were non-specific. EHEs seem to increase the risk of spontaneous pre-term births more so than medically induced pre-term births [31]. This is attributed to reductions in uterine artery vascular conductance resulting in higher placental perfusion, which can trigger premature rupture of the placental membranes [48]. Additionally, heat exposure is associated with concurrent increases in fetal heart rate, increasing distress and the likelihood of labour onset.

Fetal mortality

Evidence suggests that EHEs increase the fetal mortality rate both early and late in pregnancies, with seven studies showing associations. Both the reviews and empirical literature mostly focused on stillbirth ($n = 9$) rather than miscarriage, but one study found that EHE exposure increases the risk of early miscarriage [32]. Notably, Ha *et al.* found that approximately 17 % of all stillbirth cases in one study population were attributable to EHEs, which translated to 1019 excess stillbirths per year across the USA [35]. Another study found that EHEs resulted in excess fetal mortality compared to the expected rate in the USA, especially in states that have a cold and dry climate (such as Colorado) [34]. The mechanisms underpinning the association between EHEs and fetal death are not yet well understood. However, the effect of heat on disrupting fetal growth [6], gene expression [49] and the cellular heat-shock response [17] are all hypothesized to increase the risk of stillbirth.

Maternal morbidities

Few studies ($n = 5$) examined maternal morbidities, and roughly half of the literature reviews addressed maternal morbidities ($n = 7$). However, three key maternal morbidities were identified in the literature: 1) severe maternal morbidities (SMMs); 2) gestational diabetes; and 3) hypertensive disorders of pregnancy. One review reported that the risk of general hospitalization for pregnant people increased with elevated ambient temperatures, based on four included studies [6].

Severe maternal morbidities

Two studies identified that EHEs increased the risk of developing SMM [2,3]. Both studies identified that cardiovascular morbidities, such as cardiac arrest and cerebrovascular disorders, were strongly associated with EHEs. Notably, Jiao *et al.* found that even the least severe EHEs had significant associations with the development of cardiovascular SMMs and risks increased with exposure across pregnancy but were more significant in the third trimester [2,3]. Further, Runkle *et al.* observed a two-fold increase in the risk of SMM following exposures to EHEs above the 90th and 95th percentile of mean temperature compared to no exposure [3].

Gestational diabetes

One study found that EHEs during the second trimester increased the odds ratio of gestational diabetes by 20 % [50]. Additionally, a scoping review by Dalugoda *et al.*'s showed that gestational diabetes was the most observed maternal morbidity, with eight studies reporting an increased prevalence of gestational diabetes and increased likelihood of gestational diabetes diagnosis when pregnant people were exposed to elevated ambient temperatures [27]. Researchers hypothesized that increased serum glucose levels in response to heat stress may trigger insulin resistance and subsequent diabetes in pregnant individuals [51].

Hypertensive disorders of pregnancy

There was mixed evidence in the literature that EHE exposure increases the risk of developing hypertensive disorders during pregnancy [52–54]. Exposure to an EHE in the 3rd and 4th week of pregnancy was shown to increase the risk of developing pre-eclampsia, but EHE exposure after 20 weeks reduced the risk of developing any hypertensive disorder [53]. Furthermore, pregnant people with hypertensive disorders were found to give birth at a later gestational age if exposed to an EHE [43]. Sun *et al.* found no effect from EHE exposure on hypertensive disorder development during the first trimester, and a similar protective effect from EHE exposure in the third trimester manifested as reduced blood pressure [54]. A meta-analysis from 2023 of five studies on hypertensive disorders also showed that first-trimester exposures to EHEs increase the risk of developing any hypertensive disorder, but exposures after the first 20 weeks have no effect [52]. Finally, Jiao *et al.* found that the associations between postpartum hemorrhages caused by pre-eclampsia and EHEs were very weak, especially for long-term exposure [2]. A summary collating the specific findings by researchers on the associated effects of EHEs on adverse health outcomes can be found in Table 1.

