Climate change, extreme heat, and health

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Climate change has led to a rise in mean global temperature 1.1°C since the industrial revolution, with projected increases of 2.5 to 2.9 °C by the end of the century, without drastic reductions in greenhouse gas (GHG) emissions[1] (Supplemental Figure 1). The chance of near-surface temperature exceeding 1.5 °C above preindustrial levels for at least one year between 2023 and 2027 is 66%, and the chance of at least one year from 2023 to 2027 exceeding the warmest year on record (2016) is 98%.[2] The Intergovernmental Panel on Climate Change (IPCC) concluded unequivocally that human activity, especially the combustion of fossil fuels, is responsible for overall warming of the atmosphere, land, and oceans; changes in weather extremes driven by climate change are already observed; and recent extreme heat events are attributable to climate change.[1,3-5]

The frequency, duration, and intensity of heatwaves in the United States have increased in recent decades (Figure 1). The annual number of heatwaves is now twice that in the 1980s, and the heatwave season is over three times longer than in the 1960s.[6] While there is variation, overall heat extremes have increased in frequency and duration, whereas cold extremes have decreased.[7] Compound events, such as co-occurrence of droughts or wildfires with heatwaves, have become more common, and are expected to occur more often.[8-10]

A recent study found that over one-third of heat-related deaths in 1991-2018 across 43 countries-including the US were attributable to anthropogenic GHG emissions.[4] Other investigations modeling health impacts under scenarios characterized by varying degrees of warming project devastating increases in heat-related mortality and morbidity, although with regional differences.[11] A growing literature focuses on identifying policies to reduce risks and increase resilience of communities to heat exposures, as well as identifying subpopulations at greatest risk.[12-14]

An understanding of the broad range of health impacts of extreme heat exposure is critical to inform patient care and health care delivery as well as broader strategies for mitigating and adapting to rising temperatures. Here we summarize epidemiological evidence on the health risks from heat, its disproportionate impacts on vulnerable populations, and individual- and community-level approaches to protect against associated risks.

Heat exposure and health risks

Exposure to heat substantially impacts human health, both acutely and chronically; heat also indirectly impacts health through associated environmental effects (e.g., quality and quantity of crops and water supply, increased ground-level ozone). The greatest impact of heat on health occurs with extreme heat exposure, but impacts are also well-recognized for temperature beyond historical norms.

Acute heat-related illnesses have been covered in detail in the *Journal* previously[15] and are mentioned only briefly here. These include: heat rash (itchy or painful small blisters, papules, or pustules resulting from blocked eccrine sweat glands); heat cramps (painful involuntary muscle contractions resulting from sweating-induced dehydration and electrolyte imbalances); heat edema; heat syncope (generally associated with prolonged standing or change to a standing position in hot temperatures, and attributed in part to dehydration); heat exhaustion; and heat stroke. Heat exhaustion is typically associated with fatigue, weakness, dizziness, headache, heavy sweating, muscle cramps, and rapid pulse; core body temperature may be elevated, but mental status is normal. Heat stroke, in contrast, involves alteration in central nervous system functioning in association with core body temperature > 40 degrees C (104 degrees F) and can progress to muti-organ failure and death.

However, these acute illnesses – along with acute heat effects such as sunburn and severe burns from contact with hot surfaces – represent only a fraction of the overall health burden attributable to heat. Substantial epidemiologic evidence links both extended periods of extreme temperatures (i.e., heatwaves) and single days of high temperature with a broad range of adverse health outcomes. Table 1 summarizes key categories of health outcomes associated with high temperatures, based on systematic reviews and meta-analyses reflecting overall impacts. Risks for morbidity and mortality from cardiovascular events (acute myocardial infarction, arrhythmias, exacerbations of congestive heart failure and stroke);[16,17] respiratory conditions (e.g., asthma, chronic obstructive pulmonary disease (COPD)) increase with elevated temperatures;[18,19] and kidney disease;[20] risks are greater with exposure to fine particulate air pollution. Extreme heat is also linked to adverse pregnancy outcomes, including increased risks of preterm births, stillbirths, low birth weight, and congenital heart defects.[21] Moreover, heat exposure has been linked to increased anxiety and depression, increased suicidality, and aggressive behavior and violence.[22,23]

