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COMMENTARY

Children With Cardiac Disease and Heat Exposure: Catastrophic Converging Consequences?

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The detrimental impact of extreme heat exposure on the health and well-being of children is widely acknowledged. The direct and indirect effects of climate change have led to an increased risk of certain cardiovascular events which may be particularly harmful to children who are born with, or develop, heart disease. ***Purpose****:* To highlight the worrying paucity of investigative research aimed at differentiating how higher ambient temperatures further tax an already compromised cardiovascular system in children. ***Methods****:* This commentary describes basic thermoregulatory concepts relevant to the healthy pediatric population and summarizes common heart diseases observed in this population. ***Results****:* We describe how heat stress and exercise are important factors clinicians should more readily consider when treating children with heart disease. Countermeasures to physical inactivity are suggested for children, parents, clinicians, and policymakers to consider. ***Conclusions****:* As sudden, excessive heat exposures continue to impact our rapidly warming world, vulnerable populations like children with underlying heart conditions are at greater heat health risk, especially when coupled with the negative physical activity and fitness trends observed worldwide.

Keywords*:* thermoregulation, child, environmental epidemiology, heatwaves, hyperthermia, physical literacy, congenital heart disease, acquired heart disease

The current climate breakdown is considered unprecedented in Earth's history. Under all scenarios, global warming is expected to reach +1.5 °C in the near term (2021–2040), with a 50% probability of reaching higher levels, even considering the most optimistic scenario(s) (17). By 2100, 75% of the world's population may be subject to at least 20 days of "extreme heat conditions" per year (26) as the frequency, intensity, and duration of heat waves (14) will also increase (23). Presently, there is a clear U-shaped relationship between increased ambient temperatures and all-cause mortality (4), and risk of emergency department visits (5). The main expected cause of morbidity in children includes heat strain, exhaustion, heat stroke (15), and, sometimes, death (16). Since sudden increases in ambient temperature (ie, heatwaves) exert immediate, multisystem organ effects, maintaining a healthy and robust cardiovascular system is critical to adequately respond to these unexpected high heat events. The cardiovascular system plays an important dual role for humans exposed to hot conditions; it initiates increases in heart rate to facilitate the additional cardiac output needed to manage blood flow redistribution, and it delivers this blood to needed locations (eg, skin). Thermoregulatory responses to the heat have been well studied in adult humans (7) but much less so in the pediatric population (27,29). Prepubertal responses to heat stress are usually driven with a greater emphasis on "dry" mechanisms of heat exchange, that is, shunting a greater proportion of cardiac output to the skin (29), and under most situations, this response is sufficient to avoid overt heat illness. Importantly, when ambient temperature is near/equivalent to body temperature, dry mechanisms become far less effective, increasing the risk of an uncompensable situation where heat syncope, heat cramps, and nonfatal heat stroke may result. Children's sweat composition differs from fully mature adults (25); it can be higher in sodium which may place children at greater risk of hypovolemic heat stress. Children who are not able to increase cardiac output as efficiently as healthy children may experience a thermoregulatory disadvantage and greater heat health risk. The latest United Nations Children's Fund technical brief released in May, 2023, highlights the need to protect children from heat stress, first by attempting to widen communication surrounding pediatric thermoregulatory mechanisms, and also by setting factors that define child vulnerability (32). Although this report considers heart disease as a risk factor to heat exposure, there is minimal evidence displayed regarding risk stratification.

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Children With Cardiac Disease and Heat Exposure

Heart conditions vary widely, with some affecting the structure, electrical system, or blood vessels of the organ. Congenital heart disease (CHD), the most common type of birth defect, is defined as a significant abnormality of the heart and/or great vessels at birth, with different levels of complexity: simple, moderate, and complex CHD. Although mortality has declined to 34% in 2017 (10), CHD still exerts a heavy economic burden and significant mortality, with the existence of common complications (eg, heart failure, arrhythmia, and pulmonary hypertension). Worldwide, inequities are overrepresented in diagnosis, treatment, and mortality of CHD children between low-, middle-, and high-income countries.

Acquired or genetic heart diseases, such as pediatric cardiomyopathies (22; eg, dilated or hypertrophic), alter cardiac function, leading to impaired cardiac output. Inherited arrhythmias (eg, Long QT), another genetic abnormality caused by dysfunctional ion channels in the heart, are recognized as a cause of sudden death in structurally normal hearts (31). Acquired heart disease can also be caused by infection, for example, rheumatic fever or infective endocarditis.

