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Racial and socioeconomic disparities in heat-related health effects and their mechanisms: a review

Carina J. Gronlund, PhD, MPH

Center for Social Epidemiology and Population Health, Department of Epidemiology, University of Michigan School of Public Health, 1415 Washington Heights, Ann Arbor, MI 48109-2029, 734-615-9215

Carina J. Gronlund: gronlund@umich.edu

Abstract

Adaptation to increasing extreme heat in a changing climate requires a precise understanding of who is most vulnerable to the health effects of extreme heat. The evidence for race, ethnicity, income, education and occupation, at the individual and area levels, as indicators of vulnerability is reviewed. The evidence for the social, behavioral and technological mechanisms by which racial and socioeconomic disparities in vulnerability exist is also reviewed. These characteristics include cardiorespiratory, renal and endocrine comorbidities; cognitive, mental or physical disabilities; medication use; housing characteristics; neighborhood characteristics such as urban heat islands, crime and safety; social isolation; and individual behaviors such as air conditioning use, opening windows and using fans and use of cooler public spaces. Pre-existing and future research identifying these more proximal indicators of vulnerability will provide information that is more generalizable across locations and time to aid in identifying who to target for prevention of heat-associated morbidity and mortality.

Keywords

climate change; race; socioeconomic; sociodemographic; temperature; heat; heat wave; susceptibility; vulnerability; disparities; health; morbidity; mortality; air conditioning; social isolation; income; occupation; education; housing; urban heat island; vegetation; impervious surface; risk perception; crime; medication

Introduction

Associations between high outdoor temperatures and health have been studied for many decades, particularly in occupational settings [1-3] and with regards to specific extreme heat events, or heat waves [4]. With heat waves already increasing, and likely to continue to increase in frequency, intensity and duration due to climate change [5], interest in the health effects of heat has broadened. To adapt to extreme heat, it is important to precisely

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understand who is most vulnerable to the health effects of extreme heat. There are many studies of the associations of temperature with mortality, hospital admissions, emergency room visits, and calls for ambulances, and these studies have been reviewed previously [1, 6-10, 11-31]. Many of these summaries also address vulnerability by racial and socioeconomic characteristics. In contrast to previous work, this review will focus specifically on the racial, ethnic and socioeconomic (i.e., education, income and occupation) characteristics of vulnerability and on the potential mediators of these characteristics—the more proximate, or “downstream,” health and behavioral mechanisms by which certain people are both exposed to higher temperatures and are more susceptible to, or more adversely affected by, higher temperatures.

The more proximate indicators of vulnerability, described in Figure 1 and below, include characteristics of physiologic susceptibility such as medication use and poor cardiorespiratory, renal or endocrine health. Additional indicators of vulnerability include heat risk perception, cultural or linguistic isolation, housing characteristics and neighborhood characteristics such as crime and safety and urban heat islands. These characteristics may in turn influence heat exposure directly or via air conditioning use, window and fan use or travel to and use of cooler public spaces.

Challenges and Opportunities in Understanding Susceptibility to Heat Health Effects

Unlike many other environmental exposures, such as air pollution or lead, heat exposure is usually readily perceived by the exposed individuals. For many people, it is relatively easy to decrease personal exposure to heat, such that their actual exposures are lower than the temperatures measured at outdoor monitoring stations on a day-to-day basis. This means that estimates of individual heat exposure are often imprecise in studies of heat health effects.

However, because individuals' actions and/or ability to reduce a perceived heat exposure are often patterned by socioeconomic, cultural and other factors, researchers can gather evidence on social and behavioral modifiers of temperature and health associations using a wide range of study designs. These designs include not only secondary data analyses of previously gathered cohort data or administrative records, which may have large sample sizes but crude information on socioeconomic characteristics, but also smaller surveys and case-control and qualitative studies in which individuals or surrogates are interviewed specifically about barriers to staying cool during extreme heat [26, 32-42].

Heat-associated mortality decreases as latitude decreases [19, 43], and this may be due not only to behavioral and technological adaptation but also to physiologic adaptation. Individuals can acclimate through heat-stress-induced physiologic changes which improve thermoregulation [18]. Therefore, physiologic responses to heat may vary widely by climate, making it difficult to apply study results from one location to another if climate conditions are unique.

