Commentary

Combined impacts of extreme heat and wildfire smoke on children's health

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As the frequency and duration of wildfires and heatwaves increase, co-exposure to extreme heat and wildfire smoke is becoming more prevalent.[1,2] When heat and smoke coincide, their combined impact on human health can be greater than the sum of their individual effects. Recent studies report such super-additive risks for preterm birth and cardiorespiratory hospitalisations.[3,4] However, the impacts of joint heat-smoke exposures on children's health are not well characterised. Understanding the health risks associated with joint heat and smoke exposures can help inform potential clinical and public health interventions for children, who are more susceptible to these stressors.

Children are less capable of regulating their body temperature than adults. They sweat less, become dehydrated more quickly, and are less likely to know when they are overheated.[5] When they do feel overheated, children are often in structured environments where adults decide whether and how to respond to heat. Consequently, children are at especially high risk for health effects from heat waves. This has borne out empirically: for example, a study of the 2006 summer heat wave in California reported higher rates of emergency department visits for electrolyte deficiency among young children (<5 years), compared to older children and adults.[6]

Similarly, the health impacts of wildfire smoke can be amplified in children. Children have a higher ventilation rate per body weight compared to adults, and their developing lungs are more susceptible to inflammation from exposure to air pollution. Children typically spend more active time outdoors than adults, increasing exposure to wildfire smoke when concentrations are elevated but not to the point where outdoor activities are discouraged or restricted. Epidemiological evidence supports elevated health risks for children during smoke waves. During the 2003 wildfire season in Southern California, exposure to 1-5 smoky days was associated with increased paediatric medication use (odds ratio [OR] 1.82) and physician visits (OR 1.33).[7] Another study using data from Southern California found that a 10 $\mu g\ m^{-3}$ increase in wildfire-generated fine particulate matter ($PM_{2.5}$) concentration increased paediatric urgent care and emergency department visits by 30%, a much larger effect estimate compared to $PM_{2.5}$ from other sources.[8]

Despite decades of study on heat and smoke risks for paediatric populations and indications of super-additive effects in adults, there has been little prior focus on joint heat-smoke exposures among children. In this issue of *Paediatric and Perinatal Epidemiology*, Syed and colleagues[9] address that gap, reporting new findings about paediatric patient utilisation of acute care services during joint extreme heat and wildfire smoke events across California. They use a time-stratified case crossover method, which compares patients to themselves, assessing whether the exposure of interest was higher on event days compared to comparison days within the same month and calendar year. By design, this method controls for unmeasured individual factors that are typically stable over short time periods, such as caregiver educational attainment or the use of a gas stove in the household. The authors consider exposures to extreme heat and wildfire smoke with different cut points typical of this literature. They then estimate the relative excess risk due to interaction (RERI), a measure that indicates whether the combined risk of two exposures is greater than the sum of separate effect estimates, determining whether there is a super-additive effect.

Theei findings are concerning. At the highest exposure cut points, joint heat-smoke exposure was associated with a 16% (95% confidence interval 8, 24) higher risk of all-cause acute care visits compared to the summed estimates of extreme heat and wildfire smoke exposures considered separately. Lagged estimates for acute care use the day after exposure were similarly elevated. Notably, the effect estimates were attenuated at lower cut points. There was some indication that older adolescents (15–19 years old) had elevated risks, and the authors observed that joint heat-smoke exposures disproportionately impacted populations in far northern California and the eastern Sierra Nevada region.

There are several plausible mechanisms that could contribute to the super-additive effects reported by Syed and colleagues. As the authors point out, extreme heat and air pollution both contribute to oxidative stress in children. Heat may increase the formation of secondary pollutants in wildfire smoke plumes, such as ozone. Heat may also force children outdoors during smoky conditions, a particular concern in parts of California with historically cooler climates and, as a result, low access to air conditioning. Conversely, smoke may keep children indoors, increasing their heat exposure. Studies of health protective behaviours during joint heat-smoke days could help understand how families with children perceive and respond to such events.

The authors used different cut points to assess exposures, considering a community exposed to wildfire smoke if concentrations exceeded cut points of 5, 10, or 35 $\mu g/m^3$, and to heat if temperatures exceeded a relative cut point (e.g., the 95^{th} percentile) and an absolute cut point (e.g., 30°C). They observed that the magnitude of associations between joint heat-smoke exposures and healthcare utilisation increased with increasing heat and smoke cut points. This may be because extreme exposures are qualitatively different. For example, residents in a particular community may not perceive smoke in the air or change their behaviour at 5 $\mu g/m^3$ of wildfire $PM_{2.5}$, whereas extremely high smoke concentrations may cause behavioural changes and stress. Further study could help understand whether paediatric health risks are indeed restricted to the higher ends of the exposure ranges, or whether they are present at lower concentrations. If exposures are not qualitatively different, the observed associations could simply be due to reduced exposure measurement error at higher cut points. For example, when ambient heat reaches the 85^{th} percentile compared to historical averages, residents may be able to mitigate heat exposure by using fans, air conditioning, and avoiding strenuous activity. These measures may be less effective as temperatures rise to the 95^{th} percentile, and a greater proportion of the population may be truly exposed to clinically relevant heat. This would, in effect, mean that exposure misclassification is reduced at higher cut points, which strengthens effect estimates.

A constraint of the study is that the authors did not investigate whether marginalised populations face disproportionately high risks. This is notable given that prior studies suggest that joint heat-smoke events may exacerbate existing health disparities. For example, researchers found that older adults and low-income populations in California had disproportionately high exposure to joint heat-smoke events between 2006 and 2020.[2] This type of disproportionate exposure can contribute to health disparities. Indeed, the study of joint heat-smoke exposures and adult cardiorespiratory hospitalisation reported that risks were elevated for socioeconomically marginalised people.[4] Future researchers should investigate whether there are disparities in paediatric health outcomes related to joint heat-smoke exposures, which could help determine whether interventions need to be tailored to address those disparities.

Public health guidance on how to respond to extreme heat and wildfire smoke does not always consider socio-structural barriers to health-protective actions. For example, lower-income families are more likely to live in homes that are more permeable to ambient temperatures and air pollutants, which means staying indoors may be less protective than in homes that are less permeable. They are also less likely than high-income families to be able to temporarily relocate during extreme events. Unhoused families have fewer options to take protective action. Furthermore, linguistically isolated households may not be able to access information from official channels that primarily (or exclusively) issue warnings in English.

Collectively, findings from joint heat and smoke health studies suggest the need for specific adaptation planning to address combined exposures to heat and smoke. Communities that face cumulative social and environmental stressors are already leading the way in climate adaptation planning, including efforts to mitigate heat and smoke. In West Oakland, community-based organisations are leading tree-planting initiatives to help improve cooling and air quality. In the Imperial Valley, organisers are offering air conditioning and filtration to qualifying low-income families. More work could help evaluate the effectiveness of such interventions and how to build on and scale them.

Extreme heat and wildfire smoke events will continue to become more common and severe, and there is more that can be done to learn about the health impacts of these events. At the same time, we can work to prepare communities, healthcare providers, and healthcare systems to respond effectively to these events and mitigate health risks for children and adolescents.

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