Health effects of hot weather: From awareness of risk factors to effective health protection

Article *in* The Lancet · February 2010

DOI: 10.1016/S0140-6736(09)61711-6 · Source: PubMed

Shakoor Hajat

London School of Hygiene and Tropical Medi…

Madeline O'Connor

The Ottawa Hospital

Health effects of hot weather: from awareness of risk factors to effective health protection

Shakoor Hajat, Madeline O'Connor, Tom Kosatsky

Lancet 2010; 375: 856–63
Published Online
February 12, 2010
DOI:10.1016/S0140-6736(09)61711-6

British Columbia Centre for Disease Control, Vancouver, BC, Canada (S Hajat PhD, T Kosatsky MD); **London School of Hygiene and Tropical Medicine, London, UK** (S Hajat); **and Montreal Public Health Department, Montreal, QC, Canada** (M O'Connor MD)

Correspondence to: Dr Shakoor Hajat, Public and Environmental Health Research Unit, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK
shakoor.hajat@lshtm.ac.uk

Because of the increasing concerns about climate change and deadly heatwaves in the past, the health effects of hot weather are fast becoming a global public health challenge for the 21st century. Some cities across the world have introduced public health protection measures, with the timely provision of appropriate home-based prevention advice to the general public being the most crucial point of intervention. In this Review, we report current epidemiological and physiological evidence about the range of health effects associated with hot weather, and draw attention to the interplay between climate factors, human susceptibility, and adaptation measures that contribute to heat burdens. We focus on the evidence base for the most commonly provided heat-protection advice, and make recommendations about the optimum clinical and public health practice that are expected to reduce health problems associated with current and future hot weather.

Introduction

One of the most direct health effects arising from climate change is expected to be increased rates of mortality and morbidity associated with exposure to high ambient temperatures.[1] Many countries already have a burden of heat-related mortality that manifests during heatwaves but is insidious throughout the summer.[2] Additionally, with future susceptibility likely to be increased with ageing populations in high-income countries and rapid urbanisation in many low-income countries, the health effects of hot weather are fast becoming a global public health challenge for the 21st century.[3,4]

In recognition of this likely increase, cities in North America and Europe, and parts of Asia and Australia, have introduced public health protection measures. Prominent among these are heat health warning systems that trigger community alerts and emergency actions in response to forecasts of adverse weather conditions.[5] Because heat-related illness is largely avoidable, the most crucial point of intervention concerns the use of appropriate prevention strategies by susceptible individuals and their carers.[6] Although such home-based prevention advice already forms an integral part of many heat health warning systems, the extent to which the advice is based on medical evidence is unclear. Knowledge of effective prevention and first-aid treatment, besides an awareness of potential side-effects of prescription drugs during hot weather, is crucial for physicians and pharmacists.

We review the reported effects of ambient heat exposure on individuals and communities, and add to evidence from previous epidemiological[3] and public health reviews[7–9] to draw attention to the latest knowledge about heat-related health. Additionally, we provide information about the most commonly offered advice to the public about heat protection, and the evidence base for such guidance.

Search strategy and selection criteria

The search strategy consisted of:

1 A literature search to provide an overview of the health effects of hot weather and risk factors.
2 An internet search to establish what heat-protection advice is provided by public health authorities and other agencies.
3 A literature search to review the evidence base of the guidance identified in (2).

For (1) and (3), we searched PubMed, Embase, Geobase, and Desastres for reports in English or French using the combinations of MeSH terms "weather" and ("mortality" or "morbidity"). We included all subheadings, and also all MeSH terms that occurred in the "weather" MeSH term category, including "hot temperature" and "extreme heat". We made no restrictions about the date but restricted our search to studies of people. To focus on health effects among the general public, we excluded studies of heat effects specifically in athletes, military personnel, and individuals working in occupational health. Reference lists of retained studies were scanned to identify any further relevant information. For (2), we searched the internet with the intention of replicating information from websites in North America, Europe, and Australia—ie, intergovernmental organisations, disaster relief organisations, weather services, private agencies, care providers, patient advocacy groups and information services, and public health authorities (national, state, provincial, and municipal)—that might be accessed by people for health advice provided in English, French, Spanish, or Italian about hot weather in anticipation of a heatwave or during one. We used the search terms "heat", "heat-wave", "heatwave", "heatstroke", "heat-stroke", "heat-related", "canicule", "chaleur", "chaleur-accablante", "ondate di calore", "ola de calor", and "caldo".

2099 citations were initially retrieved for searches (1) and (3), and 60 possible websites were identified for search (2), of which 44 provided online heat-protection advice. Non-relevant reports from searches (1) and (3) were rejected on the basis of the title, and then the abstract; and experimental studies that were not restricted to young, healthy individuals were given priority.

