Minimization of Heatwave Morbidity and Mortality

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Abstract: Global climate change is projected to increase the frequency and duration of periods of extremely high temperatures. Both the general populace and public health authorities often underestimate the impact of high temperatures on human health. To highlight the vulnerable populations and illustrate approaches to minimization of health impacts of extreme heat, the authors reviewed the studies of heat-related morbidity and mortality for high-risk populations in the U.S. and Europe from 1958 to 2012.

Heat exposure not only can cause heat exhaustion and heat stroke but also can exacerbate a wide range of medical conditions. Vulnerable populations, such as older adults; children; outdoor laborers; some racial and ethnic subgroups (particularly those with low SES); people with chronic diseases; and those who are socially or geographically isolated, have increased morbidity and mortality during extreme heat. In addition to ambient temperature, heat-related health hazards are exacerbated by air pollution, high humidity, and lack of air-conditioning. Consequently, a comprehensive approach to minimize the health effects of extreme heat is required and must address educating the public of the risks and optimizing heatwave response plans, which include improving access to environmentally controlled public havens, adaptation of social services to address the challenges required during extreme heat, and consistent monitoring of morbidity and mortality during periods of extreme temperatures.

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Introduction

Periods of extremely high ambient temperatures (commonly referred to as heat waves) are associated with increases in both morbidity and mortality, especially among vulnerable populations such as older adults, children, and people with certain chronic diseases.[1–4] An appropriate and effective public health response must address and coordinate multiple components including local health services, social and cultural characteristics, and availability of human and financial resources to minimize the impact of extreme heat on the populace.[4]

Although heat waves have occasionally created substantial public health challenges, global climate changes are projected to increase the frequency and duration of heat waves.[5] Therefore, it is timely to consider the following questions: (1) How do periods of extreme heat affect disease-specific mortality and morbidity? (2) What populations are at greater risk? and (3) What public health interventions and frameworks are currently used to address health risks and how can they be further improved? The authors reviewed published studies of the impact of extreme heat on morbidity and mortality for high-risk populations in the U.S., and several European and Canadian studies from the period 1958 to 2012, representing the analyses of data collected from 1900 to 2011.

Defining the Problem

The earth's average temperature increased about 0.75°C (1.36°F) between 1906 and 2005, and more warming is predicted (2°C −6°C, or 3.6°F–10.9°F) by 2100, based on the interaction of natural fluctuations in temperature (such as "hotter/colder than seasonal average" weather occurring over decades and showing the trends when viewed over the average human life span) with the anthropogenic effect on deforestation and greenhouse-gas emissions.[6–13] From 1949 to 1995, the frequency of heat waves in the U.S. increased about 20% ($p<0.01$), with extended hot seasons in geographically diverse locations.[14,15] This trend is predicted to continue in the near future, with increasing frequency, duration, and intensity of heat waves both globally and in the U.S.[5,16–18] As heat is anticipated to have a greater impact on human health than cold,[19] this trend will be an important public health

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issue exacerbated by the synergistic effects of urbanization and the general aging of the global population.[20,21]

Although there is no universally accepted definition of a "heat wave," it is often defined relative to the prevailing temperature during a specific season at a specific location as "an extended period of uncommonly high atmosphere-related heat stress, which causes temporary modifications in lifestyle habits and adverse health-related problems affecting communities."[22–24] It is meteorologically characterized by the presence of "stagnant warm air masses and consecutive nights with high minimum temperatures."[20]

Although studies of the health impact of a single heat wave during a single season or year are common, they typically focus on short-term consequences without considering the impact of adaptation.[25–27] However, there is also a fraction of heat-related morbidity and deaths that occur throughout the remainder of the summer (i.e., beyond the heat wave). For example, when the daily mortality and specific temperature thresholds have been evaluated for 3 decades for three European metropolitan areas, it has been shown that only about half (in London), or less than one fifth (in Budapest and Milan), of all heat-related deaths occurred during the heat wave[26]; thus, preventive measures are needed during the entire hot season in order to reduce the overall heat-related morbidity and mortality burden.

