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The impact of rising ambient temperatures on the mental and physical health of children

Caradee Y Wright[a,b,*], Mary Norval[c], Natasha Naidoo[a], Muthise Bulani[a], Ashraf Coovadia[d,e], Linda Theron[f]

[a] Environment and Health Research Unit, South African Medical Research Council, Pretoria, South Africa
[b] Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Pretoria, South Africa
[c] Department of Biomedical Sciences, University of Edinburgh, Edinburgh, UK
[d] Department of Paediatrics and Child Health, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa
[e] South Africa Rahima Moosa Mother and Child Hospital, Johannesburg, South Africa
[f] Department of Educational Psychology, University of Pretoria, Pretoria, South Africa

A R T I C L E I N F O

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A B S T R A C T

Globally, mean ambient temperatures have increased by 1.6 °C between preindustrial level and 2024, alongside a rise in extreme weather events such as heatwaves and droughts. This rapid review synthesizes the existing literature on the risks to children's physical and mental health due to heat exposure. Comprehensive literature searches were conducted using PubMed, Scopus, Web of Science, and ScienceDirect. This review highlights the increased risks to children's physical and mental health from extreme temperatures in several populations. Major health concerns include heat-related illnesses, dehydration, increasing incidence of infectious diseases, reduced cognitive performance, depression and anxiety and the exacerbation of pre-existing conditions. Potential strategies to mitigate these negative health outcomes are proposed, including improved access to cooling solutions, public health interventions, and educational campaigns to improve thermal comfort.

Introduction

Climate change, including the rise in global temperatures, has a significant impact on human health and wellbeing (World Health Organization 2018). Globally, mean ambient temperatures have increased by at least 1.60 °C in 2024 since 1880 (NASA, 2025) together with the occurrence of intermittent heatwaves. As global temperatures rise, the relative increase in temperature will be larger at mid- and high-latitudes, while the intensity of heat waves will be greatest in the tropics although the relative change here will be smaller (IPCC 2022). Historical data (2009–2020) in Africa show that the number of children under 5 years old who have died from heat-related illnesses is double what it would have been in the absence of the change in ambient temperatures (Chapman et al., 2022). Children are vulnerable to environmental stress as development of the brain, nervous system, immune function (Vergunst and Berry, 2022), thermoregulation and other physiological functions (Smith, 2019) occur during childhood. Compared with adults, children and adolescents need more time to acclimatise to a hot environment (Mangus and Canares, 2019).

Children from high-income areas are less likely to be exposed to the severe effects of heatwaves, flooding, and other extreme events compared with children living in low-income areas (Arpin et al., 2021; Bennett and Friel, 2014). During excessively hot days, children in high-income areas can seek refuge in insulated buildings with cooling systems and potable tap water, whereas children in low-income areas cannot (Leiva and Church, 2025). Children in low- and middle-income countries (LMICs) are more adversely affected by the impacts of heat due to poverty, homelessness and/or pre-existing diseases (National Academies of Sciences 2019).

Several studies have considered heat-related health impacts predominantly on adults and the elderly (Leiva and Church, 2025; Trombley et al., 2017; Meade et al., 2020) but there has been no recent review, to the best of our knowledge, relating to children. Two reviews from more than ten years ago did consider the impacts of health on children's health (Z Xu et al., 2014; Xu et al., 2012). In the first in 2012, Xu et al. reported that paediatric diseases and conditions associated with heat waves include renal disease, respiratory disease, electrolyte imbalance and fever, but mental health outcomes were not considered.

* Corresponding author. SAMRC, 1 Soutpansberg Road, Pretoria, 0001, South Africa.
E-mail address: caradee.wright@mrc.ac.za (C.Y. Wright).

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In the second, a systematic review published two years later (Z Xu et al., 2014), warm and cold ambient temperatures were associated with infectious diseases among children, including gastrointestinal diseases, malaria, hand, foot and mouth disease, as well as respiratory diseases and allergic diseases, such eczema. Again, mental health was not considered. Given that more than ten years has passed since these publications, and that the mental health impacts on the health on children were not considered, we deemed it timely to review the literature, especially as increasingly warmer climates and periods of extreme heat are becoming more common. We carried out a rapid review in which the physical and mental health impacts of heat on children were examined, including heat illness, kidney disease and renal failure, respiratory and gastrointestinal illnesses, infectious and vector-borne diseases, mental disorders and diseases associated with exposure to solar ultraviolet radiation (UVR). Secondly, by understanding the detrimental effects of heat on children, interventions, policies and support systems that may help mitigate these adverse consequences and promote the well-being of children are suggested.

