Heat Stress and Public Health: A Critical Review

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Annu. Rev. Public Health 2008. 29:41–55

First published online as a Review in Advance on November 21, 2007

The *Annual Review of Public Health* is online at http://publhealth.annualreviews.org

This article's doi:
10.1146/annurev.publhealth.29.020907.090843

0163-7525/08/0421-0041$20.00

Key Words

heat waves, early warning, mortality

Abstract

Heat is an environmental and occupational hazard. The prevention of deaths in the community caused by extreme high temperatures (heat waves) is now an issue of public health concern. The risk of heat-related mortality increases with natural aging, but persons with particular social and/or physical vulnerability are also at risk. Important differences in vulnerability exist between populations, depending on climate, culture, infrastructure (housing), and other factors. Public health measures include health promotion and heat wave warning systems, but the effectiveness of acute measures in response to heat waves has not yet been formally evaluated. Climate change will increase the frequency and the intensity of heat waves, and a range of measures, including improvements to housing, management of chronic diseases, and institutional care of the elderly and the vulnerable, will need to be developed to reduce health impacts.

INTRODUCTION

HHWS: heat health warning system

NWS: national weather services

Heat is a natural hazard, and much is known about the effects of high temperatures on the human body. Episodes of extreme temperature can have significant impacts on health and present a challenge for public health and civil protection services. Further, one of the more certain impacts of future anthropogenic climate change will be an increase in heat waves in many populations, and such heat waves will be more intense (35).

Human populations are acclimatized to their local climates, in physiological, behavioral, and cultural terms. There are clear and absolute limits to the amount of heat exposure an individual can tolerate. However, human capacity to adapt to varied climates and environments is considerable. Most homes have an indoor temperature of 63°F to 87°F, and people do not comfortably live in temperatures outside this range. The tolerance range of an individual is usually much less than this and will narrow with age or illness.

This article reviews the current epidemiological information on the impacts of heat waves and hot weather and the implications for public health. This topic has become a rapidly growing area of epidemiological research. Since the 2003 heat wave, most countries in Western Europe have implemented some public health measures for heat waves, mostly in the form of heat health warning systems (HHWS). The relatively rapid development of these systems is a success of public health. However, although more is known about who is most vulnerable to heat waves, there is very limited evidence on the most effective ways to prevent heat-related mortality, particularly in community settings.

The Effects of Heat on the Body

Healthy adult persons have efficient heat regulatory mechanisms, which cope with increases in temperature up to a particular threshold. The body can increase radiant, convective, and evaporative heat loss by vasodilatation and perspiration (43). Experimental data have been used to describe a wide range of thermal indices (more than 300) (79) and for setting important occupational and other standards to limit exposure to heat and the associated health effects (77). The physiological effects of heat are reviewed extensively elsewhere, but there is a lack of evidence on heat tolerance in women, in the elderly, and in persons with chronic disease (see below).

High temperatures cause the clinical syndromes of heat stroke, heat exhaustion, heat syncope, and heat cramps (42). Severe heat stroke occurs when the core body temperature exceeds 103°F and leads to multiple organ dysfunction. Heat stroke has a substantial case-mortality ratio, and progression to death can be very rapid (within hours). In survivors, the permanent damage to organ systems (17) can cause severe functional impairment (16) and increase the risk of early mortality (97).

HEAT WAVES AND THEIR IMPACTS ON HEALTH

This review focuses on the prevention of heat-related impacts in community settings. The heat wave in France in August 2003 caused 14,802 deaths in a 20-day period (33). A major heat wave in Athens in 1987 was associated with more than 2000 deaths (39). Other well-studied heat waves include several in the U.S. Midwest region, particularly the 1995 Chicago event (46). What constitutes a heat wave event is loosely defined, and national weather services (NWS) have developed their own definitions on a national or local basis. In practice, the term heat wave is applied to a wide range of meteorological conditions, from moderate to severe. Heat waves, in terms of a disaster or emergency, i.e., that involve some aspect of the overwhelming of public services, are rare. Unfortunately, best practice guidelines had not been developed in Europe or the United States until recently. **Table 1** lists the heat wave events in Europe that have been reported in the health literature. Major heat wave events are also associated with other health hazards such as air pollution episodes,