Although temperature is recorded with accuracy, the true thermal stress on an individual usually reflects additional factors that act synergistically (more often) or antagonistically (rarely).[28] For example, the level of air pollution, humidity, air pressure, wind speed, and cloud cover can influence the health effects of high temperatures.[4,29–34] Although not all studies concur on the point,[32,35] poor air quality has been reported to affect cardiovascular and respiratory morbidities (e.g., high temperature, particulates, ozone, and sulphur dioxide synergistically worsen the impact).[32,36–38]

Because of confounding factors, measures that incorporate these additional element(s) have been proposed. Humidity is a key modifier of temperature effects: as humidity increases, the rate of evaporative cooling from sweat is reduced, making the organism's overall thermoregulation less effective, potentially leading to higher body core temperature.[33] Therefore, indices such as the Canadian-developed "humidex" and the "heat" (that is limited by use at specific levels of temperature and humidity) or "apparent temperature" (such as Steadman's that includes the wind effect) indices reported in the U.S. have been promoted to measure the heat stress on humans.[31,39–42]

The humidex reflects how the average person experiences the weather when the effects of heat and humidity are combined; for example, a temperature of 30°C (86°F) and the calculated humidex of 40 (which indicates an approximate temperature "as it feels") means that the average person feels the combination of humidity and heat like a dry temperature of 40°C (104°F). The humidex's cut-points are: 30–34="noticeable discomfort"; 35–39="evident discomfort"; 40–44="intense discomfort"; 45–54="dangerous"; and >55="high probability of heat exhaustion and heat stroke." The probability of heat exhaustion and heat stroke is higher when the temperature is 34°C (93.2°F) and humidity is 90% (a humidex of 55) than when the temperature is 41°C (105.8°F) and humidity is 30% (a humidex of 48). However, because the indices are based on the average person's subjective feeling in a hot and humid environment, the true relationships between the index and the physiologic impact on health may be skewed.

Health Effects

High heat and humidity can not only cause heat stroke but also exacerbate a wide range of medical conditions that are classified as heat-related, including heat cramps and heat exhaustion, as well as dehydration, and multiple chronic diseases that are not ICD-coded as heat-related.[43] So, the accurate estimates of the true impact of heat waves on health are challenging, and often underestimated.

Mortality

Heat waves typically increase the overall death rate of a population (e.g., during the heat waves recorded from 1939 to 1995, the overall mortality rates in large U.S. cities [New York, Chicago, and Los Angeles] increased 7%–147% compared to the baseline death rates).[44] The 2003 European heat wave caused an estimated 22,000 to 70,000 deaths,[45,46] and the 1995 Chicago heat wave was associated with more than 700 deaths.[44,47] The lower mortality in U.S. heat waves compared to the European rates might be partly attributable to home air-conditioning, which is more common in the U.S.[48]

The body typically eliminates heat during thermal stress through sweat production and evaporation, increasing cardiac output, and redirecting blood flow to the skin, thus increasing heat loss via radiation and conduction.[49] As the cardiovascular and cerebrovascular system, central nervous system, and respiratory systems are very sensitive to the heat, the increase in mortality during heat waves has been attributed predominantly to these systems: up to 90%, 52%, and 14% of the overall heat mortality increase, respectively.[50]

Heat-related illnesses do not require reporting to public health agencies by hospitals and healthcare providers, and heat-related deaths are often misclassified or unrec-

ognized[20]; thus, estimating heat wave–related mortality is a complicated task. Usually, heat exposure is counted as a primary or contributing cause of death when a core body temperature is higher than 40.6°C (105°F).[20] According to the National Association of Medical Examiners' criteria, a death can be classified as heat-related if the person is "found in an enclosed environment with a high ambient temperature without adequate cooling devices and the individual had been known to be alive at the onset of the heatwave."[51]

