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The impact of heat waves on children's health: a systematic review

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Abstract Young children are thought to be particularly sensitive to heat waves, but relatively less research attention has been paid to this field to date. A systematic review was conducted to elucidate the relationship between heat waves and children's health. Literature published up to August 2012 were identified using the following MeSH terms and keywords: "heatwave", "heat wave", "child health", "morbidity", "hospital admission", "emergency department visit", "family practice", "primary health care", "death" and "mortality". Of the 628 publications identified, 12 met the selection criteria. The existing literature does not consistently suggest that mortality among children increases significantly during heat waves, even though infants were associated with more heat-related deaths. Exposure to heat waves in the perinatal period may pose a threat to children's health. Pediatric diseases or conditions associated with heat waves include renal disease, respiratory disease, electrolyte imbalance and fever. Future research should focus on how to develop a consistent definition of a heat wave from a children's health perspective, identifying the best measure of children's exposure to heat waves, exploring sensitive outcome measures to quantify the impact of heat waves on children, evaluating the possible impacts of heat waves on children's birth outcomes, and understanding the differences in vulnerability to heat waves among children of different ages and from different income countries. Projection of the children's disease burden caused by heat waves under climate change scenarios, and development of effective heat wave mitigation and adaptation strategies that incorporate other child protective health measures, are also strongly recommended.

Keywords Heat wave · Child health · Mortality · Morbidity

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Introduction

There is a widespread consensus that climate is changing rapidly. The Earth's average surface temperature will increase by 1.8 to 4.0 °C relative to the 1961–1990 level by the end of this century (IPCC 2007). Heat waves—sporadic periods of elevated temperatures outside the normal range of climate variability for a specific region—occur throughout the world and are projected to become more frequent and intense in the future (Meehl and Tebaldi 2004). Increasing global urbanization compounds the potential risk due to the urban heat island effect, which can increase urban core temperatures disproportionately (Balogun and Adeyewa 2010; O'Neill and Ebi 2009). Heat waves are a significant threat to population health. For example, the 2003 heat wave caused nearly 15,000 excess deaths during the period of 1–20 August in France alone (Poumadère et al. 2005). To protect the population from the adverse impact of heat waves, identifying who is most vulnerable to heat-related illness and death and how to reduce their exposure is imperative.

Children are usually defined as humans under 18 years of age (American Academy of Pediatrics Committee on Environmental Health 2003), with infants referring to those under 1 year of age. Children differ from adults in a number of ways, thereby potentially increasing their sensitivity to heat waves: (1) Physiological modality: children have less developed thermoregulatory systems and a greater body surface area-to-mass ratio compared to adults, allowing greater heat and cold transfer between the environment and the body (Blum et al. 1998). (2) Metabolic modality: children have a higher metabolic rate that may render them more sensitive to heat waves (Bunyavanich et al. 2003). (3) Cardiovascular modality: children at a given activity level have a lower cardiac output than adults (Turley and Wilmore 1997). Besides, children, especially infants, have a lower cardiac index than adults, which may result in differing physiologic adaptive capacity to heat waves. (4) Behavior modality: at some developmental stages, children spend more time outdoors and participate in more vigorous activities than adults, which can result in more exposure to outdoor heat (United States Environmental Protection Agency 2011). (5) Self-care ability modality: children, especially infants, and children less than 2 years, cannot take care of themselves, and they are dependent on others to protect them from unsafe environments (Danks et al. 1962). (6) Life expectancy modality: more expected future years of life provides both an greater potential exposure period and also a longer period to experience delayed adverse health impacts from extreme heat exposure (Landrigan et al. 1999; Perera 2008).

There has been increasing interest in assessing the impact of heat waves on children's health (Basagaña et al. 2011; Knowlton et al. 2008). Nevertheless, to our knowledge, no literature review on the specific relationship between heat waves and children's health is available to date. Here, we conducted a systematic review to explore whether children are more likely to be associated with heat-related deaths and to elucidate some key pediatric diseases associated with heat waves.