A challenge to studying racial and socioeconomic disparities in heat-health effects is that these characteristics are often correlated with one another. For example, in Detroit,

Michigan, the census tract percentages of individuals of non-white race, living below the poverty level, disabled and with less education and of imperviousness (i.e., heat-retaining surfaces impervious to water) are moderately correlated with each other [44]. This makes it difficult to identify the mechanisms of heat vulnerability and to understand the relative magnitudes of their effects on heat-related morbidity and mortality.

Race/Ethnicity

Individual racial and ethnic identity is often strongly associated with heat-associated morbidity and mortality in the U.S. For example, blacks have often been found to have increased vulnerability [11, 21, 45-51, 52] and Asians have been found to have decreased vulnerability [49]. However, some studies have not found race or ethnicity to be associated with heat-associated health effects [53-55], and in a study of high temperatures and emergency room visits for various cardio-respiratory diseases in California, as compared to whites, risks were higher among Hispanics for some diseases and lower among blacks, Hispanics or Asians for others [56]. These studies largely did not control for other characteristics of vulnerability. Neighborhood or community racial and ethnic composition has been found to be a factor in heat-associated morbidity and mortality in some studies [57] but has not in other studies [45, 58].

Evidence of racial differences in heat tolerance due to genetic differences is inconclusive at best. [10, 59, 60] Racial and ethnic disparities in heat-associated morbidity and mortality are probably mainly attributable to more distal characteristics of vulnerability, at least in the U.S. Being a racial or ethnic minority in the U.S. is associated with lower income, poorer physical health, living in an area with sparse vegetation and more heat-absorbing surfaces, lower air conditioning ownership and/or being hired to do outdoor farm work [34, 61, 62, 63].

Hispanic ethnicity in the U.S. is often associated with decreased social isolation and better health [64], and increased social cohesion is thought to have played a role in lower heat-related mortality rates during the 1995 Chicago heat wave among Hispanics as compared to non-Hispanic whites [10, 65]. Additionally, a survey of Phoenix, Arizona residents found Hispanics to be more likely to perceive ambient heat as a risk [66] suggesting another mechanism by which Hispanic ethnicity is associated with decreased risk of heat health effects. However, in contrast to studies of Chicago, studies in New York and Phoenix found that Hispanic ethnicity and residing in a Hispanic neighborhood were associated with increased heat health-effects [46, 50, 57]. Furthermore, in Phoenix, this association was independent of linguistic isolation, which was also associated with heat vulnerability, perhaps because linguistically isolated individuals may not understand heat warnings[57], heat-health educational messages or be familiar yet with the local climate. Interviewees expressed concerns that the linguistic isolation of elderly immigrants increased social isolation in Australia.[39] Additionally, race or ethnicity may be a proxy for cultural isolation and a reluctance to travel to cooler public spaces because of a lack of familiar food and activities or because of concerns around immigration status and deportation.[32]

Socioeconomic/Sociodemographic Position

Several studies have used summary measures of socioeconomic or sociodemographic position in assessing vulnerability to heat-associated morbidity or mortality and have found these to be characteristics of vulnerability.[4, 67] For example, heat-related hospital admission was associated with lower socioeconomic status at the individual level in Adelaide, Australia, controlling for other characteristics.[68] Other studies used an area measure of socioeconomic status. A study in Georgia, U.S., found middle but not lower socioeconomic status, as defined by family structure, housing, education and employment in a census block group, to be associated with increased emergency department admissions for heat illnesses.[55] A study in Hong Kong found increased vulnerability among people living in low socioeconomic districts.[69] In Phoenix, Arizona, neighborhood socioeconomic vulnerability was an important predictor of heat-related death in a census block group.[63] However, other studies did not find modification by area-level socioeconomic position.[70]

Summary measures of socioeconomic or sociodemographic position provide the advantage of modeling the latent class represented by the combination of these factors which may influence vulnerability beyond the individual effects of the components. This approach also has statistical advantages when the components are strongly correlated. However, a summary measure does not provide information on the individual effects of income, education or occupation on heat vulnerability. In contrast, the studies reviewed below evaluated education, income and occupation as distinct characteristics.