Morbidity

Temperature-related effects on morbidity are less well studied than mortality.[24,52,53] The city emergency hospital admissions during heat waves are predominantly for heat-related conditions such as heat exhaustion and heat stroke, heat cramps, dehydration and electrolyte disorders, and conditions/diseases not coded as heat-related such as cardiovascular and cerebrovascular diseases, respiratory disorders, acute renal failure, neurologic conditions, and mental illnesses.[54,55] Reported emergency department admissions vary depending on time periods and country. For example, an increase in such admissions for cardiovascular disease was observed in the U.S. in 1986–1994,[56] and associations with respiratory and renal diseases were documented in London during periods of extreme heat in 1994–2000.[54] During the 2008–2011 North Carolina heat waves, the mean daily number of visits to the emergency department, on a citywide scale, due to heat-related illness increased by 1.4 for each 1°F increase from 90°F to 98°F, and by 15.8 for each 1°F increase from 98°F to 100°F.[57]

In addition, the effect of heat on pregnant women can be detrimental to the fetus. Maternal hyperthermia was associated with increased risk for neural tube and heart defects in humans and animal species.[58,59] Also, a higher risk of congenital cataracts was associated with both the number and duration of heat waves.[60]

Assessing the Most Vulnerable

'The effects of extremely hot temperatures may quickly become life-threatening, especially for individuals who have limited access to medical care.[61–63] Recent studies have identified multiple subgroups of those who are particularly vulnerable, including urban residents, outdoor laborers; some racial and ethnic subgroups (particularly those with low SES); people with chronic diseases; or those who are socially and geographically isolated.[3,4,21,62,64–66]

Urban Residents

The term "urban heat island" was coined in 1958 to describe the differences in heat load in cities compared to the rural collar surrounding a city.[67] The temperature gradient between an urban area and the nearby rural land can often reach 2°C–10°C (3.6°F–18.2°F), primarily because of absorption of heat by paved surfaces and buildings, the paucity of vegetation, heat emission from buildings and vehicles, and reduced airflow surrounding buildings within the urban canopy layer (below the rooftops in the spaces between buildings).[68–70] In addition, heat absorbed during the day is radiated at night, disrupting nocturnal cooling, which is known to increase heat-related mortality.[33] Currently, more than one half of world's population resides in urban environments, and further growth of urbanization is predicted,[71] thus increasing the health impact of extreme heat.

Outdoor Laborers

A total of 423 workers died from exposure to heat (an average annual heat-related death rate of 0.39 deaths per 100,000 workers for crop workers, compared with 0.02 deaths per 100,000 for all U.S. civilian workers) between 1992 and 2006 in the U.S.[72] Outdoor laborers (including the people who are working outdoors for hobby/household) are particularly vulnerable, as they are exposed to heat during the daytime extremes and can be exposed to pollen and dust, as well as to additional occupational hazards such as exhaust fumes, hot asphalt, pesticides, herbicides, insecticides, and increased humidity in the fields due to transpiration when water evaporates from plant surfaces.[73] Required personal protective equipment (to protect against pesticides or transdermal nicotine poisoning) worn by farmworkers may also increase the heat exhaustion risk, as it retains heat.[72] Unfortunately, many regions where a large number of heat-related farmworker fatalities have occurred[74] do not have regulations addressing heat exposure, such as changing work hours and work activities during periods of heat.[75]

Racial/Ethnic Subgroups

Ethnic groups with lower SES are more likely to live in high-density urban neighborhoods with minimal green space, resulting in greater exposure to heat and a lack of compensatory resources.[29] Consequently, higher heat-related morbidity and mortality have been reported among African Americans,[76,77] who may have more-limited access both to immediate medical care and climate-controlled housing. In addition, the prevalence of chronic diseases that are exacerbated by heat, including kidney disease,[78,79] diabetes mellitus,[80] cardiovascular and cerebrovascular diseases,[81,82] and Parkinson's and Alzheimer's diseases,[83,84] is higher in African Americans.[48] Some racial/ethnic subgroups are over-represented in occupations affected by heat (e.g., approximately 71% of the U.S. heat-related fatalities among crop workers were

among those originally from Mexico or Central and South America).[72] However, death rates from heat exhaustion and heat stroke were lower among workers who used an H-2A visa (which included regulations related to working in high outdoor temperatures) than among workers whose working hours were not under such regulations.[75]