Owing to these and other conditions, increases in emergency room visits and hospitalizations are well documented with extreme heat exposure. For example, in one large study involving adults across the US, days in the 95th percentile of local warm season temperatures were associated with a 7.8 percent excess relative risk of emergency department visits for any cause (translating to 24 excess visits per 100,000 persons at risk per day), with significant increases in visits for heat illness, renal disease, and mental health disorders.[24] An analysis involving approximately 50 million summertime hospitalizations showed increased rates of hospitalization (all-cause, and those attributed to CVD, respiratory disease, diabetes, fluid and electrolyte disorders, and renal failure) with increases in the daily maximum heat index across regions of the US.[25] Mortality rates also increase with heat and heatwaves. High temperatures, including multiple heat waves, in Europe between late May and early September 2022, were estimated to account for 61,672 (95% confidence interval (CI): 37,643–86,807) heat-related deaths.[26]

Epidemiologic literature linking heat and health outcomes

Traditionally, epidemiological analyses of heat were based on time-series analyses performed with data aggregated over large areas (e.g., city) or individual-level investigations using case-crossover design.[27] Recent more advanced analysis includes small-area assessments on finely disaggregated data or individual-level analyses using large population-based cohorts.[28,29] Exposures are often assessed as heatwaves (defined by the National Oceanic and Atmospheric Administration (NOAA) as >2 continuous days of high heat, outside historical averages for a given area; but variably defined across studies), or temperature (e.g., maximum daily temperature, heat index [temperature adjusted for humidity]). Studies have been enhanced by advancements in statistical techniques that allow study of complex non-linear and lagged risk associations.[30]

An important consideration is the possibility of “displacement,” whereby adverse health events following exposure occur mostly in frail people who would experience them soon after even without the exposure. Studies assessing longer lag times reported evidence of mortality displacement as much as 30 days,[31] but still find significant risks not explained by displacement.[31] Studies assessing long-term effects of heat, for instance using seasonal or multi-year temperature averages, confirmed increased risks.[12,32]

Deviations of temperature from historical norms substantially impact ability to physiologically tolerate and adapt to heat.[33,34] Both high absolute temperature (e.g., 37 ºC) and high relative temperature (e.g., 99th percentile temperature based on historical temperature) drive excess mortality in heatwaves. Days that are hot can be harmful even without extreme temperature levels, as evidenced by studies on temperature[35] and temperature variability.[36] A given temperature can have different health impacts depending on adaptation to that temperature (e.g., when occurs in a region where that degree of heat is rare, or when occurs earlier or later in the season than historically experienced).[37] For example, in analyses relating heat levels to hospitalizations, the heat index threshold above which hospitalization risk increased varied across regions; in colder regions, hospitalization rates increased at heat index levels below those at which heat alerts are issued.[25] Some studies suggest that humidity may affect temperature-mortality relationships, although with inconsistent findings.[38-40]

Even with air conditioning and other factors playing a role in acclimation,[13,41,42] we are approaching the physiological and societal limits of adaption.[43-46] Tipping points include the ability of the existing power infrastructure to withstand demands for cooling for prolonged periods and the costs of enhancing it to do so. This is particularly important when heat waves extend over large areas as recently experienced. Increases in “heat domes”, caused by the trapping of hot air over large areas by high pressure aloft, have caused elevated temperatures and heat waves in many regions in recent years. Increasingly prevalent water shortages resulting from prolonged extreme heat, for example in the southwest US, create additional challenges to cooling and adequately hydrating.