Methods

Study design

This rapid review examines the impact of heat on the physical and mental health of children. The review follows the PECOS (Population, Exposure, Comparison, Outcomes, Setting) framework (Table 1) to structure the literature search according to the research question (Morgan et al., 2018). Even though heat is associated with a high frequency of pre-term birth and significant effects on maternal health (Weeda et al., 2024), this review excluded publications on pre-term birth and stillbirth as we focused on the effects of heat in children and adolescents and not on pregnant women. The search was restricted to English language papers or relevant translations in English and conducted across four databases namely PubMed, ScienceDirect, Scopus and Web of Science of articles published from 2000 to 2024. The results of the search process are given in Supplementary Figure S1. The results of the literature search are given in Supplementary tables S1 and S2.

Table 1
Inclusion and exclusion criteria using the PECOS framework.

PECOS Framework	Inclusion	Exclusion
Population	Children (aged 0–18 years)	Adults or adolescents >18 years old unless data on children is provided
Exposure and comparator	Weather related elevated temperatures, including heatwaves	Non-weather-related heat such as body temperature, incubator temperature
	Short term and long-term exposure	No reference to heat exposure
	Indoor and outdoor ambient temperature	
	Reference to air pollution/air quality that exacerbates heat	Air pollution/air quality but no reference to heat
	Temperature and humidity	Exclusively studies humidity or precipitation
Outcomes	Physical health: respiratory illnesses, cardiovascular issues, kidney conditions, and other illnesses	Studies on heat but no health-related outcomes Birth related outcomes from pregnancy such as preterm birth, stillbirth, low birth weight and birth defects
	Mental health: depression, anxiety, suicide rates and other disorders in children	Studies on heat but no health-related outcomes Mental health of pregnant women, post-partum depression
Setting	Global	None
Type of paper	English language	Non-English studies without translations
	Peer reviewed, published literature published January 2000 -November 2024	Grey Literature since not always peer reviewed

Findings and discussion

Direct effects of heat on the physical health of children

Heat illness

Heat illness is caused by exposure to intense heat and proceeds on a spectrum from heat exhaustion and severe dehydration to heat stroke (Epstein and Heatstroke, 2019). Heat stroke is distinct from exertional heat stroke that is caused by strenuous physical exercise and is common among athletes (Epstein and Heatstroke, 2019). Once body temperature exceeds 40 °C, damage to the brain, heart, kidney, and muscle occur, which can be fatal (Epstein and Heatstroke, 2019; Morris and Patel, 2025). When analysing the impact of extreme heat on children, it is important to consider both types of heat stroke.

There are no significant differences between the thermoregulatory capacity of children and adults at mild to moderate temperatures (Smith, 2019), even during exercise (Rowland, 2008; Ravanelli et al., 2023). However, children are more sensitive to extreme heat than adults due in part to their lower ability to regulate their body temperature (Smith, 2019). Additionally, children have a higher body surface area to mass ratio due to their size that causes more pronounced heat absorption and dissipation (Notley et al., 2020). Thus, prioritization of skin blood flow may take precedence over sweating, whereas in adults, the emphasis shifts towards relying on the evaporation of sweat (Notley et al., 2020). The differences in thermoregulatory capacity of children, in addition to their lack of adaptability lead to various health challenges in the presence of excessive heat and heatwaves.

While there is no consistent evidence that the risk of child mortality increases significantly during heat waves, there is a marked increase in the prevalence of renal and respiratory illnesses, electrolyte imbalance, and fever (Z Xu et al., 2014). Deaths of infants and prepubescent children who are left in cars during intense heat have been reported (Ho et al., 2020; Hammett et al., 2021; Costa and Grundstein, 2016; National Safety Council). Other studies have analysed heat effects on children's cognitive function, physical discomfort, and behavioural responses in the classroom (Gibberd and Motsatsi, 2013; Haddad et al., 2017; Wargocki et al., 2019; Mishra and Ramgopal, 2015; Bidassey-Manilal et al., 2016; Munonye and Ji, 2018; Pule et al., 2021). These research areas focus on child-specific scenarios where only children are afflicted by heat. There is evidence of increased emergency department visits and hospital admissions indicative of heat-related illness in children, particularly during the summer season and heatwaves (Bernstein et al., 2022; Iñiguez et al., 2016; Niu et al., 2022; Checkley et al., 2000; Phung et al., 2015). In a Brisbane-based study, it was observed that severe heatwaves were correlated with a higher frequency of infant hospitalizations (Xu et al., 2017). Another study in South Korea investigated the association between heatwave exposure during summer and found an elevated risk of hospitalization for heat-related illnesses in children under five years of age (Oh et al., 2023).