People with Chronic Diseases

People with diabetes mellitus, cardiovascular, cerebrovascular, neurologic, mental, chronic kidney, and chronic obstructive pulmonary disease are at increased risk of disease exacerbation and death when exposed to extreme temperatures. Additionally, medications such as diuretics, neuroleptics, antipsychotics, tranquilizers, and anticholinergics reduce patients' tolerance to the heat; consequently, these patients are at higher risk of insufficient water intake, impaired thermoregulation, and death.[49,85]

Socially or Geographically Isolated Populations

During periods of extreme heat, it is crucial to have immediate access to medical care, a climate-controlled environment, and public cooling options. For example, during the 1995 Chicago heat wave, people living in neighborhoods without public gathering places were at higher risk of dying.[47] Groups at risk typically have weak social contacts with neighbors, relatives, or social services (e.g., older people, the poor and homeless, people with limited mobility due to disabling chronic conditions or excessive weight, resident housing with no air-conditioning, and individuals who abuse alcohol or illicit drugs [e.g., cocaine or amphetamines]).[20]

Individuals aged ≥65 years have been reported to be among the most vulnerable to heat.[62] Tragically, people aged >75 years accounted for more than 80% of the total excessive mortality during the heat waves.[86,87] Warning older adults about increased health risks during heat waves may have a paradoxic effect because some do not consider themselves old (and weak) or/and at risk.[88–91] Older individuals are less inclined to undertake protective actions because of an under-appreciation of their vulnerability: 67% of those aged 42–53 years take precautions during the heat wave compared with 40% of aged >65 years.[92,93] In addition, heat waves in the Northern hemisphere typically occurred during vacation months when the families often left urban centers, leaving the elderly with compromised social supports.

Outdoor Sports Participants

In the U.S. study of emergency department visits, 75.5% of exertional heat-related illnesses were associated with outdoor sports or exercise.[73] An increasingly motivated participation in intense outdoor activities, such as marathons (42.2 km), has dramatically increased recently. However, the majority of athletes are unaware of the risk of heat exhaustion and exertional heat stroke.[94] Heat illness care in schools, colleges, and professional sport settings often does not follow existing guidelines, resulting in exertional heat stroke being the second-leading cause of death among athletes. Complicating the recognition of heat illness is the fact that the common temperature assessment methods often underestimate the true thermic load, as oral and skin temperatures are influenced by sweat and fluid intake; more-accurate assessment requires core body temperature (rectal temperature, if available) and evaluation of central nervous system function.[95]

Children

Children may be at greater risk for incurring heat exhaustion or exertional heat stroke when participating in excessive outdoor activities, including those that are adult-driven. The 2006 California heat wave led to an increase in emergency department visits for children with heat exhaustion, exertional heat stroke, electrolyte imbalances, and pulmonary and renal diseases.[3] Although previously it has been suggested that children are "less effective than adults in regulating body temperature," recent studies have revealed that children and adults have similar rectal and skin temperatures, cardiovascular responses, and "exercise-tolerance time during exercise."[1,96,97]

However, children who are playing outdoors, and especially those who are involved in sports activities, lack an appreciation of heat-related illness and should be monitored by caregivers or school personnel for "adequate hydration behavior, sufficient sleep/rest before sports/outdoor activities," and "sufficient rest/recovery time between repeats of high-intensity exercise," avoiding multiple same-day sessions.[96] Specific attention is required for higher-risk children, including owerweight/obese children; children with diabetes or current or recent gastrointestinal illness (e.g., diarrhea); and children/adolescents, especially young outdoor athletes, who take attention-deficit/hyperactivity disorder medications (which can induce heat generation with concurrent vasoconstriction, cause central disturbances in thermoregulation, and increase core temperature).[96,98–101] Appropriate sport clothing, uniforms, or protective equipment should be used to minimize heat retention.[102]