Table 1
Known associations between extreme heat events and morbidities during pregnancy and parturition.

Health Outcome	Effects of Extreme Heat Events on Health
Congenital Disorders	Increased risk of congenital defects from exposure in the first 8 weeks of gestation (PR[a] 1.316 [1.242, 1.394]) [37]. Risk of congenital heart defects follows the dose-response relationship with each additional day (PR 1.035 [1.031, 1.040]), or EHE frequency (PR 1.039 [1.032, 1.045]) [37].
Low Birthweight	Overall decrease in mean body weight for all fetuses (minimum estimate of 97 g [59,135]) [43]. Increased odds of a infant being born < 2500 g from first trimester exposure (OR[b] 1.13 [1.03, 1.24]) [42]. Associated decreased placental volume (up to 152 cm^3 [110,193]) impairing growth [43].
Pre-term Birth	Increased risk of pre-term birth (15–17 %) [45–47]. Risks of pre-term birth follow dose-response relationship (OR increase from 1.03 [1.01,1.05] to 1.04 [1.01–1.08]) [24]. Higher risks for spontaneous pre-term birth rather than medically induced for highest level of exposure (RR[c] increase from 1.59 [1.01, 2.43] to 1.67 [0.97, 2.77] [31]. Associated increases in fetal heart rate resulting in fetal distress and increased risk of PTB (mediation effect ranging from 3.68 % to 24.06 %) [74].
Fetal Mortality	Increased rates of early fetal death (miscarriage, OR 2.07[1.36,3.16]) [32]. Increased rates of late fetal death (stillbirth): up to 17 % of mortalities [1019 excess cases per year [906, 1076]) [35]. Excess fetal mortality compared to expected rates (CRR[d] 2.49 [1.24,5.03]) [34].
Severe Maternal Morbidities	Increase of severe maternal morbidities during labour and delivery (7–19 %) [3]. Elevated risk for cardiovascular morbidities compared to severe maternal morbidities as a whole (OR 1.51 [1.22–1.87]) [2].
Gestational Diabetes	Up to 20 % increase in the odds of developing gestational diabetes in second trimester (all OR > 1.00) [50].
Hypertensive Disorders of Pregnancy	Increased risk of developing pre-eclampsia in 3rd and 4th weeks of gestation (HR[e] 1.76 [1.12–2.78] and 1.79 [1.19–2.71] respectively) [53]. No increased risk of developing hypertensive disorders after first 20 weeks (OR 1.05 [0.67–1.64]) [52]

[a] PR, Prevalence Ratio
[b] OR, Odds Ratio
[c] RR, Relative Risk
[d] CCR, Cumulative Relative Risk
[e] HR, Hazard Ratio

Developmental windows

Fetal risks from EHEs are not uniform across the gestation period, with increased risks during the first and third trimesters [55,56] and a reduced risk observed in the second trimester [18,19]. One study that examined whether there were windows during pregnancy that are especially susceptible to the effects of EHEs for pre-term birth found that while stillbirth and miscarriage were more strongly associated with first-trimester exposure, pre-term birth was associated with EHE exposure across the entire duration of pregnancy [57].

Many of the morbidities recorded occur at specific gestational stages—with miscarriage occurring in the first 20 weeks of pregnancy; it would follow that the association between miscarriage and EHEs would also be exclusive to the first trimester. Maternal exposure to EHEs during structural/anatomical developmental periods (mostly during the first trimester) increases the risk of congenital disorders [7,58]. Finally, studies show that births (of all gestational lengths) are more likely in the first seven days post EHE, suggesting that an EHE can act as a trigger for labour in the third trimester [6,28,59]. For pregnant people, EHE exposure during the second trimester has some associations with the development of gestational diabetes [50].