Table 1 Heat wave events and attributed mortality in Europe (adapted from Reference 52)

Heat wave event	Attributable mortality (% increase)	Baseline measure
1976—London, UK	9.7% increase England and Wales and 15.4% Greater London	31-day moving average of daily mortality in same year
1981–Portugal	1906 excess deaths (all cause, all ages) in Portugal, 406 in Lisbon (month of July)	Predicted values
1983—Rome, Italy	35% increase in deaths in July 83 in 65+ age group	Compared with deaths in same month in previous year
1987—Athens, Greece	estimated excess mortality >2000	Time trend regression adjusted
July 21–31 1991—Portugal	997 excess deaths	Predicted values
July 12–21 1995—London, UK	11.2% (768) in England and Wales, 23% (184) Greater London	31-day moving average of daily mortality in previous two years
July 30–August 3 1994—Netherlands	24.4% increase, 1057 (95% CI 913, 1201)	31-day moving average of previous 2 years
July 19–31 2003—Italy,	3134 (15%) in all Italian capitals	Deaths in same period in 2002
June 1–August 15 2003—France	14802 (60%)	Average of deaths for same period in years 2000 to 2002
August 1–20 2003—Portugal	1854 (40%)	Deaths in same period in 1997–2001
August 1–31 2003—Spain	3166 (8%)	Deaths in same period 1990–2002
August 1–31 2003—Switzerland,	975 deaths (6.9%)	Predicted values from Poisson regression model
June 1–August 31 (3 months) 2003—Netherlands	1400 deaths	Number of degrees above 72°F multiplied by the estimated number of excess deaths per degree (25–35 excess deaths)
June 1–August 23 2003—Baden-Wuerttemberg, Germany	1410 deaths	Calculations based on mortality of past five years
August 1–24 2003—Belgium August 4–13	1297 deaths for age group older than 65	Average of deaths for same period in years 1985–2002
2003—England and Wales	2091 (17%). Mortality in London region: 616 deaths (42% excess)	Average of deaths for same period in years 1998 to 2002

wild fires, and water and electricity supply failures, which also have implications for public health action.

The excess mortality attributed to a heat wave event is the short-term increase in the numbers of deaths (**Figure 1**), a peak in mortality similar to that seen for very severe pollution episodes. The estimated number of deaths therefore depend on the definition of the heat episode. Reviews have shown that the total impact of a heat wave event will be dependent on a number of factors including heat wave magnitude, timing in season, population experience of heat wave events, and public health responses (47).

The majority of heat wave studies have considered impacts on mortality because daily deaths data are generally readily available in high-income countries. Heat waves are also associated with increases in emergency hospital admissions (36, 51, 84). During the August 2003 heat wave, an increase in admissions was reported in Spain (10) and in France, where many hospitals were overwhelmed (27, 54, 96). Heat-related increases in emergency admissions are most apparent for particular outcomes, including renal and respiratory disease, particularly in the elderly (51). Higher temperatures are not associated with increases in admissions for cardiovascular disease (51, 76), although some effect is apparent in the United States (83). Health system factors, such as admission thresholds, may explain some of this difference. Studies so far have indicated that increases in hospital admissions during heat waves are not as severe as those seen in mortality data. One reason for this may be that people who die during heat waves die suddenly or do not reach the attention of the medical services. The latter hypothesis has implications for health protection measures.

METHODS OF CHARACTERIZING THE TEMPERATURE-MORTALITY RELATIONSHIP

Assessment of Heat Wave Effects

Heat waves have a greater impact on mortality than shown in the reported number of deaths or cases certified as classic heat illness. **Figure 1** illustrates the peak in all-cause mortality associated with an acute heat episode. Heat episode analyses are traditionally used to investigate health—usually mortality—during specific heat wave events (39, 48, 60, 95, 100). These describe mortality counts or rates during a heat wave and are compared with a baseline usually derived from the same time period in surrounding years. The period of interest should differ from the comparison period only with regard to a heat wave occurrence, and so any general trends in the baseline mortality series need to be avoided or allowed for. An alternative is to create the expected values using a regression model with explicit control for season and other time-varying confounders (see below).

