



# High environmental temperature and preterm birth: A review of the evidence

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## ABSTRACT

**Objective:** to examine the evidence in relation to preterm birth and high environmental temperature.

**Background:** this review was conducted against a background of global warming and an escalation in the frequency and severity of hot weather together with a rising preterm birth rate.

**Methods:** electronic health databases such as: SCOPUS, MEDLINE, CINAHL, EMBASE and Maternity and Infant Care were searched for research articles, that examined preterm birth and high environmental temperature. Further searches were based on the reference lists of located articles. Keywords included a search term for preterm birth (preterm birth, preterm, premature, < 37 weeks, gestation) and a search term for hot weather (heatwaves, heat-waves, global warming, climate change, extreme heat, hot weather, high temperature, ambient temperature). A total of 159 papers were retrieved in this way. Of these publications, eight met inclusion criteria.

**Data extraction:** data were extracted and organised under the following headings: study design; dataset and sample; gestational age and effect of environmental heat on preterm birth. Critical Appraisal Skills Programme (CASP) guidelines were used to appraise study quality.

**Findings:** in this review, the weight of evidence supported an association between high environmental temperature and preterm birth. However, the degree of association varied considerably, and it is not clear what factors influence this relationship. Differing definitions of preterm birth may also add to lack of clarity.

**Key conclusions:** preterm birth is an increasingly common and debilitating condition that affects a substantial portion of infants. Rates appear to be linked to high environmental temperature, and more especially heat stress, which may be experienced during extreme heat or following a sudden rise in temperature. When this happens, the body may be unable to adapt quickly to the change. As global warming continues, the incidence of high environmental temperature and dramatic temperature changes are also increasing. This situation makes it important that research effort is directed to understanding the degree of association and the mechanism by which high temperature and temperature increases impact on preterm birth. Research is also warranted into the development of more effective cooling practices to ameliorate the effects of heat stress. In the meantime, it is important that pregnant women are advised to take special precautions to avoid heat stress and to keep cool when there are sudden increases in temperature.

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## Introduction

Global warming is one of the fastest emerging concerns for the 21st century and environmental temperatures have risen by approximately 0.5–1 °C since the middle of the 20th century (McMichael et al., 2006; Bureau of Meteorology, 2010). This warming of the planet results in an increasing incidence of high

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environmental temperatures, or very hot weather, and heatwaves (Robinson, 2001; Frich et al., 2002; Filippidou and Koukoulia, 2011; WHO/WMO, 2012). Experts predict the incidence of very hot weather and heatwaves will increase both in frequency and severity as the impact of global warming escalates (Meehl and Tebaldi, 2004). This is of concern as high environmental temperature has serious health impacts and can trigger the onset of acute conditions, including heat stroke and dehydration (Hajat et al., 2010). It can also exacerbate a range of underlying conditions such as asthma, respiratory conditions (Filippidou and Koukoulia, 2011) and mental health disorders (Khalaj et al., 2010). Vulnerable populations such as babies, children

and pregnant women are thought to be the most at risk of these heat related effects (Balbus and Malina, 2009; Filippidou and Koukoulia, 2011).

Although it is clear that global warming has serious health consequences (Hajat and Kosatky, 2010; Hajat et al., 2010), the full extent of those consequences is still largely unknown. This is especially the case for pregnancy and birth and, to date, research on the impact of very hot weather, on mothers and babies, is very limited. Anecdotal evidence supports an association between high environmental temperature and earlier gestation, and this association appears likely, as factors such as raised maternal body temperature and stress are linked to preterm labour (Goldenberg et al., 2008; Hellgren et al., 2011). Both of these features result from heat exposure (Hajat et al., 2010).

Preterm birth is defined as the birth of an infant prior to 37 weeks gestation (Keller and Nugent, 1983) and the rate of preterm birth in developed countries such as Australia, the UK and the US is roughly 8–13% (Keller and Nugent, 1983; Ventura et al., 2006; ABS, 2009).

Rates have increased over the past decade (Moss, 2006; ABS, 2007) and this increase may in part be due to older maternal age and higher numbers of multiple births (Klebanoff and Keim, 2011). Preterm birth is linked with a number of adverse outcomes and is thought to account for 20–27% of all neonatal deaths in high-income countries (Lumley, 2003; Moss, 2006). Gestation <37 weeks is also linked to poorer ongoing child health (Langridge et al., 2010) including respiratory and gastrointestinal conditions (Moss, 2006) and long-term developmental and behavioural disorders. Developmental disorders include poorer cognitive function, such as learning difficulties (Taylor et al., 2011) and neuro-developmental delays in co-ordination, communication, and social interaction (Kerstjens et al., 2011).

At present, the causes of preterm birth are not well understood (Sayres Jr., 2010) and, for more than 50% of cases, no clear cause can be isolated (Beck et al., 2010). Known risk factors include women who have had a previous preterm birth, women from low socio-economic backgrounds and the presence of infection (Anumba, 2007; Beck et al., 2010).