Environmental factors

Environmental factors such as humidity, air pollution, seasonality and greenness all have the potential to mediate the effects of EHEs on pregnant people. High humidity, in combination with high ambient temperatures, limits the physiological ability to cool through sweating and can increase the risk of health effects [60]. However, the effect of humidity in combination with EHEs was mixed in the literature. Two studies found high humidity was a risk factor for morbidities [13,61], whereas one study found no influence [62]. Air pollution (defined as airborne particulate matter) was addressed in the literature ($n = 8$), but primarily as a covariate for sensitivity analysis as there are known associations between pregnancy morbidities and air quality [63] that could potentially confound the relationship between temperature and morbidities [40,64]. Two studies included air pollution as an exposure of interest separately and combined with EHEs in South Korea [65] and Southern California, USA. Both found that the combined effects of air pollution and EHEs on pre-term birth were more significant than either exposure alone.

The seasonal cold-to-warm weather transition also influenced the risk for morbidities. Two studies identified that pregnancies that began in cold seasons were more at risk of morbidities from EHEs [2,29]. Furthermore, late-term morbidities such as pre-term birth or stillbirth were found to be significantly higher for EHEs in late spring and early summer compared to later summer months [26,34]. Two separate reviews suggested that EHEs early in the cold-to-warm transition are riskier as pregnant people have not experienced seasonally-induced heat acclimatization through increased sweating or cutaneous vasodilation [18,66].

Ten studies addressed greenspace (or "greenness") as an environmental factor. Greenspace includes vegetation surface coverage by grass and plants (e.g., in parks or along roadways) and tree canopy coverage [64]. A high degree of greenspace within a geographic area creates microclimates that are cooler than recorded temperatures at meteorological stations, thereby reducing the amount of heat stress a person is exposed to [50,67]. By contrast, impervious surfaces such as pavement or flat roofing increase the ambient temperature by trapping heat [50]. Tree canopy cover (which provides shade) was identified as accounting for the highest reduction in both fetal and maternal morbidities from EHEs [50,67]. Greenspace also increases a pregnant person's tolerance to heat, possibly reducing their risks from EHEs. Parks encourage outdoor physical activity in earlier warm weather months, and physical activity is known to facilitate acclimation to heat stress [2].

Social factors

Several social factors were identified in the literature, which reportedly influenced the vulnerability of pregnant people and fetuses to EHE-related morbidities. The most prominent factor was socioeconomic status ($n = 24$), followed by race and ethnicity ($n = 14$) and urbanity or the degree of urban environment ($n = 11$). There is substantial evidence that low socioeconomic status increases a pregnant person's vulnerability to EHEs. [21] In studies assessing pregnant people, low socioeconomic status is also correlated with residing in areas of low residential greenness [2,50,67], employment in manual labour or industries with minimal heat protection [41], and minimal access to air conditioners [41,68]. Likewise, in pregnant people, low socioeconomic status is correlated with individual behaviours or characteristics linked to poorer health, such as lower educational attainment, tobacco consumption, alcohol consumption, and obesity [6,41,69].

In almost all studies addressing race, being part of a racial or ethnic minority increased the risk of EHE-related morbidities. Most of the studies were based in the USA and identified Black and non-White

Hispanic populations as having higher risks than White populations ($n = 11$). None of the studies based in Europe ($n = 2$) or Israel ($n = 1$) found a similar relationship between minority status and vulnerability to EHEs [39,41,68]. However, the authors of these studies noted that the proportion of the study population identified as being part of a minority group was small compared to the dominant population, which may have resulted in statistical bias [39,41,68].

Urbanity was described as a risk factor for developing morbidities from EHEs in two studies, usually attributable to a low proportion of greenspace [50,66]. A lack of green space in cities contributes to the urban heat island phenomenon, where urban centres are significantly hotter than surrounding suburban and rural areas [23]. However, the relationship between EHE vulnerability and urbanity was inconsistent across the literature. A few studies found that urban residents were protected due to having a higher socioeconomic status than rural populations [9,13]. Guo *et al.* found that residents in metropolitan areas of China were generally less at risk than rural residents (except for the most intense compound EHEs) [24]. Son *et al.* found that urban residents of North Carolina, USA, living in areas of low greenness, had a high risk of pre-term birth following an EHE, but rural residents were also at risk despite high residential greenness [64]. However, rural residents were more likely to live in mobile homes, have no access to air conditioning and work outside in agriculture.