Methods

Literature regarding heat waves and children's health published up to 1 August 2012 was retrieved using the databases Pubmed, ProQuest, ScienceDirect, Scopus and Web of Science. Peer-reviewed English-language journal articles were included in the initial search. The primary search used the following US National Library of Medicine's Medical Subject Headings (MeSH terms) and keywords: "heatwave", "heat wave", "child health", "morbidity", "hospital admission", "emergency department visit", "family practice", "primary health care", "death" and "mortality". References and citations of the relevant articles were inspected manually to make sure that all relevant articles were included. Eligibility included any studies that used original data and appropriate effect estimates (e.g., regression coefficient, relative risk, odds ratio, percentage change in morbidity, and morbidity or excess morbidity following heat waves); where heat wave was a main exposure of interest, and where children's morbidity or mortality were analyzed.

Results

A total of 628 papers were identified in the initial search. Finally, 12 studies were included (Fig. 1). The characteristics of the 12 studies meeting all inclusion criteria are summarized in Table 1.

The impact of heat waves on children's mortality

Nine studies examined the impact of heat waves on children's mortality. In Catalonia, Spain, Basagaña et al. (2011) assessed the impact of heat waves on total and cause-specific mortality in infants during the warm season from 1983 through 2006. They found that the effect of heat waves in infants was observed on the same day (Lag 0) of exposure and was detected for conditions originating in the perinatal period (relative risk (RR):1.53; 95 % CI: 1.16–2.02). The major condition originating in the perinatal period associated with heat waves was digestive system diseases (RR: 3.85; 95 % CI: 1.02–14.5).

In Shanghai, Huang and colleagues (Huang et al. 2010) quantified the effect of 2003 heat wave on mortality. This is one of the few English language studies looking at the impact of heat waves on mortality in China. The authors controlled for air pollution and did not find significant

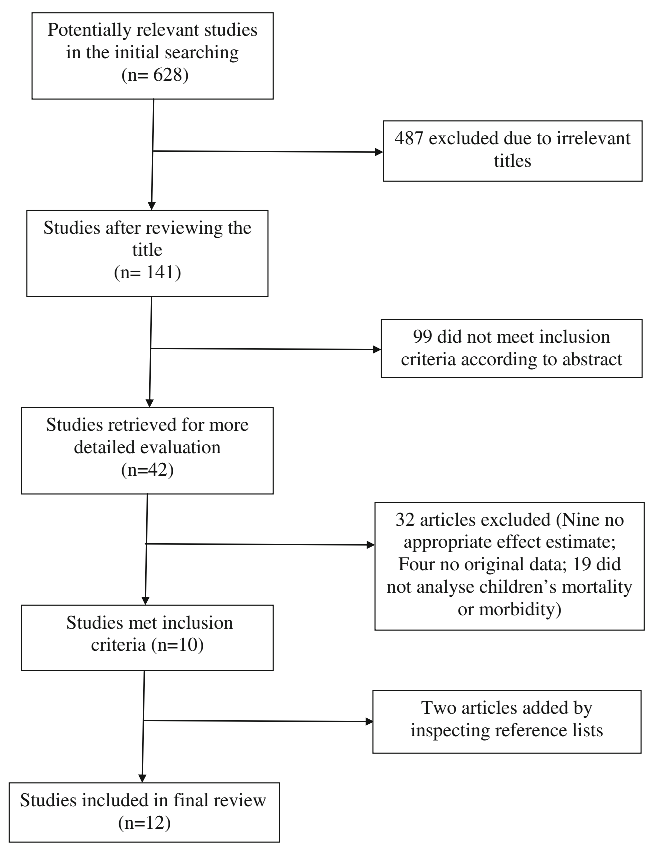

Fig. 1 The literature selection process

Table 1 Characteristics of studies on heat waves and children's health. *CI* Confidence interval, *IRR* incidence relative risk, *NA* not applicable, *RR* relative risk