People Living in Normally Cool Climates

During California's 2006 summer heat wave, the region with the greatest increase in emergency department visits for heat-related illnesses was the central coast, where

residents were less acclimatized to extreme heat (usually coastal breezes moderate the temperatures). Heat-related illnesses were considerably lower among the residents of the southeast desert region where hot weather is common.[3] Episodes of extreme heat occurring in regions typically accustomed to a cooler climate led to greater mortality,[30,103] and the minimum temperature for fatal heat illness decreases with increasing latitude.[104]

The thresholds for the effects of extreme temperatures on health differ by region because of the phenomenon of physiologic and technologic adaptations of local residents to prevailing weather[105,106]: Populations in higher-latitude cities not only are less acclimated to high temperatures but also are less likely to have air-conditioning.[19,20] However, long-term exposure to the air-conditioned environment at home, office, and in vehicles might affect the physiologic acclimatization to heat even among the residents of lower-latitude cities.[107,108]

Strategies to Minimize the Impact of Extreme Heat on Public Health

More-intense, more-frequent, and longer heat waves are projected for the coming decades; therefore, public health officials need to improve their understanding of the patterns of morbidity and mortality during heat waves so they can provide accurate information and education at both the community and individual level, and develop strategies to ameliorate the impact of heat.[5,24,35] Both local and national activities that may influence the incidence and/or magnitude of heat waves have emerged. The role of these activities as climate change interventions is notable, such as planting trees in high-density urban areas, promoting renewable energy policies and air pollution control, and land-use and transportation planning for "smart and healthy" growth of communities.[109] Public health measures specifically addressing the impact of extreme heat on human health focus on (1) improving the public's appreciation of the health risks during extreme heat; (2) developing a response plan for heat waves; (3) improving reported morbidities and mortalities during the heat waves; and (4) improving community responses to heat waves.

Improving Public Appreciation of Health Risks of Extreme Heat

Heat wave warning systems that have been instituted in several large cities are aimed primarily at preventing heat-related mortality.[62] Special attention should be paid to outdoor workers and vulnerable populations. Because of the rise in outdoor sports/activities, athletes should receive health education on awareness of the heat-related health hazards.[110]

Children engaged in sports and other outdoor physical activities should have rapid-cooling facilities easily available. Community pediatricians can be instrumental in improving heat safety by actively participating in school wellness committees; health councils; school boards; local, regional, or national sports medicine advisory committees; or in local parks and recreation programs. That will help to educate youth, parents, caregivers, coaches, and administrators on how to minimize heat-related health effects during both organized training and competitions and off-season activities.[96]

Heat Wave Response Plan

Five essential criteria have been identified to create an effective heat response plan: (1) identify a lead agency and other participating agencies and ensure that their plans are revised annually before each hot season; (2) identify criteria for activation/deactivation of the heat response plan based on city/area-specific ambient temperature, relative humidity, extreme day and night temperature highs, and deviations from local normal values; (3) develop a communication plan and public education tools; (4) define high-risk populations and how to do outreach to them (e.g., daily well-person checks of the elderly by community police or social service agency personnel, radio/TV/newspapers/Internet messages about heat health hazards, and provision of transportation for the elderly to air-conditioned centers, which can be organized in community centers, schools, and libraries); and (5) evaluation and revision at postheat event meetings, including analyses of morbidity and mortality data.[111]

Heat wave response plans should inform local physicians, emergency medical providers, and hospital staff about the range of health hazards that can increase during heat waves,[66,112] so that hospitals, emergency departments, and urgent care centers can adapt their procedures to meet the added disease burdens by reducing elective medical services to free staff and beds and by treating patients in nontraditional locations.[113] Knowing where vulnerable populations are located will help to target resources most effectively.[114] ZIP-code or census-tract level "heat vulnerability" maps would help to identify the areas of residents who are most in need of effective interventions during the hot period.