Assessment of Heat Effects

Time-series regression. Regression models of time-series data are often used to quantify the general heat-mortality relationship observed throughout the summer (8, 14, 41, 101). The general principle of a time-series regression approach involves assessment of any short-term associations between regular measurements of the health outcome and the exposure (e.g., daily death counts and daily temperature over a number of years). The methods used are closely related to those developed for air pollution epidemiology (40, 81). Unlike air pollution, however, the effects of temperature on mortality cannot be assumed to follow a general linear form. In populations with a temperate climate, a general U- or V-shaped relationship exists between daily mortality counts and temperature, with deaths increasing as temperatures fall, but also as temperatures rise above population-specific threshold values (14).

Multiple lag times are associated with temperature exposures, especially in relation to cold weather, but heat effects may also be delayed by up to a few days. The effects of exposure on multiple days, including any negative risks arising from mortality displacement (see below) may be modeled using a distributed lag curve (7, 8, 30, 99). The use of cross-basis functions has also recently been proposed to allow for flexible modeling of changes in coefficients with changing lags (3). The key issue with the time-series design is the optimal control for confounding by season and other causes of fluctuations in mortality over time.

Case-crossover study. If individual-level mortality records are available, an increasingly common alternative to time-series regression is the case-crossover design, in which the day of death of each individual is considered a case, and proximate days (e.g., +/−7 days) are controls (89). The analytic approach is then akin to that for a matched case-control study. This approach circumvents the need for seasonal control but can be subject to other biases, especially in relation to the choice of controls (58). The method is being increasingly refined as knowledge accumulates about potential biases, and investigators have recently favored a time-stratified design in which control days are chosen from time strata a priori (4, 57). Such designs are a special case of the general case-series approach (22). An important consideration in both time-series and case-crossover studies is serial correlation, the nonindependence of consecutive days.

Effect Modification

In addition to the approaches above, other designs have also been used to assess effect modification of the heat-mortality relationship. The case-only approach has been used to quantify the modification effect of several risk factors but does not give an indication of the overall effect (2, 82). Several case-control studies have also been undertaken on heat wave events in Chicago (85) and Paris (94). These studies used live controls and therefore may also be estimating factors that determine the risk of death per se, rather than the determinants of a heat-related death. Stratifying daily mortality series by subgroup can also be used to investigate effect modification (26, 31). However, the number of subgroups that can be investigated using this method is normally quite limited.

Mortality Displacement

A key consideration about the correct public health interpretation of the heat effect estimates is the extent to which heat deaths occur in already frail individuals whose death may be hastened by the heat exposure by only a matter of days—so-called short-term mortality displacement or early harvesting. Studies using heat episode analysis rarely consider post–heat wave periods to assess whether excesses in mortality during a heat wave are followed by subsequent deficits in expected deaths, consistent with a harvesting process. Recent studies using penalized splines to model the mortality pattern during the Paris (56) and Chicago (37) heat waves suggested little evidence of harvesting during these very extreme heat wave events. Assessment of a harvesting process during a heat wave is complicated by the fact that any negative risk following an initial hot day may be masked by an increased risk from further heat exposure from subsequent hot days; these two opposing effects cannot be separated. Time-series studies have demonstrated some degree of mortality displacement following general heat-related deaths (7, 30).

AT: apparent temperature

Other Issues

Also of importance is the correct parameterization of the exposures measure. Mean temperature is commonly used, with control for confounding with humidity. Combined indices of temperature and humidity, such as apparent temperature (AT), are also used as a construct that characterizes the physiological experience better than just temperature alone (90). However, in a recent assessment, AT was not a better predictor of mortality than was mean temperature in two of three European cities (29).