Although little is known about other risk factors, the literature suggests that the causes of preterm birth are complex and possibly include environmental and genetic factors (Beck et al., 2010; Sayres Jr., 2010). There is also some evidence that preterm birth rates vary according to season. Bodnar and Simhan (2008), for example, found that women who conceived in winter and spring were more likely to have preterm births, and a number of other studies have found peaks of preterm birth incidence during summer and/or winter (Matsuda and Kahyo, 1992; Flouris et al., 2009; Strand et al., 2011). This finding suggests that extremes of environmental temperature (hot or cold) may contribute to preterm birth rates. Matsuda and Kahyo (1992), for example, found that preterm births in Japan peaked in both summer and winter and these authors suggested that the associated factors might differ between the two seasons. Strand et al. (2011), who conducted a review of the epidemiological evidence around preterm birth, also concluded that extremes of both hot and cold temperatures may impact significantly on preterm birth rates. Other authors such as Keller and Nugent (1983) and Flouris et al. (2009) found an association between preterm birth and higher summer temperatures but not colder winter temperatures. Overall, the bulk of the evidence indicates a link between higher temperature and preterm birth especially. However, the exact genesis of this association is unclear and it is additionally unclear if factors other than temperature influence these peaks. Darrow et al. (2009) contend that an increased incidence of preterm births seen in summer months may simply be in proportion to a greater number of total

births in the summer season. This view does not account for the overall increasing incidence of preterm birth, which is juxtaposed against a generally declining birth rate.

Against this unclear background, both preterm birth rates (ABS, 2007; Beck et al., 2010) and the incidence of high environmental temperatures are increasing (WHO/WMO, 2012), making it important to investigate if there is a relationship between these factors. Therefore, this review has sought to open the debate and to examine evidence of an association between high environmental temperatures and preterm birth. This information may prove important in preparing for likely future increasing rates of preterm births, and for ongoing global warming.

#### *The 'evidence to date'*

At this stage, the literature is limited and absolute definitions of 'hot weather' 'high environmental temperatures' or 'heat waves' are almost impossible to locate. The following represents the most recent information found.

The US National Oceanic and Atmospheric Administration Services (NOAA) base extreme heat warnings on two factors: heat index (how hot it feels), and relative humidity (moisture in the air) (NOAA, 2011). This combination is often referred to as apparent temperature, and using this classification, environmental temperatures greater than 91 °F (32 °C) are considered dangerous whereas temperatures in excess of 105 °F (40 °C) are categorised as very dangerous, and in excess of 124 °F (51 °C) extremely dangerous (NOAA, 2011). Climate experts Frich et al. (2002) use a different grading system, which links to the usual environmental temperatures in the area in question. These authors discuss 'high temperature' in terms of the number of days in excess of the 90th percentile for that period, based on records from the 1961 to 1990 base period (Frich et al., 2002).

At this time, there is no universally accepted definition of a heatwave. However, the Australian Bureau of Meteorology considers a heatwave to be a 'prolonged period of excessive heat' of 'at least three successive days of temperatures 35 °C or greater' (Bureau of Meteorology, 2010) whereas the World Meteorological Organization (WMO) suggests that a heatwave is a 'period of unusually hot weather that lasts from a few days to a few weeks' (WMO, 2011). Robinson (2001), of the American Meteorological Society, considers a heatwave to consist of daytime temperatures >40.6 °C (105 °F), and night-time temperatures >26.7 °C (80 °F) for a minimum of two consecutive days.

Thermal adaptation in humans, to high temperatures, also poses some interesting questions and, for that reason, a brief overview of the process is described here. According to Brager and de Dear (1998) thermal adaptation to temperature changes consists of three aspects:

1. Physiological acclimatisation (including changes in physiological responses such as sweating and changes to skin blood flow).
2. Psychological adaptation (changes of perception of the temperature).
3. Behaviour adjustment (conscious actions such as altering clothing, drinking cold fluids/using fans).

When thermal adaptation thresholds are exceeded, heat stress occurs and manifests in physiological and haemodynamic changes, such as tachycardia, dehydration and hyperthermia (Hajat et al., 2010). In prolonged and untreated heat stress, fatal heat stroke can result (Simpson, 2012). The key to mitigating the physiological impact of heat stress, appears to be acclimatisation

to the hotter than usual temperature (Sawka et al., 2001; NCDOL, 2011). This is best achieved by repeated low level daily exposure and is estimated to occur principally over approximately 4 days exposure (Sawka et al., 2001). There is some suggestion, in the literature, that different populations have different degrees of acclimatisation and adaptation to environmental heat, depending on the frequency of exposure and their access to resources such as air-conditioning. This means essentially that heat-stress can occur at lower temperatures in susceptible populations. Factors such as socio-economic status and access to air-conditioning were also seen to have an impact on adaptation. Yu et al. (2012), who studied populations working (or spending time) in air-conditioned buildings, versus populations working in naturally ventilated buildings, in Beijing, China, found that individuals working in naturally ventilated buildings adjusted to changes in the ambient temperature much more easily than those who worked in air-conditioned environments (Yu et al., 2012). In Shanghai, Tan et al. (2010) found that populations living in urban areas were at an increased risk of heat stroke, when compared to populations living in rural areas. The individuals most at risk were those from socio-economically disadvantaged and ethnic minority backgrounds (Tan et al., 2010). Harlan et al. (2006), in the US, expressed a similar view and described disadvantaged populations as more likely to live in warmer neighbourhoods with greater exposure to heat stress, related to higher settlement density, sparse vegetation, and limited open spaces. The effect of birthplace on heat tolerance has also been investigated and Vigotti et al. (2006) investigated how populations from different regions of the world adjusted to their specific ambient temperatures. These authors found that climate, in the place of birth, was a modifier of heat tolerance in adult life.