Decreasing Morbidity and Mortality During Heat Waves

Ideally, a series of heat-related indicators of health could be used for collecting real-time data from emergency departments and physician offices to first identify and then predict morbidity and mortality during a heat wave.[115] For example, emergency department activity could be considered a public health "sentinel" indicator,

which could be used for triggering appropriate interventions.[116] Such a system would enable follow-up by age groups (elderly or younger), monitoring their adaptation in real time to provide public health authorities with information about the impacts of heat on the health of the community's population.[115]

Improving Community Responses to Heat Waves

Strategies to prevent heat-related morbidity during extreme heat events should include improving community access to residencies and publicly available climate-controlled spaces, encouraging increased fluid intake, advising reductions in outdoor exposure and physical activity, and increasing community outreach by increasing monitoring and prompt response to protect elderly and other socially isolated individuals.[3,117] Because spending even a few hours per day in a climate-controlled environment has been shown to be able to reduce heat-related morbidity and mortality,[118] older adults, disabled, and homebound people should be checked frequently for signs of heat-related illnesses and transported to environmentally controlled cooling centers, even for a short period of time.

However, a concern has been raised recently that increased use of residential, and workplace and commercial space, air-conditioners might not be an effective long-term strategy in regions where continuously increasing outdoor temperatures can stress the power infrastructure leading to power outages and blackouts on extremely hot days. Efficient regulation of thermostats of these facilities during critical heat periods is important.[119] Also, in the regions where substitutes for carbon-based fuels are not widely used, energy demand during the periods of increased air-conditioning can exacerbate the effects associated with fuel combustion, including health and welfare effects from air pollution.

There are limited studies on the cooling effects of indoor fans on high-risk individuals.[49] In the U.S., the use of indoor fans during heat waves is generally discouraged, because, in the absence of air-conditioning, fans provide a cooling effect by evaporating sweat and actually increase heat stress by blowing air warmer than the body temperature over the skin when the heat index exceeds 37°C (99°F).[33,120] However, this view is not fully accepted in Europe, probably because of the regional differences in humidity that modulate the effectiveness of indoor fans.[49]

Information regarding the effectiveness of public health interventions to reduce morbidity and mortality during heat episodes is often not considered in policy decision-making processes.[89,108,121,122] Many cities in North America and Europe have heat health warning systems (HHWS) in which short-term intervention measures are initiated in response to forecasts of hot weather.[42,52,86,123] However, many of these systems are designed to be triggered during days of extreme heat only and they do not address high (but not "extreme") temperatures during the season that are also responsible for a large fraction of heat-attributable morbidity and mortality.[26]

Only a few U.S. cities reported having a comprehensive written heat response plan to protect the vulnerable during hot weather.[111] Several surveys have suggested that many U.S. communities are not adequately prepared to prevent the effects of hot weather on the health of its residents.[124] Recently, the situation has been changing as local health department directors are becoming increasingly aware and are devoting more resources to minimize heat-related illnesses; however, about 85% of directors believed that their local health departments lacked expertise in developing effective adaptation and mitigation plans in changing climate.[125] European studies also have demonstrated that simply targeting one specific heat event is inadequate to prevent the predicted adverse health consequences of high-temperature periods.[4,26]

Conclusion

Further opportunities to respond to heat waves include developing optimal strategies to reach vulnerable populations by considering multiple factors to identify those at highest risk (at individual and community levels).[126] Novel approaches are developing, such as the use of high-resolution remote-sensing technologies that enable the mapping of vegetation, land use, and thermal profiles. Through geospatial mapping, these data can be integrated with demographic profiles, income, prevalence of air-conditioning, and access to transportation infrastructure, thus allowing for better resource allocations among the high-risk groups.[127,128] Adaptation strategies also need to be evaluated to determine their cost effectiveness.[25] Despite increased awareness of the health impact of heat waves and notable successes at developing strategies to minimize health hazards, there are still notable gaps such as the public's appreciation of the effects of heat waves and developing a consistent mechanism for policy interventions.[129]

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