Although some major studies of temperature and mortality have not controlled for the effects of air pollutants (7, 14), more recent work has suggested that heat effects are likely to persist even after control for air pollution, and weather risk assessments are best informed by analyses that account for PM10 and ozone in particular (73). Heat episode analyses implicitly control for the air pollution concentrations because the baseline represents the seasonal norm; however, there exists the possibility of synergistic effects of air pollution with heat, which may be more apparent during extreme events (38).

DETERMINANTS OF HEAT-RELATED MORTALITY AND MORBIDITY

Public health interventions are often targeted at high-risk groups, and it is therefore important to identify those most vulnerable to dying in a heat wave. Published epidemiological studies are available for three main categories of exposure related to hot weather:

- individual heat wave events;
- days with temperatures above a specified heat threshold, as described in time-series regression studies; and
- classic heat stroke related to hot weather (note that a significant proportion of heat stroke is not related to heat wave days).

Risk factors can also be categorized as intrinsic (age, disability) and extrinsic (housing, behaviors); the latter vary according to location and adaptations to the local climate. The risk factors can operate at many stages along the causal chain from high ambient temperature to death (**Figure 2**). Effective health protection measures have important effects on the risk of heat-related mortality at the population level and may modify the risks by age group (15). However, there is little published information as yet on the effectiveness of such measures, although it is clear that the mortality response can change dramatically from one heat wave to the next (see below) (65).

Climate itself is an important determinant of population sensitivity to temperature because it influences the level of acclimatization in individuals. The threshold temperatures for heat-related mortality effects are related to the local summer temperature. That is, the temperature above which mortality increases with increasing temperature is higher in warmer climates compared with cooler climates. The slope of the temperature-mortality response, however, is rather heterogeneous and in general not predicted by latitude, as shown by comparisons of cities within the United States (14), Europe (66), and around the world (62).

Age and Aging

Vulnerability to heat in old age occurs because of changes in the thermoregulatory system (23, 28, 93). Epidemiological studies of heat-related mortality show a larger effect in

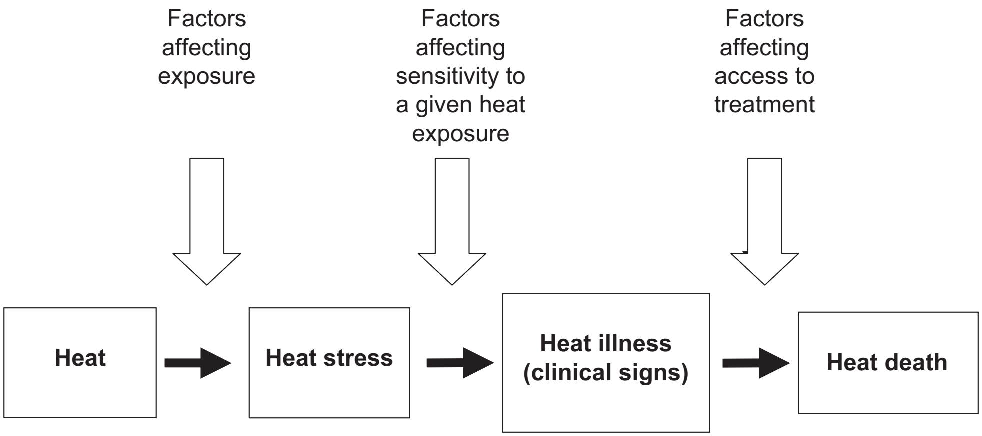

Figure 2

Points along the causal chain from heat exposure to heat death.

the elderly; the risk increases with increasing age above ~50 years old.

Children and babies also have limited ability to thermoregulate. Children are also more at risk of dehydration than are adults. Child deaths from heat stroke occurred in France during the heat waves in 2003 (78) and 2006 (21). However, time-series and episode analyses indicate no excess in mortality in children due to heat waves [except the 1981 and 1991 heat waves in Portugal (25, 74)].