Study ID[a]	Location	Design	Time period	Heat wave definition	Outcome variable	Adjusted for potential confounders	Results
Basagaña 2011	Catalonia, Spain	Case-crossover	15 May–15 October 1983–2006	Maximum temperature over 95th percentile of the period 1983–2006	Total and cause-specific mortality	Yes	In children aged under 1 year old, the effect of heat waves was observed on the same day and was detected only for conditions originating in the perinatal period (RR:1.53; 95 % CI: 1.16–2.02)
Fouillet 2006	France	Descriptive study	2000–2003	NA	Total mortality	No	During heat waves, significant excess mortality was observed for male children aged less than 1 year (observed mortality/expected mortality: 1.3; 95 % CI:1.0–1.6)
Huang 2010	Shanghai, China	Descriptive study	15 June–15 September 2003	Consecutive periods of at least 3 days during which the daily maximum temperature is ≥35.0 °C	Total and cause-specific mortality	Yes	No significant mortality increase was found in children aged 0–4 years during heat waves (RR: 0.67; 95 % CI: 0.24, 1.87)
Hutter 2007	Vienna, Austria	Time-series	1998–2004	Consecutive periods of at least 3 days during which the daily maximum temperature is ≥30.0 °C and daily minimum temperature is ≥25 °C	Mortality	Yes	The relative risk of death on a heat wave day was highest in children under 1 year old (RR=1.25; 95 % CI:0.82–1.90)
Knowlton 2009	58 counties of California, US	Descriptive study	8 July 2006–22 August 2006	Climatologic definition	Hospitalizations and emergency department visits	No	In heat waves, emergency department visits for electrolyte imbalance increased rapidly among children aged 0–4 years (RR: 1.19; 95 % CI:1.10–1.30)
Kovats 2004	London, UK	Time-series	1 April 1994-31 March 2000	Maximum daily temperatures exceeded 30 °C.	Emergency hospital admissions	Yes	Hospital admissions increased during hot weather among children under 5 years old, but not among elderly and adults (percent change: 0.24; 95 % CI: 0.02–0.46)
Kysely 2009	South Korea	Descriptive study	1991–2005	Consecutive periods of at least 3 days during which the daily heat index is ≥33.0 °C	Mortality	No	The relative increase in mortality was larger in children aged 0–14 years (183 excess deaths; 95 % CI: 133–234) than in any other age group
Leonardi 2006	England	Time-series	19 December 2001–23 May 2004	Mean temperature above 19 °C for the July episode and above 23 °C for the August episode	Calls to National Health Service[b] (fever, vomiting, difficulty breathing, heat-/sun-stroke)	Yes	In heat waves, the largest fever call rise was seen for children 0–4 years in Greater London and South East regions: 2.5 % increase in the proportion of fever calls (95 % CI 1.8, 3.3) for every 10 °C increase in mean temperature

Table 1 (continued)

Study ID[a]	Location	Design	Time period	Heat wave definition	Outcome variable	Adjusted for potential confounders	Results
Nitschke 2007	Adelaide, Australia	Case-series	1993–2006	Maximum temperature reached 35 °C or above for three consecutive days	Hospital admissions, ambulances, and mortality	No	Hospital admissions for respiratory diseases decreased during heat waves among children aged 0–4 years (IRR:0.86; 95% CI: 0.76–0.97). No significant rise was found in mortality during heat waves among children aged 0–4 years (IRR:1.19; 95 % CI: 0.82–1.71) and children aged 5–14 years (IRR:1.15; 95 % CI: 0.58–2.29)
Nitschke 2011	Adelaide, Australia	Case-series	2008–2009	Maximum temperature reached 35 °C or above for three consecutive days or more with 35 °C marking the 95th percentile for maximum daily temperature for the period 1993–2009	Hospital admissions, ambulance call outs, emergency department presentations and mortality	No	During heat waves, there were: (1) Significant rise of renal hospital admission in 5–14 year age group (RR: 2.64; 95 % CI:1.47–4.73); (2) Significant rise of emergency department presentations in 0–4 (RR:1.02; 95 % CI: 0.92–1.13) and 5–14 (RR: 1.04; 95 % CI: 0.95–1.14) year old groups; (3) Significant rise of mortality in 0–4 year old group (RR: 3.23; 95 % CI:1.30–7.99)
Rooney 1998	England, Wales, and Greater London	Descriptive study	1995	NA	Mortality	No	Mortality among children aged 0–15 years increased during 1995 heat waves in England and Wales (percent change in deaths: 4.6 %), and Greater London (percent change in deaths: 13.0 %)
Son 2012	Seven cities in South Korea	Time-series	1 January 2001–31 December 2007	Mean temperature reached at or above the 98th percentile for the warm season for ≥ 2 consecutive days	Mortality	Yes	No significant percent change was found in children aged 0–14 years during heat waves in Seoul

[a] The studies are ordered by the name of the first author

[b] A nurse-led helpline that provides health-related information and advice and directs callers to the appropriate health service and self care

increase in total mortality among children aged 0–4 years old (RR: 0.67; 95 % CI: 0.24–1.87) in heat waves.