Vulnerability to heat exposure is driven by individual susceptibility. Globally, there are around 9 million deaths annually attributed to greenhouse gases, with 62% of them due to cardiovascular disease (11). Thus, the combined effects of heat, air pollution, socioeconomic, and health status are (each) responsible for avoidable acute cardiovascular disease events. While children with common CHD such as small ventricular or atrial defects may not be at greater risk of heat-related cardiac events, children with severe cardiac complications like pulmonary hypertension or heart failure will not be able to compensate for the increased circulatory demand needed during high heat events. Children with inherited arrhythmia are at higher risk of experiencing heat-related cardiac events since body temperature is an independent determinant of heart rate, and heatstroke can impact electrocardiographic conductance which prolongs QT interval and ventricular tachycardia conduction defect (2). Notably, children with heart conditions are often prescribed drugs such as beta-blockers, diuretics, or angiotensin-converting enzyme inhibitors. Beta-blockers decrease blood flow to the skin and cardiac output, and diuretics and angiotensin-converting enzyme inhibitors can also increase the risk of hypovolemia and heat stroke (20).

Vulnerability to heat exposure is also driven by sociocultural factors (eg, poverty) and geographical factors (Figure 1). Children with heart disease living in hotter and more humid regions are more likely to have inadequate access to health care (18). According to the World Health Organization, child mortality related to heat exposure is predicted to reach over 100,000 deaths per year by 2050, with the greatest climate change-related mortality occurring in South Asia (33). This, combined with the fact that mortality rate for CHD declines according to a country's increasing sociodemographic index, forecasts that the majority of death will disproportionally occur in low and lower-middle sociodemographic index countries (10). To summarize, higher ambient temperature leads to heat-related illness diagnoses, severity, and prevalence of heart diseases in children, although direct data on this relationship are lacking. Hot environments are associated with poorer air quality, which can lead to more CHD cases, and medications commonly prescribed to CHD patients are independently associated with greater risk of heat-related illnesses. The technical brief from UNICEF did not address these complex interactions.

Practical Implications of Exercising in the Heat

Moving one's body in hot conditions places further burden on the cardiovascular system, since a by-product of muscle contraction is heat production, and exercise (depending on the intensity and duration of the activity) can be a pyrogenic activity itself (6). Physical activity (PA) represents a very wide range of pursuits, from sport participation to outdoor activities, or even exercise rehabilitation, which is recognized as a central component of cardiac rehabilitation. For instance, children and adolescents playing American football are at higher risk for heat stress since the sport requires protective gear which reduces heat dissipation and