Kidney disease and renal failure

Kidney morbidities are thought to arise from exertional heat stroke when the kidneys fail to cope with dehydration and electrolyte imbalance (Epstein and Heatstroke, 2019). However, during extreme heat (> 40 °C) kidney morbidity may occur with heat stroke alone (Epstein and Heatstroke, 2019; Goto et al., 2023). Reports from high-income countries show evidence of increased hospital admissions of children for renal dysfunction during high temperature conditions (Kovats and Kristie, 2006; Dematte, 1998; Z Xu et al., 2013). A study in Adelaide, Australia found a rise in hospital admissions for renal dysfunction among children aged 5–14 years old during heat waves at ≥ 35 °C that occurred for three or more days at a time (Z Xu et al., 2013; Nitschke et al., 2011). Furthermore, there was a significantly increased risk of emergency department visits due to renal dysfunction in the 5–14-year age group during the 2008–2009 heat waves.

Respiratory illnesses

The association between both summer and winter temperature profiles and an increased risk of respiratory disease is well supported (Phung et al., 2015; Sohn et al., 2019; Xie et al., 2017; Z Xu et al., 2014). Nevertheless, elevated temperatures have a discernible negative impact on the respiratory system of children. A study in Vietnam showed that for every 1 °C rise in ambient temperature, there was an elevated risk of 19.5 % in the probability of hospital admissions in children due to respiratory disease (Phung et al., 2015). In Alaska, there was a significant increase in emergency room visits from children < 15 years after two consecutive days of heat above a heat threshold of 21.1–28 °C (Hahn et al., 2023). The children endured symptoms of asthma, pneumonia, bronchitis, and heat illness (Hahn et al., 2023). The number of emergency department visits among children aged 0–4 years increased during and after extreme heat (RR: 1.05; 95 % CI: 1.04, 1.07) in California (Knowlton et al., 2009). Admission diagnoses included diabetes exacerbations, disorders of fluid and electrolyte balance, cardiovascular diseases, acute myocardial infarction (MI), cerebrovascular diseases, and respiratory illnesses (Knowlton et al., 2009). The number of daily outpatient visits of children aged 4–17 years old with respiratory illnesses increased during extreme heat conditions in China (RR =1.741, 95 % CI: 1.524–1.990) (Zhang et al., 2019).

Indirect effects of extreme heat on the physical health of children

Ambient air quality

Respiratory health is affected by air quality which has been linked with higher temperatures (Mirsaeidi et al., 2016). Rising temperatures contribute to an increase in ground-level ozone concentrations (Di Cicco et al., 2020; Kline and Prunicki, 2023), originating from precursor compounds like volatile organic compounds (VOCs), carbon monoxide (CO), and nitrogen oxides (NOx) (Mirsaeidi et al., 2016; Ebi and McGregor, 2008). These pollutants have a direct bearing on air quality, further compounded by the production of particulate matter (PM), polycyclic aromatic hydrocarbons, and black carbon, often stemming from forest fires exacerbated by hot and dry conditions (Perera, 2017).

Ozone exposure damages epithelial linings and causes inflammation of the upper and lower airways, increasing airway reactivity and compromising lung function (Lee et al., 2021). A study in California showed that spikes in ozone exposure during warmer seasons increased the risk of emergency department visits for asthma, acute respiratory infections, pneumonia, chronic obstructive pulmonary disease and upper respiratory tract inflammation, although few of these cases involved children (Malig et al., 2016). However, chronic ozone exposure is associated with increases in asthma exacerbations and decreased lung function in children (Sousa et al., 2009) and young adults (16 – 19 years old) (Tager et al., 2005).

According to an Australian study, children aged ≤4 years exhibited heightened sensitivity to heat, resulting in an elevated risk of seeking emergency asthma care whereas from the ages of 10 – 14 years, there was a shift in vulnerability to colder conditions (Z Xu et al., 2013). A study in Atlanta demonstrated a lagged effect between increased visits to paediatric asthma and maximum temperatures (O'Lenick et al., 2017). Statistically significant associations became apparent after the days of high temperatures (O'Lenick et al., 2017).