Fouillet et al. (2006) investigated the effect of 2003 heat waves on mortality in France. The observed mortality during 2003 heat waves was compared to that expected on the basis of the mortality rates observed from 2000 to 2002. No significant increase in mortality among infants (observed mortality/expected mortality: 1.1; 95 % CI: 0.9–1.3) or children aged 1–14 years (observed mortality/expected mortality: 1.0; 95 % CI: 0.8–1.3) was found.

Kysely and Kim (2009) examined the effect of heat waves on daily mortality during 1991–2005 in South Korea. They computed the excess mortality based on calculating deviations of the observed number of deaths and the expected number of deaths for each day of the examined period, and found that, during the heat wave in 1994, the relative increase in mortality was larger in children aged 0–14 years (+27.5 %; 183 excess deaths, 95 % CI: 133–234) than in any other age group.

Hutter and colleagues (Hutter et al. 2007) investigated the effect of heat waves on daily mortality during 1998–2004 in Vienna, Austria, and found that the point estimate for the relative risk of deaths during heat wave days was the highest in infants, even though the confidence interval was broad because of the low number of deaths in infants and the effect was therefore not significant (RR: 1.25; 95 % CI: 0.82–1.90). Sex-specific analysis revealed that male infants had increased risk compared to female babies. However, the reason for this difference remains unclear.

Nitschke et al. (2007) investigated morbidity and mortality associated with heat waves from 1993 to 2006 in Adelaide using ambulance transport, hospital admission, and mortality data. They classified the total population into five age groups: 0–4, 5–14, 15–64, 65–74, and ≥75 years. They found that mortality increased (although not significantly) among children aged 0–4 years (RR:1.19; 95 % CI:0.82–1.71) and 5–14 years (RR:1.15; 95 % CI:0.58–2.29) but decreased in the other three age groups during heat waves. They also explored the impact of 2008 and 2009 Adelaide heat waves on hospital admissions, ambulance call out, emergency department presentations and mortality, and found that there was a significant mortality rise among children aged 0–4 years (RR: 3.23; 95 % CI:1.30–7.99) during 2008 heat waves (Nitschke et al. 2011).

Rooney et al. (1998) investigated the effect of 1995 heat waves on mortality in England, Wales and Greater London. They analyzed the mortality variation in daily mortality and found that deaths among children aged 0–15 years increased during heat waves in England and Wales (percent change in deaths: 4.6 %), and Greater London (percent change in deaths: 13.0 %). In this study, air pollution was not controlled when assessing the effect of heat waves.

Son et al. (2012) examined mortality from heat waves in seven major South Korean cities from 2000 to 2007. They also investigated effect modification by individual characteristics and heat wave characteristics (intensity, duration, and timing in season) and found no significant percent change in mortality among children aged 0–14 years during heat waves in Seoul.

The impact of heat waves on children's morbidity

Five studies examined the relationship between heat waves and children's morbidity (Knowlton et al. 2008; Kovats et al. 2004; Leonardi et al. 2006; Nitschke et al. 2007; Nitschke et al. 2011). Kovats and colleagues examined the effect of heat waves on emergency hospital admissions during April 1994–March 2000 in London, using a time-series design (Kovats et al. 2004). After adjusting for long-term trend, season, day of week, public holidays, the Christmas period, influenza, relative humidity, air pollution, and overdispersion, they found no relation between total emergency hospital admissions and heat waves but they did observe heat-related increases in emergency hospital admissions for respiratory and renal disease in children under 5 years of age.

Leonardi et al. (2006) investigated the relationship between heat waves and calls to National Health Service Direct—a nurse-led helpline that provides health-related information and advice and directs callers to the appropriate health service and self care—during December 2001–May 2004 in England. They used a time-series design and focused mainly on calls for fever, vomiting, difficulty breathing and heat stroke and sunstroke. Potential confounders such as ozone, PM_{10} and seasonally varying factors were controlled in the data analysis. They found that total calls were moderately increased as environmental temperature increased, and a rise in fever calls (RR: 2.5 % per 10 °C increase in mean temperature; 95 % CI: 1.8 %–3.3 %) was seen only for children 0–4 years in Greater London and South East regions.