Overview of heat-related health

Physiological effects of heat

Whereas human adaptation to cold environments is greatly assisted by behavioural responses (eg, wearing additional layers of clothing), adaptation to heat is dependent on the body's ability to act as a natural cooling system. Human beings maintain an internal temperature within a narrow range around 37°C, independently of ambient temperature fluctuations.[10] Heat homoeostasis is achieved through thermoregulatory functions, controlling the gain or loss of heat. The processes are conduction (temperature exchange through direct contact with hot or cold surfaces); convection (temperature exchange through movement of air or fluid); radiation (temperature exchange related to emission and reception of electromagnetic waves); and evaporation (cooling caused by water from perspiration leaving the skin's surface as a vapour).[10] The main ways in which the body eliminates heat during thermal stress are through sweat production, increased cardiac output, and redirection of blood flow to the skin (increases heat loss by radiation and conduction). When environmental temperature is greater than the core body temperature, sweat production is the primary physiological way to lose heat.[10] These responses can be diminished or delayed in elderly people or other susceptible groups such as those with chronic illness or taking some drugs (eg, diuretic and anticholinergic drugs).[9,11] Reductions in heat tolerance among elderly individuals can be caused by poor aerobic fitness, differences in body composition, and chronic health conditions, rather than by increased age.[12]

Signs of heat-related illness in an individual often begin with heat exhaustion, which, if left untreated, might progress to heatstroke—clinically defined as a core body temperature of at least 40·6°C.[13] Progression to death in an individual with heatstroke can happen rapidly (within hours), and even with prompt medical care, 15% of heatstroke cases are fatal.[14] In many situations, however, heat exposure might not be confirmed as the underlying cause of death, and so heat-related illness is under-reported. Heat exposure is a factor that can contribute to exacerbation of many pre-existing health conditions. In high-income countries, most heat-related deaths are likely to be from cardiovascular or respiratory causes. For these reasons, effects in broad disease groupings rather than heat illness specifically are analysed in epidemiological studies.

Community-level effects

Evidence of heat effects in community settings derives from epidemiological studies in which the effect of each heatwave episode or the daily change in number of health events in relation to day-to-day fluctuations in temperature occurring throughout the summer months are assessed. Health effects have been shown to be mostly immediate, occurring on the same day, or within a day or two, of initial exposure.[3] Although in most epidemiological studies, health effects are modelled in relation to temperature alone or in combination with high humidity as a composite measure,[15] in some, possible synergistic effects of additional weather factors, such as air pressure, wind speed, and cloud cover, are taken into consideration.[16] Air pollution might also increase during heatwaves,[17] leading to possible synergistic effects on health.[18]

The main studies in which heatwave and general heat-related effects on mortality have been assessed are discussed elsewhere.[3,8] Early mortality and long-term functional impairment have also been reported in survivors of classic (ie, non-exertional) heatstroke.[19]

In the assessment of the effects of heat on mortality, a key question for policy makers is whether deaths mostly arise in already frail individuals in whom exposure to hot weather has hastened their deaths by a few days or weeks. Between 20% and 40% of deaths during heatwaves

	Website address
Intergovernmental organisations	
Centers for Disease Control and Prevention	http://www.cdc.gov/
WHO/Regional Office for Europe	http://www.euro.who.int/
Disaster relief organisations	
American Red Cross	http://www.redcross.org/
Federal Emergency Management Agency	http://www.fema.gov/
Weather services	
Environment Canada	http://www.ec.gc.ca/
Environmental Protection Administration/Office of Atmospheric Programs	http://www.epa.gov/oar/oap.html
Illinois State Climatologist Office	http://www.isws.illinois.edu/atmos/statecli/
Météo-France	http://www.meteo.fr/meteonet_en/index.htm
National Oceanographic and Atmospheric Administration	http://www.noaa.gov/
Private agencies	
American Association of Retired People	http://www.aarp.org/
Harvard Health Letter	http://www.health.harvard.edu/newsletters/Harvard_Health_Letter
Laboratoire de Santé Publique (France)	http://www.timone.univ-mrs.fr/medecine/
Texas A and M University	http://www.tamu.edu/
Care providers	
American Academy of Family Physicians	http://www.aafp.org/online/en/home.html
Patient advocacy groups and patient information services	
American Heart Association	http://www.americanheart.org/
Public health authorities (national)	
Department of Health, UK	http://www.dh.gov.uk/en/index.htm
Direction générale de Santé, France	http://www.sante.fr/
Health Canada	http://www.hc-sc.gc.ca/index-eng.php
Institut national de prevention et d'éducation pour la santé, France	http://www.inpes.sante.fr/
Office federal de la santé publique (Switzerland)	http://www.bag.admin.ch/index.html
Ministero della salute (Italy)	http://www.ministerosalute.it/
Ministerio de Sanidad é Consumo (Spain)	http://www.msc.es/
Public Health Agency of Canada, Canada Health Network	http://www.phac-aspc.gc.ca/chn-rcs/index-eng.php
Santé publique (Belgium)	http://www.health.fgov.be
Public health authorities (state and provincial)	
British Columbia Ministry of Health	http://www.gov.bc.ca/health/
California Department of Health Services	http://www.cdph.ca.gov/Pages/Default.aspx
California Department of Aging	http://www.aging.ca.gov/
Department of Human Services, Victoria, Australia	http://www.dhs.vic.gov.au/home
Illinois Department of Public Health	http://www.idph.state.il.us/
Ministére de la Santé et des Services sociaux Québec	http://www.msss.gouv.qc.ca/
Ontario Ministry of Health and Long-Term Care	http://www.health.gov.on.ca/en/default.aspx
Santé Ontario	http://www.santeontario.com/
Texas Department of State Health Services	http://www.dshs.state.tx.us/
Wisconsin State Government/Department of Health and Family Services	http://dhs.wi.gov/