Education

Some studies in both in the U.S. [48] and in Europe [67, 71] have found higher heat-associated mortality among individuals with less education. However, other studies have not found education to be a characteristic of vulnerability to heat-associated mortality in the U.S. [47, 72], Latin America [73] or China [74-76]. Educational attainment is not usually recorded in hospital or emergency department admissions records in the U.S., so this characteristic has not been well studied with regards to heat morbidity. Higher education was protective against heat-associated morbidity in the 2003 heat wave in Europe.[41] In Rome, less education was associated with a higher risk of heat-associated pre-term birth [77]. Neighborhood [45] educational composition has been associated with heat-associated mortality, but results have been mixed when assessing education effects at the community level [43, 58].

Similarly to race, education may only be related to heat vulnerability very distally. Differences in heat-associated health outcomes by educational attainment are probably mediated by a variety of factors such as income disparities, occupational differences (work in climate-controlled settings is more likely to be performed by more highly educated individuals), cognitive deficits, other health-related barriers to education or lack of knowledge about heat-health risk.[78] In the absence of information on the more proximate mechanisms, race and perhaps education should be accounted for when deciding which people and places to target for adaptation measures in areas where they have been identified as important characteristics of heat vulnerability. However, more proximate characteristics

of vulnerability would probably more accurately identify vulnerable individuals, and public health measures targeting the more proximate mechanisms would likely be more effective.

Income

An individual's income is usually not recorded in mortality or morbidity administrative records, but studies have found income or poverty to be related to heat-associated mortality in the U.S. at the neighborhood level[54] and the community level,[58] in China at the neighborhood level[69] and in Japan at the community level.[79] Income has been found to be associated with hospital admissions during elevated heat at the block levels in the U.S. [46] and in Italy,[80] as well.

These associations may exist because individuals with low incomes may be more reluctant to respond to warnings [66] or pay for transportation to cooler locations.[32, 39] Additionally, surveys and qualitative studies have repeatedly identified concerns over the utility costs of operating an air conditioner to be a major barrier to staying cool.[32, 33, 36, 39] Furthermore, low income may be a barrier to receiving adequate medical care prior to a heat event. Lack of private health insurance was significantly associated with heat-related hospitalization when controlling for other factors in a study of inpatients during a 2009 heat wave in Adelaide.[68]

Occupation

Working in an environment that is not climate controlled is an important risk factor for heat health effects. Controlling for other health and socio-demographic factors, a case-control study of mortality from the 2003 heat wave in France identified manual workers as having been at increased risk.[81] Among slum dwellers in Gujarat, India, occupation was independently associated with heat illness.[82] A recent review of occupational heat exposure included studies of miners, construction workers, farm laborers, first responders and military personnel. This review emphasized that heat-related illness may be the most common causes of nonfatal environmental emergency department admission in the U.S. across all age groups, and that overweight, lack of acclimatization and use of personal protective equipment can increase the risks of heat-related illness. Military discipline or business pressures may also drive these workers to the point of serious adverse heat health effects despite knowledge of the risks.[1] However, interviews of hired farm workers in California did suggest a need for increased education regarding heat-related illness.[34] Farm workers and day laborers also tend to have lower incomes and to be racial or ethnic minorities[1] and therefore are susceptible to the risks associated with these characteristics, as described above.

Proximal Mechanisms of Heat Exposure and Susceptibility

Health and Medication Use

Numerous studies have found associations between heat and deaths, hospitalizations or emergency room visits for specific diseases (besides dehydration and heat stroke) including cardiovascular diseases, respiratory diseases, cerebrovascular diseases, diabetes, renal disease, physical disabilities, psychiatric disorders and substance abuse.[7-9, 11, 13, 17, 21,