While we did find studies that explored the combined effects of air pollution and heat on cardiovascular health outcomes (Alahmad et al., 2023), there is emerging evidence of an association between the concomitant effects of maternal exposure to both particulate matter and heat during pregnancy and an increased risk of congenital heart defects in the offspring (Simmons et al., 2022; Stingone et al., 2019). Despite these studies, there is a need for more research to confirm these findings in other places around the world. Although elevated temperatures are likely to impact health, partly through its impact on air pollutant levels, more work is needed to directly establish these pathways, particularly in developing countries.

Infectious and vector-borne diseases

Mosquito-borne diseases such as malaria and dengue fever have started to appear in regions where they were previously non-existent or had been eliminated (Metcalf et al., 2017). Meteorological factors are known to influence vector lifecycles and are useful in predicting outbreaks of vector-borne diseases (Eikenberry and Gumel, 2018; Adeola et al., 2019). The risk of such diseases being influenced by higher ambient temperatures has been evaluated (Colón-González et al., 2021). The projected global impact of increased temperature on transmission seasons of malaria and dengue shows an additional 1.6 and 4 months per year, respectively (Semenza et al., 2022). In addition, the epidemic area for both diseases are projected to expand towards temperate regions, dramatically increasing the number of people at risk, especially children.

Although the relationship between temperature and the incidence of infectious and vector-borne diseases in children is complex, higher temperatures have been linked to disease outbreaks and the lifecycles of vectors. Possible additional factors include the exploratory nature of children in the outdoor environment particularly during ages 6 months to two years, to the lack of previous exposure to most pathogens, and to the higher metabolic activity and greater oxygen consumption of children compared to adults [National Research Council (US); Institute of Medicine (US). Children's Health, the Nation's Wealth: Assessing and improving Child Health. Washington (DC). National Academic Press (US). Chapter 3. Influences on Children's Health.). In addition, if a liquid environment contains a contaminant children could drink more of it relative to their size than adults.

Higher temperatures in Indonesia were found to significantly increase paediatric dengue outbreaks (Incidence Rate Ratio: 1.27; 95 %, 95 % CI: 1.22–1.31, $p < 0.001$) with the rise in incidence occurring 2–4 months later, aligning with the mosquito lifecycle (Astuti et al., 2019). In hyperendemic areas in Asia, dengue fever affects mainly children under 15 years of age while in the Americas all ages are susceptible, although most deaths occur in children (Gubler, 2002; Tantawichien, 2012). A higher average temperature and relative humidity were linked to a higher risk of malaria in children under five in the Zomba district, Malawi (Hajison et al., 2017). It is not known why children are particularly susceptible to these diseases.

Infection with several *Vibrio* species can also be affected by heat. The distribution of case numbers due to *Vibrio vulnificus* infections has been monitored along the east USA coast during the past 30 years. During this time, the northern case limit shifted by 48 km per year (Archer et al., 2023). The mean air temperature and maximum air temperature significantly correlated with the presence/absence of case numbers. Although this disease mainly affects adults, there is evidence of ambient temperature increases shifting the distribution of pathogenic organisms, which is relevant for children's health. The child population in Bangladesh is especially vulnerable due to the country's strong susceptibility to widespread cholera outbreaks (about 10 % of children there contracted the disease in 2012) (Hanna and Oliva, 2016; UNICEF).

Globally, gastrointestinal diseases and dehydration during hot weather continue to be major contributors to mortality, accounting for approximately 450,000 annual deaths (Ghazani et al., 2018; UNICEF). Most of these fatalities occurred in children under 2 years old, particularly in South Asia and sub-Saharan Africa (Ghazani et al., 2018; UNICEF). An 11 % increase in the number of emergency hospital visits due to gastrointestinal infections was linked to every 1 °C increase in the maximum temperature in Sydney, Australia (Lam, 2007). In Vietnam, the incidence of hospitalization for children aged 0 to 5 years with gastrointestinal infections increased as the temperature rose above 24 °C

(Phung et al., 2015).

Solar ultraviolet radiation (UVR) exposure

An increase in ambient temperature could lead to children spending more time outdoors, thereby increasing their sun exposure. This possibility will depend on the extent of the temperature rise as, for example, if it is above 30 °C, children particularly if they live in what are normally temperate regions of the world, may find it too hot for outdoor activities.