Temperature-related health risks are highly heterogeneous across locations and populations. Large multi-country analyses identified striking differences in heat risks across the world.[30,47] There is evidence of substantial acclimatization; temperatures associated with increased health risks are higher in warmer regions, and risks attenuate proportionally to average historical temperature patterns.[48] In some but not other countries, risks associated with extreme heat have attenuated markedly over recent decades.[49] This risk reduction is only partly explained by increased prevalence of air conditioning.[41]

High-Risk Populations and Disparities in Heat Impacts

Both susceptibility, referring to internal factors, and vulnerability, referring to external factors, modify impacts of heat on health. Race/ethnicity and socio-economic position are key factors affecting risk (discussed below), but several other factors also increase risks, including social isolation, extremes of age, comorbidities and medications.[41,50-53] Patients with cardiac, cerebrovascular, respiratory, renal disease, diabetes mellitus, and dementia are among those at higher risk for heat-related conditions, as are patients taking medications such as diuretics, antihypertensive drugs, other cardiovascular medications, some psychotropic agents, and antihistamines.[54,55] Older persons, whose thermoregulatory systems are often compromised, are more likely to have underlying conditions, use medications that interfere with heat dissipation, have mobility issues that may compromise access to hydration or cooling, or live in older housing without air conditioning or windows that readily open.[56]

Disparities in health impacts and responses by race/ethnicity and socio-economic position

Racial and ethnic minoritized communities and low-income populations are at particularly high risk of heat-related illness. Disparities in health impacts from heat are not fully explained by socio-economic status or availability of air conditioning.[57,58] These disparities relate to complex interconnected social, economic, and cultural systems, both current and historical, including structural racism. A notable example is redlining, a discriminatory practice introduced in the 1930s that limited or disallowed mortgages in certain areas, especially racial and ethnic minoritized communities.[59] Historically redlined areas, which continue to be comprised disproportionately of racial/ethnic minority and low-income persons, tend to have more impervious surfaces and less greenspace, resulting in higher ambient temperatures (i.e., "urban heat islands").[60,61] Poorer urban communities can be as much as 5º C hotter than wealthier communities.[62] The lack of greenspace also results in less relief from extreme heat.

Research suggests that health impacts of heat differ in relation to many factors of the built environment, such as socio-economic patterns, greenspace, and air pollution.[13,53] Heat exposure is also affected by individuals' and communities' capacity to respond, such as the ability to afford and use air conditioning, install cooling roofs, or access cooler environments. Racial/ethnic minority communities and low income communities have higher risks of adverse health outcomes at given ambient temperatures, owing to these and other factors, including less access to care,[41,57,63] more frequent occupational exposures (e.g., employment in factories without air conditioning[64] or outdoor labor), and pre-existing disparities in chronic medical conditions, such as hypertension, diabetes mellitus and kidney disease.[20,65]

Individual- and Population-Level Interventions to Protect Against Heat

In addition to mitigation of climate change by rapidly transitioning from fossil fuels, there are many protective adaptation measures that can reduce the health burden from heat. Individual protections during heatwaves include limiting exposure, loose-fitting light-color clothing, adequate hydration, sunscreen, and cooling devices (Figure 2).[15] Some interventions have negative consequences, such as air conditioning, which is often powered by fossil fuels, and releases GHGs and other air pollutants. Health professionals can play an important role by providing mitigation and adaptation information for heat prevention to their patients as a component of comprehensive health education. This is especially important for patients at high risk.[15]

A range of population-based interventions can mitigate risks during high temperatures, especially heatwaves, including broad public education regarding health risks and strategies for risk reduction.[66] Public health and medical professional organizations have critical roles in educating communities and policy makers on the health dangers of heat and appropriate protective measures. Because populations respond differently to heat and communities have varying characteristics (e.g., housing conditions), public health policies for heat should be tailored to local conditions. Table 2 provides examples of public health strategies for which some supporting evidence exists, including: location-specific heat alerts during periods of high heat and humidity; location-specific action plans, including accessible cooling centers and health checks (especially for socially isolated persons);[66-78] programs for pre-identification of high-risk populations requiring special services during heatwaves such as medical or physical assistance owing to housing conditions or reduced mobility; and infrastructure changes that can reduce temperatures (e.g., reflective surfaces on buildings and roads, increased trees and other greenery). However, limitations of available data include the respective uncertainties from the reliance on observational data, modeling, or simulations; and inconsistencies in results across studies.

Adaptation measures should consider compound events, such as simultaneous exposure to extreme heat with high air pollution, drought, and other conditions,[8-10] Collaboration and coordination of multiple systems and organizations, including medical centers, public health agencies, government agencies, and community organizations, are needed to most effectively protect public health from heat.