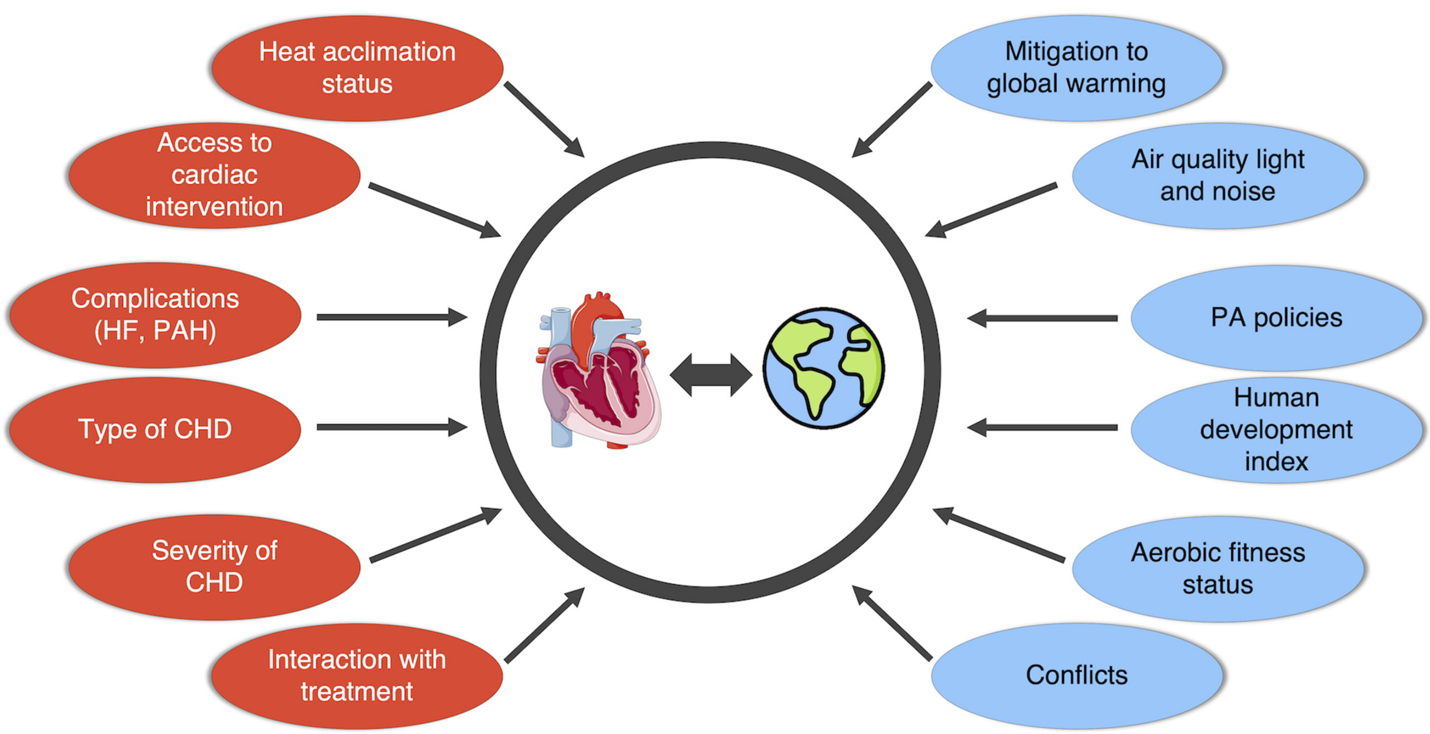

Figure 1 — Cardiac (left) and environmental (right) factors affecting heat exposure adaptations in children with heart conditions. CHD indicates congenital heart disease; HF, heart failure; PA, physical activity; PAH, pulmonary arterial hypertension.

high energy expenditure (1). The situation is complicated when climate change acts as both a cause or consequence to greater physical inactivity (21) which currently affects >80% of adolescents globally (13). Children with heart conditions already present with lower cardiorespiratory fitness compared to healthy controls (3,30), and this decline remains so over time (9). Higher fitness elicits efficient heat balance since fitter people sweat more and can tolerate higher core temperatures (24) than unfit people. There are multiple structural and functional cardiovascular adaptations which lessen external system demands when people move in the heat (28) (Figure 2). It is therefore critical to adapt public health policies in favor of achieving adequate PA to be better equipped and meet the challenges of global warming and other environmental challenges.

The UNICEF technical brief provides essential clues for public health policymakers advocating for a multisectoral approach to minimize the detrimental health outcomes for children exposed to the heat. The specific approaches can be viewed in the report, but briefly, UNICEF describes a risk communication strategy called “B.E.A.T. the Heat,” where B.E.A.T. is an acronym for B = BE AWARE of heat stress and protect yourself, E = EASILY IDENTIFY the symptoms of heat stress, A = ACT IMMEDIATELY to protect the individuals affected, and T = TAKE to a health facility if the person is presenting with severe symptoms. For children with heart conditions, in addition to the approaches specified in the policy brief, cardiologists and clinicians should be mindful of the risk stratification regarding diagnosis and clinical status of each child.

Countermeasures to Physical Inactivity in Children With Heart Disease

Robust and Diverse Physical Education Programs in Schools

Globally, schools are considered an important avenue to reach children for health promotion, physical education, and after-school sport (19). For children with cardiac conditions, individualized adaptation strategies must be implemented to ensure safe participation in PA. It is important for physical education teachers to work closely with cardiologists to adapt exercise sessions to each student’s unique needs.

Coordinated Kinesiology and Cardiology Expertise in Hospital Settings

Children with cardiac conditions meet many health professionals in the hospital system, but direct involvement with exercise specialists remains rare worldwide. PA promotion and education should be incorporated in every health care setting. Exercise rehabilitation programs (8) are an excellent opportunity to expand in scope since they are already considered a “nondrug” care management approach. Proper medication should match exercise prescription to avoid increasing the child’s risk of hypovolemia, and it is important to stress that the cardiovascular prevention community has a critical role in global health (12).