If overexposure to solar UVB occurs, it has multiple detrimental effects on physical health with children being particularly vulnerable. This is because the skin of children, especially those under three years of age, has a lower concentration of the photoprotective pigment, melanin, and a thinner stratum corneum, with the result that UV rays cause more photodamage as they penetrate more deeply into the skin layers than in adults (Garnacho Saucedo et al., 2020; Stamatas et al., 2010; Stamatas et al., 2011). This together with greater percutaneous absorption and trans-epidermal water loss makes children more susceptible to sunburn than adults. There is also greater susceptibility to UV-induced mutations in the basal skin layer in children, another factor which is likely to be important in determining the risk of skin cancer in later life. Finally negative health consequences in the eyes of children can result from spending more time outside. These include photokeratitis (snow blindness) and photoconjunctivitis (Chawda and Shinde, 2022). The eyes of children are more susceptible than adults to these conditions as the lens only becomes fully protective in preventing UV rays reaching the retina after the age of 12 years, and children can look directly at the sun without blinking until adolescence.

(Semenza et al., 2022), (Astuti et al., 2019), (Eikenberry and Gumel, 2018; Adeola et al., 2019; Colón-González et al., 2021), (Gubler, 2002; Tantawichien, 2012), (Hajison et al., 2017), (Archer et al., 2023), (Hanna and Oliva, 2016), (UNICEF), (Ghazani et al., 2018), (UNICEF), (Lam, 2007; Garnacho Saucedo et al., 2020), (Stamatas et al., 2010; Stamatas et al., 2011)

Food security and nutrition

Rising temperatures driven by climate change have reduced global food production for major crops during the last half-century. It has been calculated that for every 1 °C increase in temperature, maize, wheat, rice and soybean yields decrease by 6 %, 3.2 %, 7.4 % and 3 %, respectively (Zhao et al., 2017). Similarly, a rise in sea surface temperatures threatens fisheries and aquaculture which represent a substantial food source for many communities world-wide (Heck et al., 2023). These changes have caused food insecurity and undernutrition, particularly in low-income countries.

Undernutrition has the most significant impact on children under the age of 5 years, resulting in stunting, wasting, micronutrient deficiencies and poor breast feeding (Black et al., 2008). A recent survey compared the nutritional status of children under the age of 5 years in Iran between 1998 and 2020 (Ghodsi et al., 2023). Despite an overall improvement, there remained provinces with lower food security, leading to childhood undernourishment, stunting, and wasting (Ghodsi et al., 2023).

A study in Uganda assessed the effect of extreme weather on the nutrition and health outcomes in rural children (Amondo et al., 2023). A negative relationship was found between extreme events and the availability of nutrients and calories in children in rural households. Importantly, high temperature conditions, including heatwaves and droughts, were associated with decreased agricultural growth with observed consequences on crop quality (Amondo et al., 2023). In Brazil, a rise in temperatures was linked to heat illness in children. The risk of hospital admissions due to heat illness was significant for children aged 0–4 years (OR 1.039, 95 % CI 1.024–1.055, $p < 0.001$), and for those aged 5–19 years (OR 1.042, 95 % CI: 1.015–1.069, $p = 0.002$) (Xu et al., 2019).

The psychological impacts of heat exposure on children

The brain and neurological system of infants and children are still developing and are more vulnerable to environmental influences than in adults (Z Xu et al., 2013; Ngu et al., 2021; Watts et al., 2019). Although there are few studies on the effects of extreme heat on the mental wellbeing of children (Clemens et al., 2022) and any neurological effects (Bansal et al., 2023), there are sufficient data to warrant further investigations (Walinski et al., 2023; Xu et al., 2018; Basu et al., 2018; Sugg et al., 2019).

In New York City, a sample of 82,982 emergency department and hospital visits due to mental health-related morbidity revealed elevated risks of 28 % (OR: 1.28; 95 % CI: 1.13 – 1.46) and 17 % (OR: 1.17; 95 % CI: 1.09 – 1.25) in the 6–11-year-old and 12–17-year-old age groups respectively (Niu et al., 2023). The mental health outcomes included anxiety, reaction disorders, bipolar disorders, and psychosis (Niu et al., 2023). At the Shanghai Mental Health Centre from 2014 to 2019, the frequency of clinical psychiatric outpatient visits increased with escalating temperatures, particularly among children, (Shao et al., 2020). The analysis involved examining outpatient data alongside corresponding weather reports. Notably, the impact of elevated temperatures was most pronounced with a one-month lag ($r = 0.292, p = 0.020$) (Shao et al., 2020).

Among 1 891 suicides reported for a population of Belgium individuals aged 5 years and older, the cumulative Relative Risk (RR) for suicide in the week after moderate heat (20.9 °C) was 1.8 (95 % CI: 1.27 – 2.54) and after extreme heat (defined as 24.4 °C) it was 2.16 (95 % CI: 1.28 – 3.63) (Casas et al., 2022). Also, a systematic review of 16 studies reported that disrupted sleep due to high temperatures put adolescents and young adults at high risk of self-harm (Khazaie et al., 2021).