Thermal adaptation in pregnancy is a unique case, and is likely to be challenging as many of the cardiovascular changes present in late pregnancy are similar to the body's adaptation to thermal stress (Vaha-Eskeli et al., 1991). Although most of the evidence is confined to animal studies, Vaha-Eskeli et al. (1991), in Finland, undertook a study measuring the effect of moderate heat stress on cardiovascular responses and rectal and skin temperatures on three groups of women: (1) healthy non-pregnant women, (2) women 13–14 weeks pregnant, and (3) women 36–37 weeks pregnant. A variety of measures, including, heart rate, cardiac output, arterial blood pressure and peripheral vascular resistance, were recorded every 5–10 minutes during a resting period (20 minutes, 21–23 °C) followed by the heat stress intervention (20 minutes, 70 °C) and a recovery period (45 minutes, 21–23 °C). The authors found that rectal temperature increased 0.3–0.4 °C in each group during thermal stress. Heart rate before intervention was highest in the advanced pregnancy group but increased similarly in each group by 36–37 beats per minute during stress. Peripheral vascular resistance fell at the start of the thermal stress but returned to prestress levels at the end of the recovery period. The authors concluded that although some haemodynamic changes were seen in this short intervention period, pregnancy did not alter the cardiovascular responses to moderate thermal stress. However, women in the study indicated that they found it extremely difficult and would not be able to tolerate much more than the 20 minute intervention.

Animal studies suggest that heat stress is associated with preterm labour and stillbirth. Omtvedt et al. (1971), for example, found that pigs exposed to heat stress gave birth to more stillborn young ( $p < 0.01$ ) and were more susceptible to heat stress during early and late pregnancy. Edwards et al. (2003) also found that hyperthermia in pregnancy resulted in shortened gestation and although an association with heat stress is likely, this evidence is not conclusive as hyperthermia is also associated with fever and infection. Other evidence indicates that both placental weight and

fetal weight is reduced in sheep and cows exposed to chronic heat (Collier et al., 1982; Bell et al., 1989).

## Methods

In May 2012 published research, which explored the impact of high environmental temperature on preterm birth was sought via a systematic search of the literature. Electronic databases, included in the search, were as follows: SCOPUS, MEDLINE, CINAHL, EMBASE and *Maternity and Infant Care*. Publications were targeted from the previous two decades (1992–2012) and this period was chosen as congruent with increasing concerns about the impact of global warming on human health. Studies were sought if they included a keyword for preterm birth (preterm birth, preterm, premature, < 37 weeks, gestation) and a search term for high environmental temperature (heatwaves, heatwaves, global warming, climate change, extreme heat, hot weather, high temperature, ambient temperature) in the abstract.

Search results were managed in an Endnote library (Endnote X4). This exercise produced 159 abstracts, of which 20 were duplicates ( $n=139$ ). Initial screening involved the exclusion of abstracts on the following basis:

- Editorials, letters, opinion pieces, reviews.
- Papers not focussed on high environmental temperature and preterm birth (Table 1).

A total of seven abstracts remained after this process (see Fig. 1 and Table 1) and these full papers were retrieved. Hand searching of reference lists of these papers yielded an additional two papers ( $n=9$ ). In all, nine papers were examined closely for fit with the review's intent. Two final papers were excluded at this stage as the authors did not examine environmental heat in relation to preterm birth, but compared seasonal rates of birth between summer and winter seasons (Matsuda and Kahyo, 1992; Flouris et al., 2009). At the final count, seven papers were included in the review (Lajinian et al., 1997; Porter et al., 1999; Lee et al., 2008; Yackerson et al., 2008; Basu et al., 2010; Dadvand et al., 2011; Strand et al., 2012).

## Quality assessment of included studies

Critical Appraisal Skills Programme (CASP) guidelines for evaluating quantitative studies (CASP, 2003, 2004) were used to determine the quality of research studies included in this review. This critical appraisal approach was pioneered by the NHS in the UK and to date, CASP guidelines have been used to determine the quality of a number of nursing, medical and midwifery

**Table 1**  
Overview of excluded abstracts ( $N=132$ ).

<b>1. Reviews, letters, editorials, discussion papers</b>	4
<b>2. Care of preterm infants</b>	108
Includes thermoregulation, prevention of infection	
<b>3. Animal studies</b>	4
<b>4. Scientific evaluation</b>	8
(e.g. Rapid multiplex high resolution melting method to analyse inflammatory related SNPs in preterm birth)	
<b>5. Prevention of preterm birth</b>	2
Includes discussion of treatment for threatened prem labour	
<b>6. Maternal causes of preterm birth</b>	3
Including ROM, infection, maternal medications	
<b>7. Miscellaneous</b>	3
Including risks of preterm birth for health workers	
<b>Remaining abstracts <math>n=7</math></b>	

publications (Milne and Oliver, 1996; Carolan and Frankowska, 2011; Luker et al., 2011). CASP guidelines ask three main questions of research publications:

- Is the study trustworthy?
- Does it show important results?
- Is it relevant to the area of practice?