Heat mortality risk varies by both age and sex. The majority of European studies have shown that women are more at risk, in both relative and absolute terms, of dying in a heat wave. There maybe some physiological reasons for an increased risk in elderly women (9, 32), but social factors are also important. In Paris, the heat risk increased for unmarried men, but not unmarried women (11). In the United States, elderly men are more at risk in heat waves than are women, and this was particularly apparent in the Chicago events (85, 100). This vulnerability may be due to the level of social isolation among elderly men (46). Evidence for the importance of social contact as protective for heat wave mortality is based on case control studies conducted in the United States (68, 85). Men are also more at risk of heatstroke mortality because they are more likely to be active in hot weather (13).

Clinical or Pathophysiological Factors

In addition to the natural patterns of aging (or senescence) on homeostatic mechanisms, several medical conditions increase vulnerability to heat stress. Epidemiological studies indicate that people with depression, cardiovascular and cerebrovascular conditions (89), and diabetes (82) need to take extra care in hot weather. The literature on pathophysiology of heat is incomplete. Many deaths that are attributed to heat are not caused by heat stroke nor are they even in persons that exhibit the clinical signs of heat stress. There are likely several mechanisms by which a person may die during a heat wave because the environmental temperatures place extra strain on the cardiovascular system. The person becomes dehydrated, displaying increased blood viscosity and other physiological changes. In theory, any illness that compromises thermoregulation will increase the risk of heat-related death. If the exposure to heat is severe enough, even healthy people will succumb to heat stroke. Illnesses also compromise mobility, awareness, and behavior. Therefore, some conditions, such as dementia and Parkinson's disease, are also important risk factors for heat mortality. In addition, a range of common medications interfere with thermoregulation (anticholinergics interfere with sweating, diuretics can cause dehydration, etc.) (17, 19, 44).

Living in Institutions

The heat wave in 2003 caused a severe impact on elderly persons in hospital and in residential homes. The mortality rate doubled in the 75+ age group for persons living in retirement homes in France (24). In 2003, such institutions in France, Italy, and the United Kingdom were generally without air conditioning. A study in the United Kingdom also found a much higher heat risk in nursing home patients and care home patients, with lowest risk in persons living at home (31). The residents of institutions therefore represent an important high-risk group for heat wave interventions. In France, the government has since recommended that homes for the elderly have at least one cool room (63). In the southern United States, there appears to be little heat-related mortality in care homes, except when an air conditioning system failure occurs (92). The risk of heat-related mortality is determined by level of disability (or frailty) in the nursing home setting (5); however, a study in France suggested that as medical care during the heat wave was directed toward the most vulnerable patients, the less-frail patients made the largest contribution to the excess mortality estimated during the heat wave (34).

Housing Characteristics and Air Conditioning

People spend the most of their time indoors. There is relatively little evidence that certain types of housing (and thermal behavior) increase vulnerability. Brick houses (with a high thermal mass), top floor apartments with no through ventilation, and closed windows are associated with an increased risk of mortality during a heat wave (67, 94).

U.S. studies indicate that air conditioning is an important protective factor for heat-related mortality (85). In Europe, there is little domestic air conditioning, although this is expected to change in the coming decades. Lack of air conditioning may explain the risk of heat stroke in poor urban elderly persons in some U.S. inner cities because the role of high energy costs and the loss of income support was an issue during the Chicago heat wave (46). Power failures are common during heat waves because of sudden increases in electricity demand (20). Some investigators suggest that widespread use of air conditioning may reduce physiological acclimatization and can therefore make people more susceptible to heat waves, but the evidence is unclear (72).

Socioeconomic Factors

Deprivation, particularly in the inner city, is an important determinant of heat wave and heat stroke mortality risk in the United States, but the evidence is less clear for European populations. The heat wave in Pheonix in 2006 was responsible for 13 heat stroke deaths, of which 11 were homeless people. Most studies of the 2003 heat wave in Europe report little or no effect of deprivation on mortality risk (6, 31, 89), although one study in Italy reported a higher risk in low-income groups (64). Individuals on low incomes are more likely to have a chronic disease or other medical risk factors, such as obesity or mental illness, and less adequate types of housing, which will all modify the risk of heat-related mortality.