The incidence of paediatric pharmacotherapy adversely impacting thermoregulatory processes remains unexamined and unreported. However, it is recognized that certain medications can interfere with the body's ability to cool down during hot weather (Cuddy, 2004) such as those used in the treatment of Type 2 diabetes, obesity, cystic fibrosis, diabetes insipidus as well as anticholinergic medications, diuretics, dopamine and serotonin uptake inhibitors in children (Smith, 2019). Since dopamine and serotonin uptake inhibitors are included, this could potentially accentuate existing mental health conditions, especially in cases of depressive or bipolar disorders.

There is a complex connection between insomnia and mental disorder (Khurshid, 2018) as sleep plays a pivotal role in growth, cognitive function, and emotional well-being (Lõhmus, 2018). The distal skin temperature is a significant determinant in promoting the initiation and sustenance of sleep in infants and children (McCabe et al., 2018; Barcat et al., 2017; Abe and Kodama, 2015; McCabe et al., 2022). Children need the environment's temperature to be regulated more than adults do because of their larger body surfaces compared to their body masses (McCabe et al., 2022). Lean body types and thin body segments, such as the arms and legs, are more likely to experience significant and quick heat exchanges with the environment than thicker body parts or larger body shapes (McCabe et al., 2022; Bach et al., 2011). A heightened stress response following lack of sleep impairs brain neuroplasticity, which contributes to the development of mental disorders (Palagini et al., 2022). Infants ($n = 413$) experienced adverse effects on their sleep when exposed to temperatures exceeding 37.7 °C (Berger et al., 2023). During heatwaves, infants received less total sleep, with poorer sleep efficiency, prolonged sleep initiation, increased sleep fragmentation, and increased parental interventions during the night (Berger et al., 2023). High ambient temperatures have significant implications for common mental disorders, particularly depression and anxiety.

A survey of low-income residents in an urban area of California found physical and mental health problems, including depression, anxiety and irritability, among their children during heat waves (Palinkas et al., 2022). However, there was no attempt to seek medical help for these conditions, possibly due to financial constraints (Palinkas et al., 2022).

Guidelines for the prevention of physical and mental health impacts of heat on children

Healthcare sector / health systems

Improving the healthcare system can play a crucial role in preventing the adverse impacts of increasing heat on children's mental and physical health by enhancing prevention, detection, and response mechanisms. Implementing robust early warning systems and public health alerts for heatwaves can help healthcare providers and communities prepare for extreme heat events (Hess et al., 2023).

Several developed countries, including the United States (e.g., Philadelphia's Hot Weather-Health Watch/Warning System), the United Kingdom (through its "Hot Weather and Health" guidance), France (with its Heat Health Watch Warning System), Portugal (Watch Warning System for Heatwaves), and Spain (National High Temperature Plan), have implemented early warning systems for heatwaves that are informed by assessments of population health risks. Despite these initiatives, many current heat-health early warning systems have limitations. They often operate only during heatwave events rather than covering the entire warm season. Additionally, their warning levels are not always grounded in comprehensive health risk assessments. Some rely heavily on local data, making them unsuitable for use in other regions, and many systems overlook days with moderately elevated temperatures that still pose health risks. These approaches tend to focus only on the most extreme heat days and ignore less severe but still harmful conditions. Moreover, most of these systems have not undergone rigorous evaluation using disease-specific mortality data, nor have they been adequately compared to existing weather-based warning systems. However, with improvements, timely communication of heat-related health risks and preventive measures may help to reduce the incidence of heat-related illnesses and deaths among children.

Ensuring equitable access to healthcare services, including primary care, urgent care, and emergency services, is essential for addressing heat-related health concerns among children, especially in vulnerable populations (Hasan et al., 2021). Improving healthcare access in underserved communities may help to facilitate timely diagnosis and treatment of heat-related illnesses. Developing and disseminating paediatric-specific guidelines and protocols for the prevention, diagnosis, and management of heat-related illnesses can help healthcare providers effectively care for children during heatwaves (UNICEF). These guidelines should address age-specific risk factors, symptoms, and treatment approaches tailored to children's unique needs. Lastly, leveraging telehealth and remote monitoring technologies can enhance access to healthcare services for children during heatwaves, particularly in areas with limited healthcare infrastructure or during times of increased demand (UNICEF). Telehealth platforms enable remote consultations, monitoring of symptoms, and timely intervention for children experiencing heat-related health concerns.