In the current review, CASP guidelines were used to assess studies for clear and unambiguous focus, acceptable method, appropriate recruitment strategy, presence of bias, treatment of factors that might influence results, believable results, and consistency with existing evidence (see Box 1). Similar to approaches in earlier reviews (Milne and Oliver, 1996; Carolan and Frankowska, 2011), the guidelines were modified slightly for this review, and questions 7 and 11 were omitted. Q.7 related to follow-up, which is not a feature of the cohort studies appraised

in this review. Q.11 examined results in relation to the local population. As this review intended to look broadly at the impact of high environmental temperatures on preterm birth, Q.11 was considered superfluous. Questions were scored 1 for present and 0 for absent with the exception of Q.6, which considered the identification and treatment of confounding factors. This question was allocated a score of 1 for each section, a total of 2. A new question (Q.13) was included to estimate external validity, or the degree to which the results of a study can be generalised to others. This question was based on Downs and Black's (1998) work which examined the feasibility of creating a methodological checklist to assess the quality of quantitative studies in health-care settings. In the final tool, scores ranged from 0 to 12, with a score of 12 signifying the highest possible quality (Box 1).

## Findings

### Characteristics of included studies

The original aim of this review was to examine the evidence in respect to heatwaves (using Frich et al.'s (2002) definition of a heatwave as  $> 5^{\circ}$  above normal temperature  $\times 5$  consecutive days). However, only one paper was located which specifically examined preterm birth rates in relation to heatwaves. Therefore, a decision was made to review the evidence of high environmental temperature in relation to preterm birth, as this feature is consistent with global warming and accompanies increasing heatwave activity. A total of seven research studies were included in the review. Three were conducted in the USA, and one each in the UK, Spain, Israel and Australia. All considered the impact of high environmental temperature on preterm birth. Preterm birth was measured in a variety of ways: such as abstraction from birth certificates (Basu et al., 2010); hospital birth data (Lajinian et al., 1997; Yackerson et al., 2008); birth statistics (Porter et al., 1999; Basu et al., 2010); last menstrual period (Porter et al., 1999); ultrasound measurements in early pregnancy (Dadvand et al., 2011) and credibility checks of gestational age/birth weight combinations (Lee et al., 2008). Most studies retrospectively examined preterm birth ( $< 37$  weeks) against meteorological data such as temperature and humidity indexes (Lajinian et al., 1997; Basu et al., 2010; Dadvand et al., 2011; Lee et al., 2008;

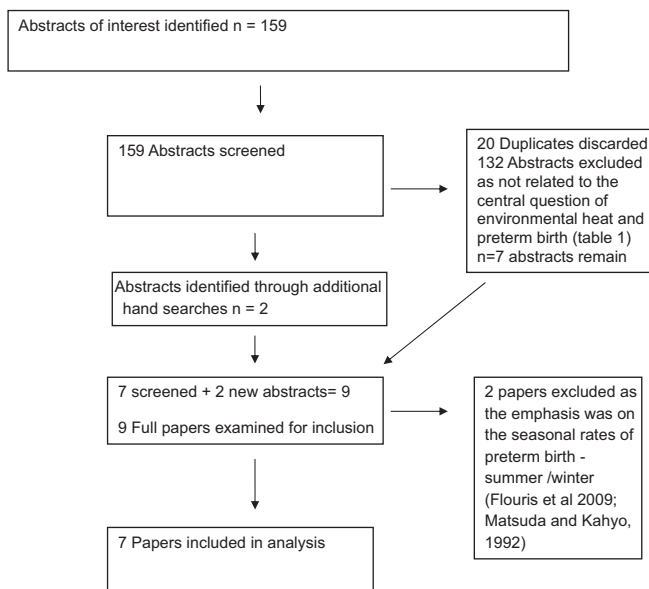


Fig. 1. Selection of papers.

### Box 1

CASP guidelines	Score 0/1
Q1. Did the study address a clearly focused issue?	0/1
Q2. Did the authors use an appropriate method to answer their question?	0/1
Q3. Was the cohort recruited in an acceptable way?	0/1
Q4. Was the exposure accurately measured to minimise bias? (maternal age)	0/1
Q5. Was the outcome accurately measured to minimise bias? (maternal/perinatal/ outcome)	0/1
Q6. a. Have the authors identified all important confounding factors?	0/1
b. Have they taken account of the confounding factors in the design and/or analysis?	0/1
Q7. a. Was the follow up of subjects complete enough?	N/A
b. Was the follow up of subjects long enough?	
Q8. What are the results of this study? (Are they communicated clearly?)	0/1
Q9. How precise are the results?	0/1
Q10. Do you believe the results? (How believable are the results?)	0/1
Q11. Can the results be applied to the local population?	N/A
Q12. Do the results of this study fit with other available evidence?	0/1
Q13. Was the study representative of the entire population from which subjects were recruited?	0/1