Socioeconomic status, race, and urbanity were all intersecting factors. Low socioeconomic status was correlated with a lack of green space for urban residents and a need for cooling infrastructure for rural residents. Black and Hispanic populations in the USA are also more likely to live in communities without green space and cooling infrastructure [20,21]. Evidence suggests that these communities can be up to 7°C hotter due to higher amounts of paved surfaces, fewer parks, and little shade [21]. Overall, the combination of low socioeconomic status, racial marginalization and urban dwelling increases the risk of heat-related morbidities in pregnant people more than any individual factor alone [2,8,20,21,45].

Individual factors

Some individual factors related to the pregnant person's physiological state or health-modifying behaviours can interact with EHE exposure to increase the risks to maternal and fetal health. Higher maternal age was found to augment the risks from EHE exposure in several studies ($n = 8$). Evidence suggests that pregnant people who are over 30 years of age generally have more complications, more significant perturbations in placental blood flow, and may be more vulnerable to environmental stress [2,43]. However, as Terada *et al.* point out, they are more likely to have greater familial or social support during their pregnancies and a higher socioeconomic status [14]. Lower maternal age was also found to augment EHE exposure risks due to a lack of support and lower socioeconomic status rather than any physiological factors [2]. Also, the use of commonly prescribed medications [70] and maternal smoking [9,45] were found to augment the effect of EHEs. Additionally, while a high body mass index has strong positive associations with poor birth outcomes and maternal morbidities [6,33,45], it was not found to have any interactions with EHEs in the literature [14,15,30,38].

Interventions

None of the studies reviewed directly evaluated interventions (i.e., actions taken that can mitigate the effects of EHEs on pregnant people and fetuses). However, researchers did make reference to interventions that likely influenced their results, and others have proposed interventions that may mitigate the effects of future EHEs. Multiple studies ($n = 16$) indicated that cooling systems (e.g., air conditioning) were critical for reducing the incidence of morbidities for pregnant people and fetuses, and based their evaluation of their efficacy on known usage rates or access within the context of the population studied [8,68]. Access to cooling systems was also linked to socioeconomic status and racial status, in that socioeconomically disadvantaged or racialized populations are less likely to have air conditioning systems in their homes and work in temperature-controlled environments [18,40,41,50]. Increasing green space by planting trees or grass in residential areas and replacing pavement with permeable surface covers was also recommended by some sources as an alternative cooling strategy that would benefit the health of pregnant people and fetuses, given the effect of green space on reducing surface temperatures [2,25,50,64]. Heat warning systems were also suggested in 11 sources as a mitigation tool for heat-related morbidities in both pregnant people and fetuses, based on their efficacy in reducing morbidities in other vulnerable populations [14]. Specific recommendations included targeting pregnant people in early warning systems (similar to ones implemented for other vulnerable populations) [13] and accounting for acclimatization effects (i.e., increasing focus on providing heat warnings during transitional seasons) [18,71].

Furthermore, eight studies and three reviews recommended actions directed to clinicians. The main recommendation was for health clinicians to be educated on heat risks and disseminate this information to their patients [16,31,33] during pre-conception and early prenatal counselling visits [3]. Also, one study recommended that healthcare providers closely monitor patients who conceive shortly before or during hot weather months [53]. A few studies ($n = 5$) also recommended that pregnant people take action to limit exposure to EHEs [32,34,42,53,64]. To this point, some researchers have suggested that pregnant people are more naturally inclined than the general population to take actions such as hydrating frequently, avoiding outdoor activity during EHEs, and using cooling systems [53,64] but may not be made aware of the need to limit their exposure to heat during key developmental periods by clinicians [63] or publicly available resources [42].