Knowlton et al. (2008) investigated the effect of heat waves on hospital admissions and emergency department visits during July–August 2006 in 58 counties of California in the United States, using a descriptive design. They found that emergency department visits for all ages were increased but the effect was greatest in the 0–4 year age group (RR: 1.05; 95 % CI: 1.04–1.07) with emergency department visits for heat-related (RR: 6.17; 95 %CI: 2.58–17.88) and electrolyte imbalance diagnoses (RR: 1.19; 95 % CI: 1.10–1.30) being elevated specifically among the 0–4 year age group during the heat wave period.

Nitschke et al. (2007) quantified the impact of heat waves from 1993 to 2006 on morbidity and mortality in Adelaide using ambulance, hospital admission, and mortality data. They found that the hospital admissions for respiratory diseases decreased during heat waves in children aged 0–4 years (RR: 0.86; 95 % CI: 0.76–0.97). They also assessed the association between heat waves and hospital admissions, ambulance call outs, emergency department presentations and mortality from 2008 to 2009 in Adelaide, Australia (Nitschke et al. 2011), and found that, during heat waves, there was a significant rise of renal hospital admissions in the 5–14 year age group (RR: 2.64; 95 % CI: 1.47–4.73). In addition, significant rises in renal emergency department presentations in the 0–4 (RR: 1.74; 95 % CI: 1.06–2.45) and 5–14(RR: 1.51; 95 % CI: 1.02–2.23) year-old groups were also detected during heat waves occurring in 2008 to 2009.

Discussion

The existing literature does not consistently suggest that heat waves increase the risk of death among children. Some studies found that heat waves had a significant impact on children's mortality in Australia (Nitschke et al. 2011), Great Britain (Rooney et al. 1998), Spain (Basagaña et al. 2011) and South Korea (Kysely and Kim 2009), but other studies did not find a significant effect of heat waves on children's mortality (Son et al. 2012; Nitschke et al. 2007; Hutter et al. 2007; Huang et al. 2010; Fouillet et al. 2006). In the setting of extreme heat, young children experience greater risk of renal disease, respiratory disease, electrolyte imbalance, and fever.

The inconsistencies in the impact of heat waves on children's mortality across regions could be explained by the following reasons. (1) Different adaptability to heat waves: due to factors such as caregiver behavior, air conditioning use (Ostro et al. 2010), nutritional status, vaccination status and access to environmental infrastructures, the adaptability to heat waves varies worldwide. (2) Different characteristics of heat waves: even a small change in the heat wave definition had an appreciable effect on the estimated health impact (Tong et al. 2010). The existing literature looking at the impact of heat waves on children's health used various definitions of heat waves, which might render the results inconsistent. Further, even using the same heat wave definition (Nitschke et al. 2007, 2011), the intensity, duration, timing of every heat wave differs, which may also cause different health outcomes in children (Anderson and Bell 2009). (3) Different age groups: the current studies assessed the effects of heat waves on the health of children of different ages. Some researchers analyzed children aged 0–4 years (Huang et al. 2010) or 0–14 years (Nitschke et al. 2007), and others focused on infants (Basagaña et al. 2011). Apparently, children of different ages have specific characteristics, including their ability to adapt to heat waves.

The findings of our review illustrate that studies in Australia (Nitschke et al. 2007, 2011), Austria (Hutter et al. 2007), South Korea (Kysely and Kim 2009), and Spain (Basagaña et al. 2011) support the assumption that heat waves have a greater effect on mortality among children than adults, while studies in Great Britain (Rooney et al. 1998) and Korea (Son et al. 2012), which considered children aged 0–14 years as a whole group, challenged this assumption. This finding may indicate that very young children, especially those aged under 1 year, rather than older children, were more vulnerable to heat wave impact when compared with adults. This age-specific vulnerability could be due partly to their less developed thermoregulation ability and their low self-care ability. A study found that heat-related mortality among infants was detected only for conditions originating in the perinatal period in Catalonia, Spain, especially for digestive system diseases (Basagaña et al. 2011). This result indicates that exposure to heat waves in the perinatal period may pose a threat to children's health. The impact of maternal exposure to high temperature on adverse birth outcomes has attracted increasing research attention (Strand et al. 2012), but no study has elucidated the relationship between heat waves and birth outcomes to date.