Strand et al., 2012; Yackerson et al., 2008), while Porter et al. (1999) studied preterm birth rates in relation to ambient temperature alone, during a heatwave of 5 days duration in Chicago, US. Six studies examined the lag effect of ambient temperature for 1–7 days after exposure (Lajinian et al., 1997; Porter et al., 1999; Lee et al., 2008; Yackerson et al., 2008; Basu et al., 2010; Dadvand et al., 2011), whereas Strand et al. (2012) examined both preterm and stillbirth rates in relation to high ambient temperature in Brisbane, Australia, in the four weeks prior to the birth. Four of the included studies examined the impact on preterm birth of other meteorological factors such as sunshine, rain, barometric pressure (Lee et al., 2008), strong winds (Yackerson et al., 2008) and air pollutants, such as carbon monoxide (Basu et al., 2010; Strand et al., 2011). Five studies excluded multiple births (Lajinian et al., 1997; Porter et al., 1999; Lee et al., 2008; Basu et al., 2010; Dadvand et al., 2011) and a smaller number of studies excluded preterm births which had been induced for medical reasons (Lajinian et al., 1997; Basu et al., 2010; Dadvand et al., 2011). Some studies controlled for confounding factors, such as: socio-economic factors (Porter et al., 1999; Basu et al., 2010), racial/ethnic groups and maternal education (Porter et al., 1999; Basu et al., 2010; Dadvand et al., 2011), indigenous status, smoking during pregnancy (Strand et al., 2012), and infant sex (Basu et al., 2010; Dadvand et al., 2011; Strand et al., 2011). Studies were all large retrospective cohort studies and sample size varied from  $n=3972$  to  $n=492,568$ . Measurement outcomes included preterm birth, generally characterised as more than 20 weeks, but less than 36/37 weeks gestation (Lajinian et al., 1997; Yackerson et al., 2008; Basu et al., 2010). In contrast, Dadvand et al. (2011) and Strand et al. (2012) discussed births from 19 to 43 weeks gestation, measuring gestational age at birth. Meanwhile Lee et al. (2008) examined births > 24 weeks gestation, which is later than the cut-off considered in Australian and US papers but consistent with the UK definition of fetal viability as greater than 24 weeks. The focus of studies varied although all had a central focus on environmental temperature and preterm birth (see Table 2).

#### Methodological quality of included papers

Studies in this review were measured using Critical Appraisal Skills Programme (CASP) guidelines. Study scores varied from 7 to 12, out of a total of 12 possible points. All studies addressed their aims and objectives clearly. Research approach varied but all used quantitative methods, including: retrospective cohort methods ( $n=6$ ), ecological design ( $n=1$ ), and case-crossover design ( $n=1$ ). These methods were well argued and appropriate for the type of study concerned. Each approach contributed different strengths. The retrospective cohort method is useful when categorising members of a cohort according to the level of their exposure to risk factors (Jirojwong et al., 2011), such as in this case, when exposure to high environmental temperature was measured. These large population based studies, provide a useful and efficient means of examining population trends and associations between variables such as environmental temperature and preterm birth. The ecological study design offers a different approach and is best used when at least one of the variables is to be measured at a group level (such as the group exposure to environmental temperature). Similar to the retrospective cohort design, the ecological study approach also permits the use of data collected for other purposes (Carneiro and Howard, 2011). Case-crossover design on the other hand, is especially useful for investigating short-term associations such as the short-term higher temperature exposure and preterm birth (Darrow, 2010). In the review, all but one study accessed two types of data: population and environmental. All population data was extracted from reliable sources, such as state databases ( $n=3$ ) and hospital

databases ( $n=4$ ). Environmental data was accessed from reputable meteorological services. The use of birth/death certificate data for studies of preterm birth, as in Basu et al. (2010) is however a limiting feature, as birth certificate data is often incomplete (Newburn-Cook et al., 2002). To counter this problem, Basu et al. (2010) also used information from California's Office of Vital Records, and this additional data source is likely to have improved overall data accuracy. All studies used exclusion criteria, such as multiple births, and medically induced preterm births. Most employed additional measures to ensure reliability of the sample. These measures involved the inclusion of only those records that were complete and the exclusion of implausible gestation/birth weight combinations.

The reviewed studies employed a number of well-recognised and valid statistical approaches to analyse the data. This included regression models, from linear regression (Dadvand et al., 2011) to complex multivariate logistic regression models (Lee et al., 2008; Yackerson et al., 2008; Basu et al., 2010) and Strand et al. (2012) used a Cox proportional hazards model. Statistical tests employed included exact trend test (Lajinian et al., 1997) and *t*-test (Porter et al., 1999).