Urban Heat Islands

Urban heat islands are a factor in many cities and refer to the difference in temperatures measured inside and outside the city (70, 71). Heat islands have been particularly important in some heat wave events (53, 98). Heat islands are dynamic in time and space and are therefore hard to quantify either spatially or temporally for individual heat wave events. Although much is known about the factors of the built environment that increase temperatures, when estimating health effects within a city, confounding by housing type and socioeconomic factors becomes very important. Several studies show that mortality is more sensitive to heat in urban areas compared with rural and suburban areas. One reason for this could be that urban heat islands magnify night time temperatures. The importance of heat islands may vary, as cities in southern Europe are more adapted to heat than are those in northern Europe (31, 87). A study in Spain found that excess mortality during the August 2003 heat wave was comparable in rural villages and in the provincial capital (61).

IMPLICATIONS FOR PUBLIC HEALTH

Many public health lessons were learned following the August 2003 heat wave in western Europe (86). The key problems identified by the French government included the lack of an intervention plan for heat waves and the lack of coordination between the social services and health agencies. In addition, very few care homes ("maison de retrait") had air conditioning or other space cooling, and these buildings simply became too hot. However, the heat wave itself was so severe that it could not have been anticipated (59, 86). It is very likely that anthropogenic climate change has doubled the likelihood of such events (91).

Many countries now have heat wave plans that dictate a range of public health interventions. Health education about prevention and identification of the first signs of heat stress is the most important public health strategy, but such campaigns must be repeated at the beginning of every summer. HHWSs use meteorological forecasts to reduce the impact of heat waves on human health (49). The challenge lies in determining at which point the weather conditions become sufficiently hazardous to human health in a given population to warrant intervention (47, 50, 69, 88). Warnings issued to the general public during a heat wave reinforce the general heat-avoidance messages. The active components of HHWSs, such as identifying and contacting high-risk individuals, vary from city to city. Intervention plans should be best suited for local needs through coordination between the local health agencies, social services, voluntary agencies, and the NWS.

The heat wave in 2006 in western Europe was associated with much less impact on mortality than that in 2003 (21). It is not straightforward to compare directly the impacts of heat waves in terms of numbers of deaths, either in different cities or in the same city over time (15, 50). Fewer heat-related deaths occurred in Chicago during the 1999 heat wave compared with the earlier 1995 event. Although some of this reduction in mortality was attributed to the successful implementation of prevention measures, such as the opening of cooling centers (75), as well as an increase in air conditioning use, there would also have been a significant increase in the general level of awareness of heat waves impacts and public health messages.

Another important issue that has been identified is lack of health surveillance for heat wave mortality. In 2003, surveillance of general mortality on a daily basis was not available, and systems could not detect an increase in deaths in the elderly from nonspecific causes (1). Some countries consequently

Table 2 Recent trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late-twentieth-century trend [Fourth Assessment Report of the Intergovernmental Panel on Climate Change (35)]

Phenomenon and direction of trend	Likelihood that trend occurred in late twentieth century (typically post-1960)	Likelihood of a human contribution to observed trend	Likelihood of future trends based on projections for twenty-first century
Warmer and fewer cold days and nights over most land areas	Very likely	Likely	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Likely (nights)	Virtually certain
Warm spells/heat waves. Frequency increases over most land areas	Likely	More likely than not	Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely	More likely than not	Very likely
Area affected by droughts increases	Likely in many regions since 1970s	More likely than not	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970	More likely than not	Likely
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	More likely than not	Likely

now use other indicators that are available on a 24-hour basis, such as a telephone advice line in the United Kingdom, to support decision making for heat wave alerts (55).

CONCLUSION

Heat health protection strategies require further research to identify those that are truly effective in reducing mortality due to heat waves. The limited epidemiological evidence suggests that targeting high-risk groups may not be the most effective strategy but that sustainable improvements in the health of the vulnerable elderly are required.