Published studies in English regarding the impact of heat waves on children's mortality are mostly from developed countries, but the drivers of mortality in developing countries are very different, with a high burden of infectious disease and dehydration. In the early twentieth century, when infectious disease contributed greatly to mortality also in developed countries, heat waves were associated with greater number of deaths in the whole population (Infoplease 2007), and also in children. For example, the 1911 heat wave in France was associated with 40,000 deaths, of which 29,000 were children (Rollet 2010). To some extent, the relatively lower impact of recent heat waves on deaths observed in children reflects improvements in care.

The key pediatric diseases or conditions significantly affected by heat waves include renal disease, respiratory disease, electrolyte imbalance and fever (Knowlton et al. 2008; Kovats et al. 2004; Leonardi et al. 2006; Nitschke et al. 2007, 2011). A recent analysis of the contribution of extreme temperatures to years of life lost in Australia drew attention to the concept that consideration of age and life expectancy are important in mortality studies (Huang et al. 2012), but to date there is no research concerning the impacts of heat waves on children's years of life lost. The outcomes examined in these studies likely represent the most extreme effects of a continuum of health impacts from heat. Other outcomes, such as missed school days and impaired cognitive performance, are other potentially important parts of the total burden of disease from extreme heat.

Pediatric renal disease is an important adverse consequence of heat waves among children. Several studies have reported increases in hospital admissions for renal dysfunction during periods of high ambient temperature (Dematte et al. 1998; Kovats and Kristie 2006). Exposure to extreme hot weather can induce heat-related conditions including hyperthermia and heat stress in children (Semenza et al. 1999), and the thermoregulatory physiological and circulatory adjustments necessary to cope with extreme heat can place stress on the kidneys and compromise the function of the renal system. Physiologically, children have poor ability to cope with heat, which can make them more vulnerable to the impact of heat waves. Heat-related renal dysfunction has also been attributed to other factors, including direct thermal injury, prerenal insult, rhabdomyolysis, and disseminated intravascular coagulation (Kew et al. 1967; Raju et al. 1973). Persons with diabetes have an increased susceptibility to extreme heat (Semenza et al. 1999) and heat-related renal dysfunction, possibly due to pre-existing renal conditions resulting in compromised kidneys (Mogensen et al. 1983).

Respiratory disease is another adverse consequence of heat waves in children (Kovats et al. 2004). It seems that very young children are more influenced by heat in terms of respiratory function. While the underlying mechanisms through which high temperatures may increase the risk of hospitalization for respiratory diseases are unclear, we assume that young children's susceptibility to respiratory disease during heat waves can be due partly to their still developing respiratory system and generally smaller airways. For young children, exposure to heat waves may result in exacerbation of any existing chronic respiratory disease, which will result in mortality increases during subsequent hot days (Stafoggia et al. 2008). One such mechanism is through the effect of heat on formation of ozone—a known respiratory irritant. A recent study estimated that ozone-related asthma emergency department visits for children could increase as much as 7 % in a major metropolitan area due to temperature-driven changes in ozone concentrations (Sheffield et al. 2011). Further understanding of the underlying mechanisms through which high temperatures influence respiratory disease is an area where further research and development are clearly needed, especially because the burden of such diseases is expected to grow as climate change continues (Mannino and Buist 2007).

During a heat wave period, in an effort to prevent hyperthermia and dehydration, the body's physiological mechanisms attempt to regulate electrolyte and water imbalance. In the setting of unreplaced fluid losses through perspiration and respiration, children, in particular, may face electrolyte imbalance (Knowlton et al. 2008). Electrolyte imbalance can precipitate heat exhaustion or heat cramps, which in turn can further intensify electrolyte imbalance in the setting of continued exposure to intense heat.