Guidelines and curricula for healthcare providers

Providing education and training for healthcare providers on recognizing, diagnosing, and treating heat-related illnesses in children is essential. Healthcare professionals should be equipped with the knowledge and skills to identify warning signs, conduct heat-related assessments, and implement appropriate interventions for paediatric patients (Dupraz and Burnand, 2021). It is crucial to recognize that in children, an altered mental state is the most critical heat-related symptom, indicating the onset of heat stroke (United Nations Children's Fund May 2023). Prompt calming of individuals with changed mental status and arranging for their immediate transfer to hospital is indicated, where possible (United Nations Children's Fund May 2023).

Caregivers and front-line workers should be trained to distinguish between moderate heat-related illnesses and heat stroke, the most severe heat-related illnesses necessitating emergency medical intervention, using a streamlined list of symptoms (United Nations Children's Fund May 2023). There is an urgent need for the establishment of guidelines that can aid healthcare providers and caregivers to recognize and manage the detrimental effects of heat on children. A thorough evaluation of current medical curricula is needed to determine the extent to which future healthcare providers are educated about heat and its health implications. Medical guidance should be provided to educational institutions about managing outdoor activities during heatwaves and extreme weather conditions to ensure the safety and well-being of children (exertional heat stroke).

Community education

Improving education can play a significant role in preventing the adverse impacts of increasing heat on children's mental and physical health by raising awareness, promoting adaptation strategies, and fostering resilience (Rother and Case, 2022). Teaching children about the dangers of extreme heat and how to stay safe during heatwaves is indicated. Education can include information about the signs and symptoms of heat-related illnesses, such as heat exhaustion and heatstroke, as well as practical advice for staying cool, such as maintaining hydration, seeking shade, and wearing lightweight clothing where possible (taking cultural preferences into consideration).

Education can empower children about the importance of hydration, nutrition, and proper rest during hot weather. By understanding how heat impacts their bodies and health, children can make informed decisions to protect themselves and lessen the risk of heat-related illnesses (UNICEF). Educating children and their families about the availability of cool spaces, such as air-conditioned public buildings, community centres, and cooling centres, can help ensure that they have access to safe environments during heatwaves, especially for those who may not have adequate cooling at home.

Education can also help children develop coping skills and resilience to manage the psychological impacts of heat stress, including anxiety, stress, and depression (Wiedermann et al., 2023). Teaching mindfulness techniques, stress management strategies, and positive coping mechanisms can empower children to navigate challenging situations more effectively. Education can mobilize children to become advocates for heat-resilient communities by raising awareness, promoting green initiatives, and advocating for policies that prioritize public health and climate adaptation

Green spaces

Green spaces play several roles in mitigating the adverse impacts of increasing heat on children's mental and physical health (Sakhvidi et al., 2023). Trees and vegetation provide shade and reduce temperatures in urban areas through the process of evapotranspiration. This helps to lower the ambient temperature, reducing the risk of heat-related illnesses. Green spaces act as natural filters, trapping air pollutants and improving air quality (Venter et al., 2024). Exposure to pollutants such as particulate matter (PM) and nitrogen dioxide can exacerbate respiratory problems and increase the risk of asthma in children.

Green spaces provide opportunities for physical activity and outdoor play, which are needed for children's physical development and overall well-being (Sakhvidi et al., 2023). Engaging in outdoor activities encourages children to be active, which can help combat sedentary behaviour and reduce the risk of obesity and related health problems. Spending time in nature reduces stress and anxiety levels in children by offering a peaceful and calm environment that can help alleviate the mental health impacts of stressors, particularly in urban environments.

Green spaces also serve as important gathering places for communities, fostering social connections and promoting a sense of belonging. Access to green spaces encourages outdoor social interactions and recreational activities, which contribute to children's social and emotional development.

The need for further research

To further understand the health impacts of heat on children and develop effective prevention strategies, several areas of research are required. Conducting large-scale epidemiological studies to assess the prevalence, incidence, and distribution of heat-related illnesses among children is critical. These studies should examine the demographic, socioeconomic, and environmental factors associated with increased vulnerability to heat-related health risks in paediatric populations. Longitudinal studies are also needed to investigate the long-term health effects of repeated or chronic heat exposure during childhood. Understanding the cumulative impacts of heat on children's physical, cognitive, and psychological development can inform early intervention and prevention efforts. Specific risk and susceptibility factors that increase children's vulnerability to heat-related health problems need to be identified. This includes examining genetic predispositions, pre-existing medical conditions, socioeconomic disparities, and environmental factors that contribute to heat susceptibility in paediatric populations.