Discussion

Our synthesis of the current literature describes the known associations between EHEs and adverse pregnancy outcomes, including an increased risk of congenital disorders, fetal mortality, pre-term birth, low birthweight, severe maternal morbidities, and gestational diabetes. Associations between EHEs and maternal and fetal morbidities have been found across countries and climate zones. Furthermore, evidence demonstrates that environmental, demographic, and economic factors can augment the risk to pregnant people and fetuses.

Knowledge gaps

This rapid review included 68 sources that covered a wide range of outcomes, populations, and geographic regions with diverse climates. However, notable knowledge gaps were identified and would benefit from further attention to augment future policy and practice. First, although extensive research has been carried out using animal models and in vitro cellular techniques to generate theories [16,36,66,72,73], the physiological mechanisms underpinning the relationship between heat exposure and morbidity development in human populations has not been well documented and warrants further investigation. Second, despite emerging research demonstrating a relationship between heat exposure and placental function [43], uterine artery conductance [31], and fetal heart rate [74], further research using direct physiological measurements to explore exposure-outcome associations is needed to understand better the mechanistic pathways of maternal and fetal health risks. Third, in a review of high-temperature associations with pre-term birth, low birthweight and stillbirths, Chersich *et al.* noted that exposure misclassification might have biased research examining the influence of EHEs on pregnant people [28]. In some instances, study populations have been misclassified as being exposed to EHEs because estimates of temperature exposures are not accurate at a specific spatiotemporal scale. A strategy to more accurately represent the temperature exposure may include additional metrics as either covariates or predictors in analysis. For instance, Teyton *et al.* used external data sources to aggregate microclimate indicators (i.e., tree canopy cover, vegetation coverage of surface area, and water use efficiency) for all residential addresses [50]. Future research could explore this approach to generate further insights. Finally, this review found no evaluations of the effectiveness of interventions aimed at reducing the risks of EHE exposures to pregnant people and fetuses, despite some theorized benefits of interventions, such as education programs for health care providers. Further research is therefore needed to assess the effectiveness, feasibility and acceptability of potential interventions.

Limitations

The results of this rapid review should be considered within the limits of the search. The review revealed that most of the literature has focused on adverse health outcomes relating to fetuses. Therefore, future reviews may consider an exclusive focus on maternal health. Many studies were excluded from this review as they used high ambient temperature as an exposure but did not contextualize the exposure as being an EHE. A future review examining the influence of high ambient temperature rather than EHEs may be beneficial in capturing other sources of evidence. The benefit of using a more conservative exposure definition was that while temperature exposures across the literature were highly variable, EHE thresholds account for the population's acclimatization to heat, allowing for comparison across climates [16]. Additionally, our search strategy did not include terms specific to mitigating factors or interventions, limiting our capacity to address these objectives. Future reviews should prioritize explicit inclusion of search terms such as "intervention," "adaptation," "prevention," or "mitigation strategies" to systematically capture suchevidence. Finally, studies included in the rapid review were not assessed for quality or bias. Although quality and bias appraisals are important for comprehensive evidence synthesis, they are not strictly necessary for a rapid review, especially one intended to guide policy or clinicians, for whom the priority is timely decision-making.

Interventions and actions for clinicians and policymakers

Contextualizing the evidence for the harms of EHEs on pregnant people and fetuses is essential for effective knowledge translation for government and healthcare policy. Beyond knowledge translation, it is also crucial to implement targeted interventions to bridge the gap between awareness and actionable strategies during EHEs. Intervention efficacy was not directly evaluated in any study or review; however, researchers supported several potential heat mitigation strategies, especially those that address multiple intersections of vulnerability for pregnant people [16]. Tailoring perinatal care delivery to pregnant people before and during EHEs was advocated by several researchers as a viable strategy to protect pregnant people [3,6,8]. Maternal healthcare workers are aware that heat exposure may negatively impact their patients, but may not be aware of what action to take [75], or wish for support from national-level organizations [76]. To better protect pregnant people and fetuses before and during EHEs, clinicians should be engaged in dialogues and education regarding their attitudes on heat messaging, current clinical use of heat mitigation and perspectives on the effect of heat on their patients. Based on subject-matter expert recommendations, a potential discussion guide to engage with clinicians is described in Table 2.