Fever calls increased on heat wave days, especially for children 0–4 years (Leonardi et al. 2006). Ambient temperatures in excess of 41 °C were often associated with hyperthermia (Feld and Hyams 2005). When the hypothalamus receives information that the body temperature is lower than the setting of the internal thermostat, thermoregulatory responses that conserve or produce heat are put into action. Heat is generated by shivering and is conserved by vasoconstriction. If the body temperature is higher than the internal thermostat setting, heat is lost by vasodilatation and increased sweating (Feld and Hyams 2005). Other responses include extracellular fluid volume regulation via arginine vasopressin, and behavioral responses such as seeking a warmer or cooler environmental temperature (Feld and Hyams 2005). If a body is involved in a sustained heat environment (e.g., heat wave) and cannot seek a cooler environment, the physiological responses may not suffice and increased body temperature (i.e., hyperthemia) may occur.

Susceptibility to disasters decreases through activities such as prevention and mitigation measures that prevent or limit a population's exposure to the hazard, which is particularly important for children. Preparedness, response, and recovery capacity building increase resilience. Heat wave resilience is composed of (1) the absorbing capacity; (2) the buffering capacity; and (3) response to heat wave and recovery from the damage sustained (Boer and Dubouloz 2000).

In the process of building resilience to cope with heat wave impacts, preventive measures are essential, not only because many causes of death may increase but also due to the fact that the mortality rate of some diseases, such as heatstroke, is high even when treated (Bouchama and Knochel 2002). The mortality of patients with heat stroke admitted to intensive care units during the 2003 heat wave in France was 62.6 % (Misset et al. 2006). In addition, for those patients who recovered from heat stroke, they suffered from severe sequelae (e.g., persistent neurological sequelae) (Rav-Acha et al. 2007; Romero et al. 2000). The best method for handling heat waves is through primary prevention, which means preventing exposure to extreme heat in the first place, rather than treating symptoms. Primary prevention includes health education of children, and families about the risk factors of heat-related illnesses, their signs and symptoms, and how to recognize and treat affected children. When they are aware of the potential health effects of heat waves and the special physical and emotional vulnerabilities of children, parents and caregivers can do a lot to protect children from potential harm (Luber and McGeehin 2008).

There is a growing appreciation amongst policy makers and societal actors that the policy context in which climate change adaptive decisions are made must be considered (Burton et al. 2002). The importance of policy on preventing children from the impact of heat waves should be specifically focused, even though the heat wave prevention policy made for children is currently scarce (Department of Human Services 2009). Governments at all levels should make great efforts to reduce carbon emissions, including heat waves, and to mitigate their impact on children's health.

Similar to studies of risk factors for heat vulnerability among the elderly (Semenza et al. 1996), heat vulnerability in children can be reduced by reshaping the built environment(Rosenthal et al. 2007). Alert systems or early warning systems have been developed (Díaz et al. 2006; Kalkstein et al. 1996; Metzger et al. 2009; Nicholls et al. 2008; Pascal et al. 2006) and could perhaps be adjusted to see if the locally relevant "threshold temperatures" used to issue alert levels could be revised to apply to pediatric mortality or morbidity, and give parents and caregivers advance warning to take precautionary measures.

Knowledge gaps

Existing research provides evidence that children are more likely to be associated with heat-related morbidity. Nonetheless, there are still substantial knowledge gaps. Several key methodological challenges should be addressed in future research, such as: (1) what is the definition of heat wave from a children's health perspective? (2) How is children's exposure to heat wave best measured? (3) What are the most common health consequences of heat waves among children? (4) What are the impacts of heat waves on years of life lost or disability-adjusted life years among children? (5) What are the differences in vulnerability to heat waves among children of different ages? (6) How does vulnerability of children, particularly the very young, vary between high income and low or middle income countries? (7) What are the best ways to project children's disease burden from heat waves under different climate change scenarios? (8) What are the most effective modifiable risk factors of a public health response to the impact of heat waves on children's health? And how do those risk factors differ by developmental stage of the child? And consequently, (9) What are effective heat wave mitigation and adaptation strategies from a children's health perspective?

Conclusion

The evidence for whether heat waves significantly increase children's mortality is still inconsistent. However, more heat-related deaths among infants are reported during heat wave periods. Additionally, children are more likely to be affected by respiratory disease, renal disease, electrolyte imbalance and fever during persistent hot episodes.

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