Global climate change is likely to be accompanied by an increase in the frequency and intensity of heat waves (**Table 2**). In the long term, as the climate changes, populations are likely to become less sensitive to temperature extremes owing to improvements in the underlying health of the population (12, 18). Conversely, populations are aging, and the number of elderly people susceptible to temperature extremes will increase. There is also a trend toward more energy-intensive buildings that need to be artificially cooled (80). Thus we must also build houses and cities that are cooler as well as more sustainable and energy efficient.

SUMMARY POINTS

1. A range of epidemiological study designs are used to quantify the effect of temperature on mortality and explore effect modification, including time-series regression; episode analyses; and case-control, case-only, and case-crossover methods.
2. Mortality due to heat waves is most pronounced among the elderly, but other groups are also at risk, including adults with chronic disease and children. The epidemiological evidence base needs to be reviewed regularly to determine the advice on targeting certain groups with prevention strategies.
3. A range of measures, including health advice and weather-based alerts, are used to prevent heat wave deaths, but there is no clear evidence about the most effective measures in community settings, particularly in targeting the very vulnerable.
4. Climate change will increase the frequency and the intensity of heat waves, and a range of measures—including improvements to housing, management of chronic diseases, and institutional care of the elderly and the vulnerable—will need to be developed to reduce future impacts of heat.

DISCLOSURE STATEMENT

The authors are not aware of any biases that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGEMENTS

The authors thank Bettina Menne and Franziska Matthies, and all participants in the EUROHEAT network. The authors' work was funded in part by the European Commission DG SANCO (agreement number 2004322).

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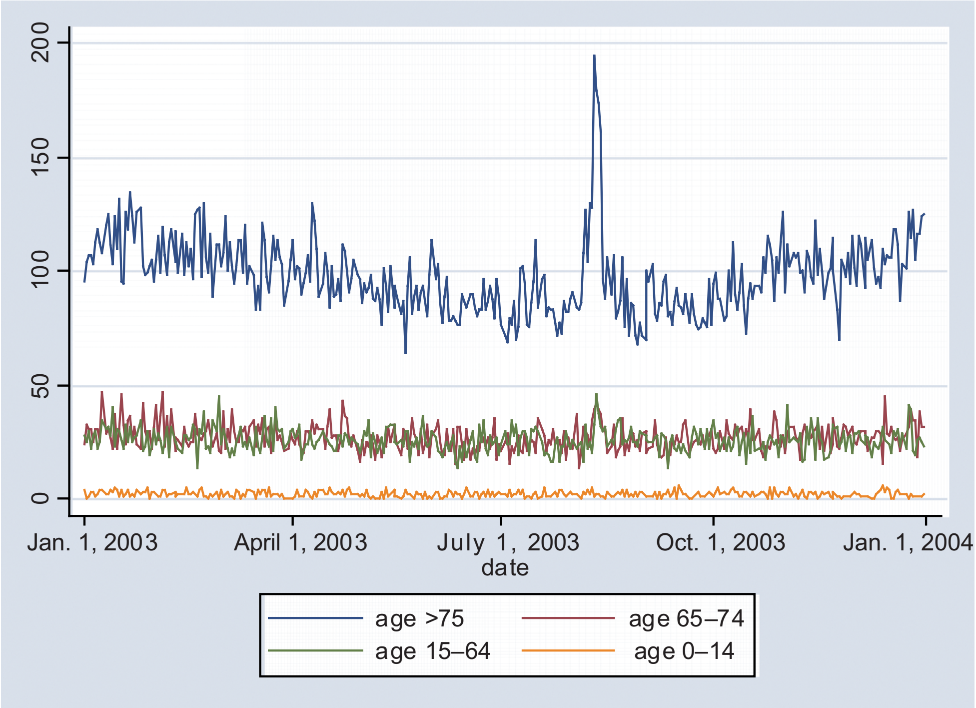

Figure 1

Daily mortality in Greater London, 2003, by age group.