Standardized methods require development to assess children's heat exposure, including measuring ambient temperature, and humidity, as well as individual-level factors such as indoor heat exposure and physical activity. Conducting comprehensive health impact assessments to evaluate the direct and indirect health consequences of heatwaves on children is critical. These assessments should consider a range of health outcomes. Designing and implementing intervention studies evaluating the impact of interventions is required.

Practical strategies for the control of indirect factors

Overall, public health officials are well positioned to execute prevention strategies, particularly during the initial stages of warmer seasons when the risk of heat-related illnesses and fatalities is heightened due to a lack of acclimatization to higher temperatures (Groot et al., 2014). Community resources, including air-conditioned facilities should be available for vulnerable groups. Public health officials should be able to communicate these facilities to the public and also flag heatwaves.

Given that children spend several hours at school each day (Sadrizadeh et al., 2022), school interventions to prevent the indirect health effects of heat remain a potential solution. In addition, a positive atmosphere for learning boosts attendance, test scores, and productivity (Sadrizadeh et al., 2022). Research indicates that classroom circumstances are often poorer than those in workplaces or homes (Sadrizadeh et al., 2022). More research with larger sample sizes, including prospective cohorts should be done to assess the impact of indoor school environmental quality on the health and wellness of pupils (Sadrizadeh et al., 2022; Fernandes et al., 2023; SE et al., 2021).

Conclusions

As described above, children's exposure to increasing ambient temperature has direct adverse consequences for their physical and mental health. Heat illness occurs during periods of intense heat and results in a range in adverse health outcomes, from heat exhaustion and severe dehydration, to heat stroke. Children exposed to heat may also experience kidney disease, renal failure and respiratory diseases with evidence for a rise in hospital admissions occurring during heatwaves. Associations between heat and cognitive function, and heat and behavioural responses have also been observed among children, with these outcomes deteriorating when ambient temperatures were high.

Indirect consequences of extreme heat on the physical health of children are related to increases in ambient air pollution when ambient temperatures are hot; one such pollutant is ozone. Ozone concentrations increase during hot weather and exposure to ozone is associated with an increase in emergency room visits for asthma, acute respiratory infections and pneumonia, including among children. Rising ambient temperatures also affect infectious diseases, such as malaria, cholera and dengue and children living low- and middle-income countries are vulnerable to infectious disease outbreaks. Finally, heat affects food production and therefore food security, placing children living in vulnerable settings at risk of malnutrition and other nutrition-related adverse outcomes.

The psychological impacts of heat exposure on infants and children is an emerging area of research, with sufficient data to warrant further investigation. These impacts are anxiety, reaction disorders, bipolar disorders and psychosis. In some instances, high temperatures have disrupted sleep and put children at risk of self-harm, while suicides have also increased after periods of moderate and extreme heat.

The timely communication of heat-related health risks and ways to prevent them is important to protect children from illnesses, diseases and even mortality. Equitable access to healthcare services, especially in underserved areas, is essential as well as developing and disseminating information on how to prevent and manage heat-related health impacts among children. Healthcare providers have a role to play in recognising, diagnosing and treating heat-related illnesses in children, as well as explaining warning signs and interventions to prevent them. To this end, the medical curriculum needs to be assessed and amended where guidance on heat-related health risks, their treatment and prevention interventions are lacking. Improving education plays an important role in preventing the adverse impacts of increasing heat on children's mental and physical health by raising awareness, promoting adaptation strategies, and fostering resilience. By educating children and their families about cool spaces, such as air-conditioned public buildings and even green spaces, like parks and gardens, it can help ensure children have access to safe environments during periods of high temperatures and heatwaves. Finally, there is a need for further research to better understand the health impacts of heat on children and to develop prevention strategies that are effective. Incorporating climate change projections and scenarios into health impact assessments can help anticipate future trends in heat-related health risks and inform adaptive strategies. Research should explore the potential health impacts of projected changes in temperature variability, extreme weather events, and urban heat island effects on children's health.

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CRediT authorship contribution statement

Caradee Y Wright: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Mary Norval:** Writing – review & editing, Writing – original draft, Conceptualization. **Natasha Naidoo:** Writing – review & editing, Writing – original draft. **Muthise Bulani:** Writing – review & editing. **Ashraf Coovadia:** Writing – review & editing, Writing – original draft. **Linda Theron:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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