#### High environmental heat and preterm birth

In the reviewed papers, high temperature was defined differently in each instance. However, most used a combination of meteorological data, such as temperature and humidity indexes (Lajinian et al., 1997; Lee et al., 2008; Yackerson et al., 2008; Basu et al., 2010; Dadvand et al., 2011; Strand et al., 2012). Basu et al. (2010) calculated weekly average apparent temperature, based on 5th/95th percentile for the time of year, within a range of 77.7 °F (25.4 °C)–98.9 °F (37.1 °C), with an average of 88.7 °F (31.5 °C). Dadvand et al. (2011) also based their calculations on apparent temperature using percentiles (90th, 95th and 99th), although only for a single day of extreme heat/humidity combination (29.4 °C, 30.4 °C, 32.5 °C) within a range of 27.9–38.8 °C. Lajinian et al. (1997) chose heat-humidity index in a range of 25–79.5 °F (–4 to 26.4 °C). Similar to Dadvand et al. (2011), Lee et al. (2008) examined the impact of maximum temperature on the day of birth, but within a range of (10–38 °C). Porter et al. (1999) studied preterm birth rates in relation to ambient temperature alone, during a heatwave of 5 days duration in Chicago, US, within a temperature range of 90–> 110 °F (32–> 43 °C). Strand et al. (2012) employed a slightly different approach and using 21 °C as the reference temperature, compared outcomes based on weekly mean temperatures from 15 to 27 °C (highest temperature 33 °C). In the final paper, Yackerson et al. (2008) used monthly average temperatures and relative humidity in a range of 18–36.2 °C. In each case, the most extreme summer temperatures experienced in the area, were included in the analysis, and maximum temperature preceded the preterm birth.

The results of the review are presented in Table 2 and the weight of evidence supports an association between increasing preterm birth rate and high environmental temperature. This finding persists despite a lack of homogeneity among included studies in terms of approach or sample size. For example, the lowest parameter of preterm birth was described by the majority of studies as 19/20 weeks gestation (Lajinian et al., 1997; Yackerson et al., 2008; Basu et al., 2010; Dadvand et al., 2011; Strand et al., 2012). However, Lee et al. (2008) defined preterm birth as > 24 weeks and this definition is likely to have caused the exclusion of infants born between 19 and 23 weeks, resulting in a lower rate of preterm births, compared to the other included studies. Similarly, sample size varied considerably from  $n=3972$  to  $n=492,568$  and this feature is also likely to have impacted on the strength of association between preterm birth and high

**Table 2**

Characteristics of included papers.

Study, country	Study description	Dataset/s	Sample	Gestation	Outcome measures	Heat effect on PTB Y/N	Statistical approach	Findings	Study quality score (0–12)
Basu et al. (2010) California	Case-crossover analysis. Cases of preterm birth were matched with meteorologic and air pollution data.	California's Office of Vital Records and birth certificate data. California Irrigation Management Information System (20) US Environmental Protection Agency Air Quality System	Singleton births 1999–2006 May–September ( $n=58,861$ ) Exclusions: medically induced preterm births	20–36 weeks	Preterm birth	Y	Case-crossover method: (1) Logistic regression model. All analyses performed in two steps: (1) county-level estimate based on residential zip codes; (2) overall estimate using meta-analytical techniques.	High ambient temperature was significantly associated with preterm birth for all mothers, regardless of maternal racial/ethnic group, maternal age, maternal education, or sex of the infant. Results indicated that an 8.6% increase in preterm delivery was associated with a 10° F (5.6 °C) increase in weekly average temperature. Greater associations were observed for younger mothers, and Black and Asian mothers.	11
Dadvand et al., Spain	Retrospective cohort study. Analysis of birth data matched to data on daily temperature and humidity	Hospital Clinic of Barcelona birth data. Daily temperature humidity data Spanish meteorological agency, Catalonia Meteorological Service	Singleton births spontaneous labour 2002–2005 ( $n=7585$ ). Exclusions: elective CS. Multiples. Medically induced preterm births	22.2–43.5 weeks	Preterm birth Term birth Post-term birth	Y	Two-stage analysis: (1) dynamic model separating the monthly trend gestational age at delivery for the region as a whole from within-region variation. (2) Linear regression with individual gestational age at delivery as the outcome.	Extreme heat was associated with a reduction in the average gestational age of babies born the next day, suggesting an immediate effect of this exposure on pregnant women.	12
Lajinian et al. (1997) USA	Retrospective cohort study. Preterm labour and birth was compared during the two summer and two winter weeks with the highest and lowest heat humidity indexes for each season.	Hospital birth data Brooklyn. Local climatologic data on daily heat-humidity indexes National Climatic Data Center (Asheville, NC).	Women at risk of preterm birth March 21, 1993–March 20, 1994 ( $n=3972$ ). Exclusions: Multiples, cerclage. Medically induced preterm births	20–36 weeks	Preterm labor rate during selected time periods	Y	Statistical significance was assessed with an exact trend test to determine whether the increasing percentage of preterm events for the study periods could be explained by chance.	The rate of preterm labor increased consistently from 1.23% to 3% as the heat-humidity index rose. When preterm births were examined, the trend was similar but not statistically significant.	8
Lee et al. (2008) London, UK	Ecological study design, investigating associations between preterm birth and various environmental factors using time-	Birth data from St. Mary's Maternity Information System (SMMIS) database meteorological data from the British Atmospheric Data Centre	All live, singleton births 1988–2000 ( $n=492,568$ )	> 24 weeks	Preterm birth	N	Regression analysis of daily time-series data to evaluate any associations between the probability of preterm birth (per 1000 fetuses-at risk) (1) a core model was created. followed by (2) a separate binomial model for each	The risk of preterm birth did not increase with exposure to the levels of ambient air pollution or meteorological factors, such as summer temperatures, experienced by this population. Cumulative exposure from 0 to 6 days	10

