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Review

Children's health and vulnerability in outdoor microclimates: A comprehensive review

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ABSTRACT

Background: Children are routinely identified as a vulnerable population in environmental health risk assessments, experiencing adverse health outcomes due to exposure to a suite of atmospheric constituents.
Objective: To provide a substantive overview of the research literature pertaining to biometeorological effects on children. Key information areas within urban environmental health research related to atmospheric variables (heat, air pollution, radiation) are assessed and integrated to better understand health outcomes and vulnerabilities in children. Critical avenues for improvement and understanding of children's health related to such biophysical parameters are also identified.
Methods: This comprehensive review assesses past and current primary studies, organizational reports, educational books, and review articles. Emphasis is placed on the differential ambient exposures to temperature, air pollution, and radiation within urban microclimates commonly used by children (e.g., schoolyards, urban parks), and the resulting health impacts.
Discussion: Exposure to heat, air pollution, and radiation are often enhanced in urban areas, specifically under the current design of the majority of outdoor child play places. Many heat indices, energy budget models, and health outcome studies fail to adequately parameterize children, yet those that do find enhanced vulnerability to ambient stressors, particularly heat and air pollution. Such environmental exposures relate strongly to behavior, activity, asthma, obesity, and overall child well-being. Current research indicates that a changing climate, growing urban population, and unsustainable design are projected to pose increasing complications.
Conclusions: Evidence-based research to link children's health, physiology, and behavior to atmospheric extremes is an important future research avenue, underscoring the fact that children are among the population groups disproportionately affected by ambient extremes. However, current methods and population-based models lack child-specific inputs and outputs, as well as designated thresholds for accurate predictions of child health impacts. More substantive evidence is needed for applicable child-specific policies and guidelines.

Contents

Abbreviations: BSA, body surface area; eNO, exhaled nitrogen oxide; FEF, forced expiratory flow; FEV, forced expiratory volume; HR_{max}, maximum heart rate; PMV, predicted mean vote; SDD, standard vitamin D dose; SVF, sky view factor; T_{mrt}, mean radiation temperature; T_{sfc}, surface temperature; UFP, ultrafine particles; UVB, ultraviolet radiation B; UVR, ultraviolet radiation

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1. Introduction

Children are uniquely sensitive to their ambient environments due to numerous physiological and psychological mechanisms. Incorporating such mechanistic differences in biophysical models in child-specific environmental health studies, specifically related to outdoor exposures of heat, air pollution, and radiation, is essential for improved understanding of children's health. It has been well-established that exposure to extreme heat and air pollution has separate and simultaneous health impacts across the globe (Luber and McGeehin, 2008; Hondula and Barnett, in press; Vanos et al., 2014), with children routinely identified as vulnerable populations in heat and air pollution health studies (Perera, 2008; Revi et al., 2014). However, empirical research encompassing the specific behavioral and physiological mechanisms of children is vital in order to provide support that is substantive enough to formulate adaptation policies and guidelines for this subpopulation. As high-priority aspects of the lives of many humans, the health of children can be substantially protected and improved through preventative environmental health measures. Here, a thorough literature review is provided on three of the most critical environmental factors impacting children's health and well-being: heat, radiation, and air pollution (Fig. 1).

The aim of this review is to comprehensively combine knowledge of the various ambient exposures that children receive within commonly frequented outdoor microclimates. For the purposes of this evaluation, these include current and future levels of heat, air pollution, and radiation linked to resulting health impacts early in life. Specifically, this review is guided by four objectives to provide insight on what we know, and need to know, about children's health and well-being under times of physiological environmental stress. These objectives include:

1) Review current research related to the atmospheric stressors of heat, air pollution, and radiation, and how they differentially impact children and adults.
2) Classify and compare the various outdoor spaces used by children (e.g., schoolyards), as well as how their design and associated microclimates impact children both positively and negatively.
3) Demonstrate biometeorological principles as they relate to the current state of knowledge of children's health and well-being based on ambient stressors, and provide insight from the literature into potential improvements of outdoor environments.
4) Identify the most important areas for future research for enhanced understanding of the impacts of the ambient environment on children via improved observations and models.

The microclimatic design of outdoor spaces is a fundamental aspect of the thermal environment, which can improve or hinder a child's overall health, functionality, and development based on learning and

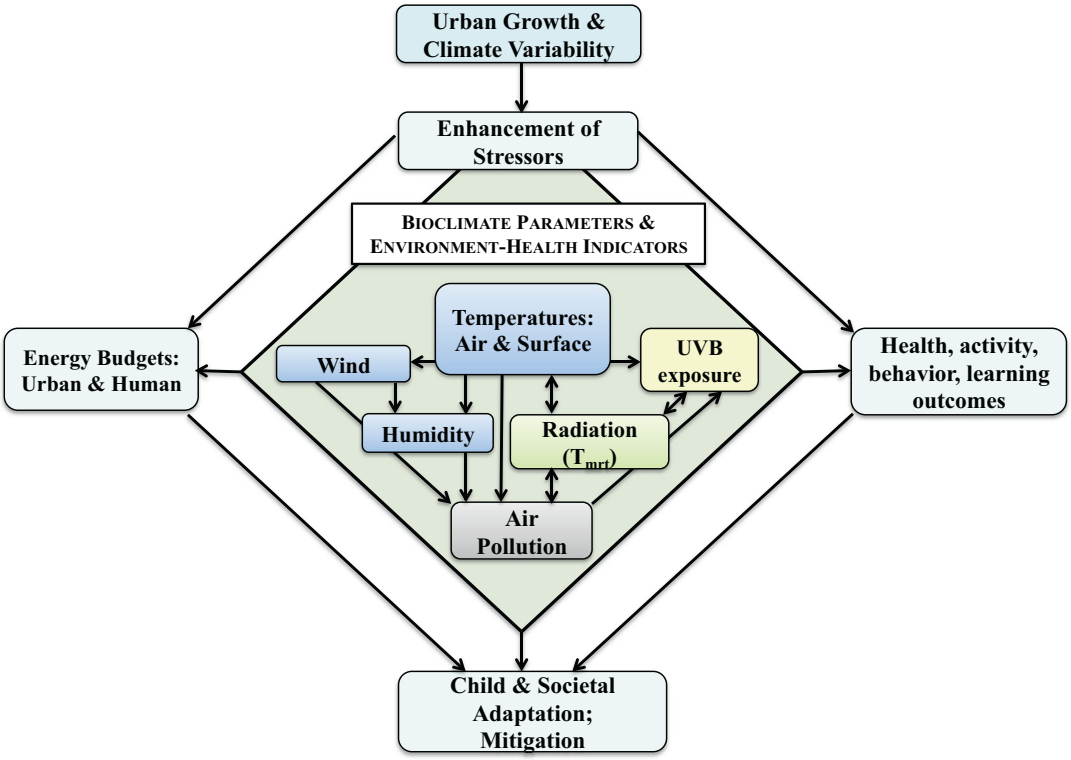

Fig. 1. Conceptual diagram of the interacting factors related to environmental stressors on children, which synergistically act upon children in varying degrees to impact a child's energy budget, behavior, activity levels, learning processes (e.g., cognitive development), and overall health. Arrows depict one-way or two-way interactions of the variables within an urban microclimate.