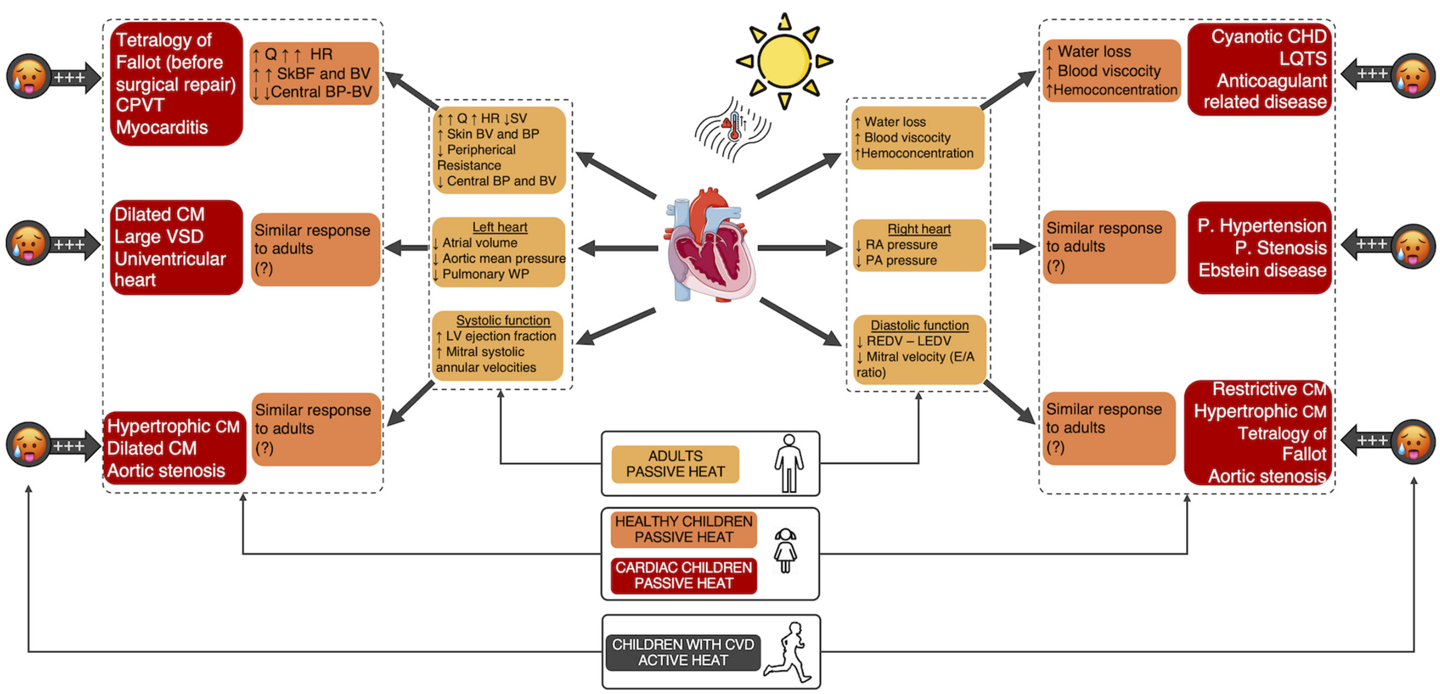

Figure 2 — Heat stress and the heart. The figure depicts typical responses in adults and healthy children, to passive heat stress, and potential consequences for children with heart conditions. Adult heart adaptations to the passive heat (inside boxes), healthy children (middle boxes), and children with cardiac disease to the passive heat (outside boxes). Arrows on each side represent a reinforcement due to exercise (active heat). Where there is a lack of data or robust evidence, we place a question mark symbol. In the absence of studies, speculative projections were made for children with cardiac conditions. BF indicates blood flow; BP, blood pressure; BV, blood volume; CHD, congenital heart disease; CM, cardiomyopathy; CPVT, catecholaminergic polymorphic ventricular tachycardia; HR, heart rate; LEDV, left-ventricular end-diastolic volume; LQTS, long QT syndrome; LV, left ventricular; P, pulmonary; Q, cardiac output; RA, right atrial; REDV, right-ventricular end-diastolic volume; SV, stroke volume; VSD, ventricular septal defects; WP, wedge pressure.

Physical Fitness Inclusion in Holistic Heat Health Policies

Health policies need to prioritize physical fitness in children with cardiac conditions by promoting greater active transportation and nature-based infrastructure. Public health policies may also address significant disparities in access to care and mortality rates for children with heart disease in diverse socioeconomic countries.

There remain significant gaps in this research area. Thus, the "Top 4" suggestions for managing increased heat risk projections for children with cardiac conditions are: (1) health professionals, including cardiologists, need to be knowledgeable on the risks that a hot environment poses to children with cardiac conditions. (2) Physical education teachers and kinesiologists must consider the type, intensity, and environmental conditions to accommodate PA in this population. (3) Health policies must create greater health equity with children at the fore (eg, indoor activities, water access, and food for refueling). (4) Conduct more experimental research on how children respond to passive and active heat exposures, especially those with cardiac diseases, and across all income-strata countries.

Conclusions

The expected increase in the frequency, intensity, and duration of heatwaves worldwide will pose additional heat health risks to humans. Children with cardiac conditions already present with lower cardiorespiratory fitness, so it will be necessary to consider the specific heat health impacts of a warming world on this vulnerable population.

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