Table 2 (continued)

Study, country	Study description	Dataset/s	Sample	Gestation	Outcome measures	Heat effect on PTB Y/N	Statistical approach	Findings	Study quality score (0–12)
	series regression techniques						exposure variable was generated. (3) A parametric approach using Fourier terms was used to recreate a regular seasonal pattern.	before birth also did not show any significant effect on the risk of preterm birth.	
Porter et al. (1999), Illinois, USA	Retrospective cohort study. Preterm labour and birth rates were compared to meteorological data from the Chicago heatwave 1995	Birth data from the Illinois vital records files. Local climatological data from the National Climatic Data Center (Asheville, NC)	Singleton vaginal births June–August, 1995 ( $n=11,792$ )	All	The outcome variable was mean gestational age (in weeks)	N	(1) Mean gestational age was calculated based on confounder/temperature combinations. (2) With temperatures less than 90 °F, $t$ -tests for independent means were conducted, and a 95% significance level was used. (3) A 1-tailed test tested the hypothesis that the heat wave shortened gestation.	No evidence was found to suggest an association between shortened gestation and increased maximum apparent temperature.	7
Strand et al. (2012) Brisbane, Australia	Retrospective cohort study. Gestation and stillbirth rates were compared to meteorological data (mean temperature, humidity, and air pollutant levels)	Queensland Perinatal Data Collection. Queensland Department of Environment and Resource Management	Births 2005–2009 ( $n=101,870$ births). No exclusions	19–43 weeks	Stillbirth/Livebirth. Gestation at birth	Y	(1) Cox proportional hazards model was used with gestational age as the time scale and the outcomes of livebirth and stillbirth. (2) Levels of temperature, humidity, and pollutants in the previous 4 weeks were modelled using a linear distributed lag.	There was an association between higher temperature and shorter gestation. This effect was greatest at later gestational ages.	11
Yackerson et al. (2008)	Retrospective cohort study. The distribution of PTB and PPRM, were examined against several meteorological factors	Hospital birth data. Soroka University Medical Center. Meteorological data collected by CR10 datalogger	Births 1999, ( $n=11,979$ )	< 37 weeks	Preterm birth. Prem rupture membranes	Y	Statistical analysis was performed with the SPSS software package (SPSS, Chicago, IL, USA). Multivariate analysis, time series approach and Poisson regression were used.	Preterm delivery was correlated with humidity and maximum temperature ( $p < 0.01$ ), its rise preceded their sharp variations by three days ( $p < 0.01$ ). PPRM was influenced by the variations in the weather state: desert heatwave arrival ( $p < 0.093$ ), strong winds, overall daily differences of humidity and temperature (all with $p < 0.05$ ).	9

environmental temperature. Nonetheless, despite these difficulties, all but two of the included studies found that high environmental temperature was related to an increase in preterm birth rates (Basu et al., 2010; Dadvand et al., 2011; Lajinian et al., 1997; Strand et al., 2012; Yackerson et al., 2008). This impact varied and while Basu et al. (2010) found that a weekly increase in temperature of 10° F (5.6 °C) resulted in an 8.6% higher preterm rate, others such as Lajinian et al. (1997) found that the evidence was much less clear. Lajinian et al. (1997) found that although rates of preterm labour increased more than two fold in response to a rise in heat-humidity index, trends of preterm birth were similar but did not reach statistical significance. Strand et al. (2012) also found that preterm birth rates increased with higher temperatures but also that preterm birth became more common generally, as gestation progressed, meaning that the greatest number of preterm births were clustered close to 36/37 weeks gestation. Part of the difficulty in establishing a clear link between high environmental heat and preterm birth rates arises from the different periods of time over which the impact of temperature was examined by review studies. This varied from one day (Dadvand et al., 2011) to one month (Strand et al., 2012). Dadvand et al. (2011), for example, investigated the impact of a single day of very high ambient temperature and found a corresponding reduction in average gestational age among babies born the following day. Strand et al. (2012) found that higher mean ambient temperature, in the month of birth, resulted in lower gestational age. In contrast, Yackerson et al. (2008) described an increase in preterm birth that mirrored maximum temperature and humidity, but which preceded the temperature increase by three days.

Just two papers reported no correlation between high environmental temperature and preterm birth. Lee et al. (2008) found that none of the meteorological variables examined, such as ambient temperature, sunshine, rain or barometric temperature, had an impact on rates of preterm birth in the UK, which showed seasonal variation but peaked in winter. Porter et al. (1999), who examined preterm birth rates related to the Chicago heatwave in July 1995, also found no increase in preterm birth rates, related to this event.

Finally, higher rates of preterm birth were linked to high environmental temperature among different subgroups. Basu et al. (2010), for example, found a greater association among younger mothers, and among Black and Asian mothers. Black mothers had the highest risk, followed by Asians, Hispanics, and Whites. However differences between the estimates for any racial/ethnic group did not reach statistical significance ( $p=0.17$ ). Dadvand et al. (2011) found a relationship between very high ambient temperature on the day of delivery and an 8-day reduction in average pregnancy duration for European women compared with a 1-day reduction for non-Europeans. However this also did not reach statistical significance ( $p=0.11$ ). Both these authors suggest that racial differences in heat tolerance (Dadvand et al., 2011) and socio-economic differences among groups (Basu et al., 2010) may account for some of this variance.