Future Needs and Directions

Further study is warranted to understand benefits of individual- and community-level interventions for heat, many of which have independent benefits (often called "co-benefits"), such as increased physical activity and improved mental health and social cohesion from parks and other greenspace. Enhanced standard reporting of heat-related injury and death is needed, including a better understanding of the health impacts of heat beyond those directly linked to heat in International Classification of Diseases (ICD) codes (i.e., health impacts other than those with "heat" in the ICD code). Currently, a generally accepted definition of a heat-related death does not exist. A clear and accurate accounting for heat-related morbidities and deaths will aid communities and policy-makers in prioritizing programs to address heat-related health burdens. Further research is needed including longitudinal cohort studies to better ascertain differential impacts of heat on health according to population characteristics and temporal trends in adaptation across regions and populations.

Multi-sectoral research is needed to better understand direct and indirect health consequences of a warmer world and to identify effective strategies to improve resilience (e.g., in water and sanitation systems, energy, transportation, agriculture, and urban planning).[79] Particular attention is needed to develop effective strategies for adaptation among those at the highest risk (e.g., communities of color and low-income populations, intersectionality among at-risk groups).

Conclusions

Climate change is increasing overall temperatures and the frequency, duration, and intensity of heatwaves, resulting in multiple adverse health outcomes. The impacts are inequitable, with some individuals and communities disproportionately affected. Intervention strategies and policies targeted to location and population are needed to minimize these diverse health impacts.

Disclosure forms provided by the authors are available with the full text of the article at NEJM.org.

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Table 1. Health Conditions Associated with Extreme Heat

Category of health condition	Representative conditions increased with heat	Example of findings
Cardiovascular (CVD)	Acute coronary syndrome with or without myocardial infarction, stroke, congestive heart failure, arrhythmia	A meta-analysis of 60 studies found that the relative risk of CVD mortality was 1.12 (95% CI 1.09-1.14) comparing heatwave days to non-heatwave days. A 1°C increase in temperature was associated with a 21% (20-23%) increased risk of CVD mortality. Heat-related CVD risks were higher for low-middle income countries.[16] A meta-analysis of 4 studies found that the relative risk of mortality from myocardial infarction was 1.64 (1.09-2.47) comparing heatwave days to non-heat waves days.[17] A meta-analysis of 13 studies found that a 1°C increase in temperature was associated with a 16% (4-28%) increase

		in risk of hospital admissions for myocardial infarction.[17]
Kidney disease	Acute renal failure, nephrolithiasis, electrolyte abnormalities, rhabdomyolysis with renal insufficiency or failure, urinary tract infections	A meta-analysis of 4 studies found a relative risk of mortality from kidney disease of 1.03 (1.02-1.04) for a 1ºC increase in temperature.[20] A meta-analysis of 32 studies found that a 1ºC increase in temperature was associated with a 11% (9-13%) increase in kidney failure.[20]
Respiratory disease	Acute respiratory distress, asthma and COPD exacerbations, pulmonary hypertension, increased respiratory infections, pulmonary edema	An epidemiological analysis of 452 locations in 24 countries found that respiratory mortality was 1.34 (1.22-1.47) times higher for the 99th percentile warm season temperature versus the MMT.[18,19]
Mental health	Anxiety, symptoms in people with bipolar disorder or depression, suicide attempts, suicide completion, aggressive behavior, mental fatigue	A meta-analysis of 12 studies found that a 1ºC increase in temperature was associated with a 22% (15-20%) increase in risk of mental health-related mortality.[22]

		An epidemiological analysis of 341 locations in 12 countries found that risk of suicide increased 33% (30-36%) comparing the 93rd and 1st percentiles of temperature, which were the temperatures with the maximum and minimum suicide risk, respectively.[23]
Birth outcomes	Preterm birth, lower birth weight, stillbirth, congenital heart defects	A meta-analysis of 6 studies found that a 1°C increase in temperature increased risk of preterm birth by 5% (3-7%). Risk of preterm birth was 16% (20-23%) higher on heatwave days compared to non-heatwave days.[21] A meta-analysis of 8 studies found that a 1°C increase in temperature was associated with a 5% (1-8%) increase in risk of stillbirth.[21]

Notes: This table is not a comprehensive list of all health impacts from heat. CI denotes confidence interval. CVD denotes cardiovascular. MMT denotes the minimum mortality temperature (i.e., the temperature with the lowest mortality).