23, 28, 46, 56, 58, 83, 84] With the exception of myocardial infarction, it is likely that deaths and hospitalizations associated with these diseases reflect a greater susceptibility to heat among individuals who had these diseases prior to the heat event rather than a causal association between heat and onset of the disease. Other observational studies have addressed physiologic susceptibility more directly, finding susceptibility to death or hospitalization during extreme heat among people with these pre-existing conditions.[26, 35, 45, 51, 68, 82, 85, 86] Laboratory studies have shown that cooling is achieved physiologically through increased blood flow to the skin and sweating and that these cooling mechanisms rely heavily on the cardiovascular system, but also on endocrine, urinary and integumentary processes.[18, 20, 87] Therefore, individuals with pre-existing conditions which compromise these processes are likely more susceptible to heat. Additionally, individuals with poor mental health may be less able to take actions to reduce their exposure to extreme heat.[35, 88] There is also evidence that many of the drugs used to treat these physical and mental conditions, such as anticholinergic, antihypertensive and antipsychotics drugs, reduce sensory perception of ambient heat or suppress or inhibit thermoregulatory responses such as thirst, thereby increasing the risk of an adverse heat-related health event. [30, 35, 39, 89-96] However, the relative influences on heat susceptibility of the medications vs. the underlying diseases are unclear.

Crime and Safety

Research examining the role of crime or safety concerns in discouraging cooling behaviors is limited. An ethnographic study of the 1995 Chicago heat wave, for example, indicated that some of its victims chose not to open their windows or travel to cooler locations because of fears of crime.[65] In qualitative interviews of the elderly in the U.S. and Australia, respondents cited crime and safety concerns and fears of assault as barriers to opening windows or traveling to cooler locations.[32, 39]

Heat risk perception

Studies in Canada, the UK and the U.S. have identified a wide range of attitudes towards the risks associated with heat in their respective populations. Often, elderly respondents incongruously expressed heat as something that other “old” people were vulnerable to, but not themselves.[32, 97] Respondents in a study in Australia expressed ambivalence or held individualistic attitudes towards heat, reporting high air conditioning use, swimming, acclimatization and personal resilience to heat.[36] Most respondents in Canadian studies did perceive heat as a personal risk and also reported that they would take actions to stay cool during extreme heat.[40, 98] Finally, the perceived risk of heat was not predictive of air conditioning use among residents with poor cardio-respiratory health in Montreal[37] suggesting that low perceived risk is not always a barrier to staying cool.

Air conditioning

Air conditioning is a powerful means of reducing exposure to heat. In studies in the U.S., associations between heat and mortality are reduced or absent in communities or ZIP codes with high air conditioning prevalence [43, 58, 62, 99, 100, 101, 102]. Similarly, reduced heat-mortality associations are seen in analyses of individual air conditioning ownership during heat wave events.[26, 81] Air conditioning also has the added benefit of reducing

exposure to ambient air pollution.[103, 104] However, air conditioning ownership was not associated with self-reported heat illness in a study in Canada.[40] As discussed above, having the cognitive and financial abilities to operate the air conditioner is also important.

Air conditioning use has substantial drawbacks. Its use may actually increase vulnerability because during blackouts, air conditioning is not available as a cooling strategy and individuals who have come to depend on it or who have not acclimated to outdoor temperatures may not be able to adequately cool themselves by other means during extreme heat.[38, 39, 105] Also, in countries dependent on fossil fuels for electricity production, the electricity generated to operate air conditioners contributes to greenhouse gas emissions and therefore to climate change. Efforts to increase air conditioning access and use should do so as sustainably as possible--with efficient technologies, accompanied by weatherization of the buildings, and ideally should target communal spaces.

Opening Windows and Using Fans

Natural ventilation is a long-standing and effective cooling technique. Having a working fan was suggestive of being protective against death during heat waves in a meta-analysis[26]. Furthermore, surveys and interviews have identified fan and window use as a common method for staying cool[32, 33, 40], although fans can be harmful when used to circulate hot rather than cool air.[32]

Use of Cool Public Spaces

Traveling to cooling centers or cooler locations has also been identified as an effective technique to staying cool. In a meta-analysis of deaths during heat waves, visiting other air-conditioned places was highly protective.[26] However, studies suggest that opportunities exist for improving cooling center awareness and use in the U.S. and Canada.[32, 40]

Social, cultural and linguistic Isolation

Social isolation is often found to be associated with adverse health effects from heat. In studies of heat-wave associated mortality, being unmarried or widowed, living alone or not leaving home were identified as risk factors.[26, 80, 85] Interviewees in Australia and the U.S. have identified social, cultural and linguistic isolation as risk factors for heat-associated illnesses.[32, 39, 65]

Social isolation may be a consequence of a mental, physical or cognitive impairment, but it may also *modify* the effects of these impairments such that socially isolated individuals who are not able to adequately decrease their exposure to heat, by cooling their homes or traveling to cooler locations, may be more vulnerable to extreme heat than individuals who have assistance.