## Discussion

Limitations of the review include a lack of homogeneity of studies and study characteristics, such as design, statistical approach, sample size and population, varied considerably from study to study. These factors limit the generalisability of results. Nonetheless, despite these difficulties, the general consensus of opinion supported an association between high environmental temperature and preterm birth.

One possible explanation for this association may be physiological and Basu et al. (2010) postulate that pregnant women may

experience difficulty with thermoregulation and become dehydrated during heat exposure. This results in a decrease in uterine blood flow which may trigger labour. Lajinian et al. (1997) concur with this view and further suggest that active treatment of preterm labour, such as rehydration and tocolytic therapy may have reduced the overall incidence of preterm birth in their study compared to high rates of preterm labour. Yackerson et al. (2008) also suggest a similar physiological mechanism, but focus instead on heat stress, induced by high environmental temperatures, to explain the association. These authors suggest that maternal heat stress may trigger a release of hormones such as cortisol, which may in turn induce labour. Earlier studies support this link between heat stress and increased uterine contractions in both humans (Vaha-Eskeli and Erkkola, 1990) and in animals (Dreiling et al., 1991). Increased contractions are thought to result from increased secretion of oxytocins and prostaglandin, during heat stress (Dreiling et al., 1991). At this stage however, although studies generally agree that high environmental heat gives rise to an increase in preterm birth, there is no clear consensus as to the mechanism by which the increase occurs.

Additionally, the degree of association varied considerably between studies and it is not immediately clear why such difference exists. Dadvand et al. (2011) propose one explanation and suggest a dose response relationship, in which more extreme environmental heat gives rise to a more acute reduction in gestational age. However, Porter et al. (1999), who examined preterm birth rates during the Chicago heat wave, found no such association. Both Lee et al. (2008) and Porter et al. (1999) found no link between high environmental temperature and preterm birth and there is no immediate or obvious explanation for their findings. One possible reason for Lee et al.'s (2008) results is the generally cooler climate in the UK, where maximum temperature seldom exceeds 25 °C (Lee et al., 2008). Both these authors examined exposure from up to 6 days prior to the birth to the time of birth (Lee et al., 2008; Porter et al., 1999) and it is possible that a greater association between high environmental temperature and preterm birth would be found in a more generous time frame, or with greater time lags.

Other factors that may contribute include unstable weather patterns and air pollutants, and for that reason, a brief discussion of those factors is included here. Although the evidence is limited, Yackerson et al. (2008) examined the effect of unstable weather and found that preterm premature rupture of membranes (PPROM), but not preterm birth, was associated with desert heat wave arrival, strong winds and daily differences in humidity and temperature. These authors cautioned that the influence of unstable weather on preterm birth and PPROM should not be underestimated. The evidence for air pollutants is equally limited, however Basu et al. (2010) and Lee et al. (2008) investigated the impact of ambient air pollution on preterm birth rates in the US and UK. Both these authors concurred that the risk of preterm birth did not increase with exposure to ambient air pollution.

Finally, although there is no consensus among reviewed studies as to what constitutes high environmental temperature, the authors have taken the position that the figures presented in each case include the extremes of hot weather for that country. It seems likely that populations have adapted to climatic conditions in their region which is in line with what Robinson (2001) describes as adopting social and cultural adaptive practices, such as having a siesta during the hottest part of the day (p. 726). Similarly, populations are likely to respond to higher than normal temperatures in their region, which may vary from 25/26 to 43 °C, depending on the location. In this way, individuals from cooler climates may experience heat stress at lower temperature than individuals living in hotter climates.



## Implications for practice

Health promotion is an important part of the professional midwife's role and, as such, midwives must be conversant on health determinants, including environmental influences. Moreover, midwives base their practice on the latest evidence, and current evidence suggests that the incidence of heatwaves is increasing. Global warming, and associated high environmental temperature, appears to contribute to increasing preterm birth rates, although the exact nature of this relationship is unclear. Nonetheless, it is clear that pregnant women are vulnerable to heat stress. For this reason, it is prudent that midwives are aware of heat stress and can advise pregnant women to adopt supportive measures to protect their health and the health of their unborn baby, during periods of extreme heat. Such measures may include increasing fluid intake, remaining in a cool or air-conditioned area and reducing activity levels to avoid exertion (Hajat et al., 2010).

## Conclusion

In conclusion, preterm birth rates are increasing and this condition gives rise to a significant health burden for families and communities. High environmental temperatures, and more especially heat stress, may contribute to increasing preterm birth rates. What is not as clear at this stage is the depth of association between heat stress and preterm birth or how it comes into being. For these reasons, more large-scale studies of environmental temperature, heat stress and preterm birth are required to improve our understanding of these events. Research is also warranted into the development of more effective cooling practices. In the meantime, it is important that pregnant women are advised to take special precautions to avoid heat stress and to keep cool when there are sudden increases in temperature.

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