Table 2
Points of engagement with clinicians to improve awareness about EHEs[a] and pregnancy.

Situation and/or Patient Population	Subject-Matter Expert Recommendations	How can a clinician act on this recommendation?
Patients planning or trying to conceive before the summer	*"We recommend that clinicians inform women about the risks associated with exposure to high temperatures around the time of conception and very early pregnancy."* [53] *"The integration of more education around avoiding extreme… hot ambient temperature… in preconception and prenatal care counseling is a necessary first step."* [3]	Introduce the patient to information about EHEs and pregnancy, especially first-trimester risks. *"Extreme heat can impact your pregnancy."* *"It is important to stay cool during the first months of your pregnancy"*
Patients in their 3rd trimester	*"Identifying pregnancy windows during which women are most susceptible to adverse effects associated with exposure to extreme temperatures can determine the best periods for effective interventions. We suggest that pregnant women avoid temperature extremes, especially in the third trimester of pregnancy."* [48] *"Patients should be counseled on the links between high heat, dehydration, and health risks, especially to themselves and their infants."* [6]	Provide information about how EHEs can increase the likelihood of pre-term birth and counsel them on how to keep cool. *"You may give birth earlier than expected when it gets very hot."* *"Drinking more fluids, staying in cool environments and limiting the amount of work or exercise you do in the heat is important for your health and comfort."*
Patient visits prior to an approaching EHE	*"A clear understanding of the association between heat waves and pre-term birth, along with a better understanding of the unequal way this outcome affects disadvantaged groups, could serve to inform women and caregivers who could plan to minimize exposure."* [21] *"Given that temperature over short periods is reasonably predictable and women at advanced stages of pregnancy have ongoing contact with health care providers through prenatal care, there is an opportunity to identify the high-risk population and time period if we can develop effective approaches to mitigation."* [8]	Ask the patient about their social networks and living spaces (what type of residence/place do they live in, how they typically keep cool in the summer, what support systems they have) and provide information about their options. *"How do you usually keep cool during a heat wave?"* *"Do you have friend or family who can let you stay with them if your home gets too hot?"* *"Do you know where you can go to cool down if it gets too hot?"*

[a] EHEs, extreme heat events

Conclusion

The global evidence suggests that pregnant people and their fetuses are vulnerable to several severe health morbidities and mortality resulting from EHEs. These risks exist across the duration of the pregnancy; however, the first trimester and third trimester are associated with more severe adverse outcomes. These risks are also exacerbated by pre-existing health conditions, higher maternal age, tobacco use, air pollution and factors relating to socio-economic status. To prevent adverse health outcomes in pregnant people and fetuses, action must be taken to combat climate change, while also addressing critical knowledge gaps to develop evidence-based interventions in the immediate and interim period.

Ethical approval

No ethical approval required for this submission

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CRediT authorship contribution statement

Caroline Li-Maloney: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Project administration, Writing – original draft. **Katie E. Wagar**: Investigation, Data curation, Formal analysis, Writing – review & editing. **Emily J. Tetzlaff**: Methodology, Writing – review & editing. **Glen P. Kenny**: Conceptualization, Writing – review & editing.

Declaration of Competing Interest

There are no known conflicts of interest to be declared.

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Author declaration

The authors declare:

- that the article is the author(s) original work
- the article has not received prior publication and is not under consideration for publication elsewhere
- that all authors have seen and approved the manuscript being submitted
- the author(s) abide by the copyright terms and conditions of Elsevier and the Australian College of Midwives

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.wombi.2025.101931.

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