Urban heat island

Results have been mixed among studies of urban heat island characteristics and heat-associated health effects. Studies in multiple U.S. cities and studies specifically in Phoenix, Montreal, Barcelona, Hong Kong and Taiwan have found associations between remotely sensed land surface temperature, imperviousness or vegetation and heat-associated health

effects.[45, 57, 63, 106-108] However, studies in Philadelphia and Worcester, Massachusetts did not find effects of vegetation or imperviousness.[57] In a case-control study of the 2003 heat wave in France, the surface temperature around the decedent's building was associated with increased mortality.[81]

Housing

Housing characteristics have also been associated with heat-health outcomes.[38] In the 2003 heat wave in France, having a well-insulated home was protective against heat-related mortality.[81] In Barcelona, heat-associated mortality was greater in census tracts with older buildings, adjusting for other census tract characteristics.[108] However, in the 1995 and 1999 Chicago heat waves, housing characteristics such as the floor the decedent resided on were not found to be significant characteristics of vulnerability after controlling for other characteristics of vulnerability.[86, 109]

Conclusions

Racial and socioeconomic characteristics have been found to be associated with increased susceptibility to heat-associated health effects in some studies but not others. Occupation is directly associated with risk of heat-related health effects, but associations with race, education and income are likely mediated by characteristics such as use of air conditioning or cool environments, comorbidities, medication use and urban heat island effects. Figure 1 is not an exhaustive list of the characteristics of heat-associated morbidity and mortality, nor does it indicate all the possible connections between these characteristics, but it outlines some of the major pathways by which racial or ethnic minorities or individuals of low socioeconomic status might have increased vulnerability as suggested by heat-health research. As research identifying the more proximal characteristics accumulates, findings will become more generalizable from place to place and through time and more precisely identify target populations prior to and during extreme heat.

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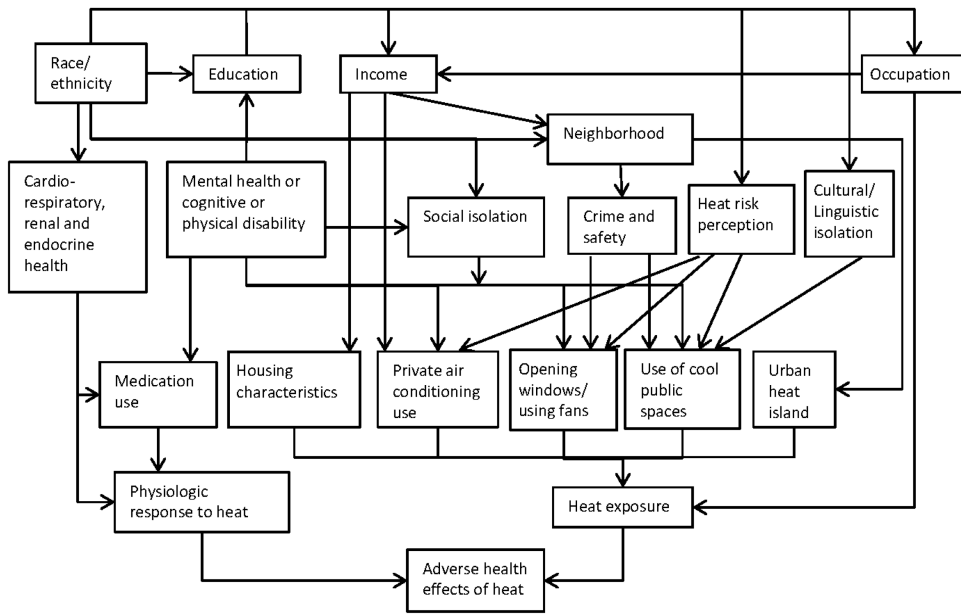


Figure 1. Associations between racial and socioeconomic characteristics and more proximal determinants of adverse health effects of heat.