Table 2. Community Interventions that May Reduce Health Impacts from Heat

Intervention	**Description**	**Examples of Impacts**
Education[66,75]	Public awareness programs can encourage individual-level actions (e.g., loose-fitting light-color clothing, adequate hydration) to minimize harm from heat.	Heat-related illnesses decreased in workers with risk factors after a heat stress awareness program on training, acclimatization, and medical monitoring.[75]
Heat alerts and heat wave action plans[69-74]	Heat action plans can be used in relation to a predicted heat wave or single day of high temperature. They can include heat monitoring systems; predictions of future days' conditions; mobilization of public health, medical, social work, and community organizations; and surveillance.	Following the implementation of heat action plans in Montreal in 2004 there were an estimated 2.5 (95% CI: –0.3, 5.4) fewer deaths per hot day, with significant reductions in differences in death rates between older and younger persons, and low versus high SES neighborhoods.[73]
Cooling centers[78]	A temporary cool space, typically air-conditioned, can provide relief and shelter during extreme heat events. Centers can be established in libraries, public housing, parks, community pools, businesses,	A laboratory-based analysis simulating heat conditions and cooling centers found that participants in the cooling group had 0.8ºC lower core temperature compared to the control group, although such differences

	shopping centers, or other spaces.	between the groups were not sustained when they returned to heat conditions.[78] A simulation found that brief exposure to air conditioning limited psychological strain in older adults.[78]
Health checks	Check-ins of people at risk can aid early identification of heat-related illness.	Excess heat wave related mortality was significantly lower in 3 areas of Rome where a program was instituted to reduce social isolation among persons > age 80 (e.g., phone calls, home visits as needed), as compared with areas without this program.[76]
Green infrastructure[68,77]	Green infrastructure (e.g., green roofs, green playgrounds, increased vegetation near roadways) can reduce temperature and address urban heat islands. Vegetation can also sequester carbon.	By 2100, under a high GHG emissions scenario, greening could mitigate land warming by 0.71°C, with 83% of the effect driven by carbon sequestration.[77] In New York, NY, the most vegetated areas were 2°C cooler than the least vegetated areas.[68]
Reflective surfaces	White roofs, “cool” pavements, and other changes to impact surface albedo can lower local	A regional modeling study in the UK estimated that cool roofs could reduce city center mean daytime temperatures

	temperature.	during heatwaves by 0.5ºC and reduce associated heatwave- related mortality by ~25%; xxxapplying cool roofs to commercial or industrial buildings was projected to have the greatest benefit.[67]

Note: The table includes interventions for which there are some data to support benefit. However, studies of many of these interventions have yielded inconsistent results and further study of targeted interventions is needed. The listed impacts are descriptive examples and not comprehensive. These categories are not distinct (e.g., cooling centers and health checks can be part of a heat action plan).

Figure 1. Increase over time in the frequency and duration of heatwaves for the United States

Note: Data based on analysis of 50 metropolitan areas in the United States. Data for 2020s based on 2020 and 2021. Data source: U.S. Environmental Protection Agency.

Figure 2. Protective measures for heat

Notes: These lists are meant to provide illustrative examples and are not exhaustive.

Key Points

- Heat waves are increasing in frequency, duration and intensity and are already a significant threat to human health.

- Health risks from heat include cardiovascular events, respiratory conditions, kidney disease, adverse pregnancy outcomes, increased anxiety and depression, increased suicidality, and aggressive behavior and violence.

- Heat exposure is a significant health threat both in terms of the level of heat and the increase from the historical temperature baseline.

- Multi-sectoral research is needed to better understand direct and indirect health consequences of a warmer world, with increased extremes, and to identify effective strategies to improve resilience.

- Particular attention is needed to develop effective strategies for adaptation among those at the highest risk, such as older populations, racial/ethnic minority populations, persons with low socio-economic status, and those with comorbidities.