(Continues on next page)

	Website address
(Continued from previous page)	
Public health authorities (municipal)	
Chicago Department of Public Health	http://egov.cityofchicago.org/city/webportal/home.do
City of Columbus–Columbus Public Health	http://publichealth.columbus.gov/
Direction de la Santé publique de Montréal	http://www.santepub-mtl.qc.ca/
Los Angeles County Health Department	http://www.ladhs.org/wps/portal/
Maricopa County Dept of Health Services (Phoenix, Arizona)	http://www.maricopa.gov/Public_Health/
Milwaukee Health Department	http://www.milwaukee.gov/health
New York City Department of Health and Mental Hygiene	http://www.nyc.gov/html/doh/html/home/home.shtml
Ottawa Public Health	http://ottawa.ca/residents/health/
Toronto Public Health Department	http://www.toronto.ca/health/
Vancouver Health Department	http://www.vch.ca/

Table: **Categories and website addresses of 44 health-related or weather-related organisations**

have been attributed to such short-term mortality displacement in selected locations.[20] The role of displacement is likely to be smaller in situations in which heat-related deaths are not restricted to chronic diseases in elderly individuals—eg, during heatwaves when a higher proportion of deaths might arise from heatstroke in otherwise healthy individuals,[21–23] or in low-income countries where heat-related deaths from infectious diseases might be common.[24]

In Europe, increases in emergency hospital admissions among individuals with respiratory diseases have been noted during hot weather, but not in those with cardiovascular disease or stroke.[25–27] By contrast, in studies from the USA, heat-related increases were noted in admissions for heart disease,[28,29] acute myocardial infarction, and congestive heart failure.[30,31] Reasons for the differences between Europe and the USA are not obvious, but might relate to factors associated with health-service delivery. A consistent increase has been noted in admissions for renal disease in Europe,[25] the USA,[28,32] and Australia.[33,34] Increases have also been noted for other conditions, including diabetes[28] and mental disorders.[35]

Surrogate outcomes for morbidity that are also sensitive to ambient heat include ambulance transportation,[33,36,37] calls to telephone helplines,[38] and despatches by fire departments.[39] As data for some of these outcomes are routinely gathered and available in real time, they might be useful in surveillance for identification of the early public health effects of heatwaves.[40–42] Their usefulness, though, might be limited by situations in which perceived symptoms, rather than a diagnosis, are the basis of the outcomes.

Effects of heat have been characterised in various settings.[43,44] They are stronger early in the summer season,[44] and can vary within a city because of spatial variations in temperature.[45] New epidemiological evidence suggests that a high yearly summer mortality burden might be linked to low mortality rates in the previous winter.[46,47]

Risk factors

Kovats and Hajat[8] discuss risk factors for heat illness in more detail than discussed here. In a meta-analysis of six case-control studies, the factors associated with the highest risk of death during heatwaves were confinement to bed (odds ratio 6·4 [95% CI 4·5–9·2]); pre-existing psychiatric illness (3·6 [1·3–9·8]); not leaving home every day (3·4 [1·6–6·9]); and an inability to care for oneself (3·0 [1·8–4·8]).[48] In some of the studies, cases of heat-related deaths were compared with controls who were still alive, resulting, perhaps, in the identification of risk factors for death in general, rather than specifically heat-related deaths.[48]

Rates of heat-related mortality and morbidity are high in elderly and chronically ill individuals, particularly those with cardiovascular, respiratory, and renal diseases.[32,44,49] People with diabetes, neurological disorders, and psychiatric illnesses might also be at increased risk.[3,48,50–54] Some drugs, notably diuretic, psychotropic, and anticholinergic drugs, have been implicated in increasing the risk of heat-related death or illness.[55–57] Results from physiological studies have shown that young children might be unable to meet the need for increased cardiac output in hot conditions.[58] Social deprivation has been identified as a risk factor for heat-related death in many US studies,[59,60] but the evidence from Europe is not as clear.[61–63] The difference might be partly attributable to home air conditioning, which is more common in US cities than in Europe.[64]

Social isolation and little mobility were identified as key risk factors during heatwaves.[51,52,54] Other contextual risk factors include no access to an air-conditioned environment, living in homes with high thermal mass and little ventilation, and living on the upper floors of high rise buildings.[54] Elderly people in hospital and residential homes are also at increased risk because of their frailty and therefore need particular attention from carers.[62,63,65] People living in cities are more vulnerable than those living in rural areas,[63,66] partly because of the urban heat-island effect, whereby city temperatures are raised as a result of increased thermal storage capacity.[67] In the USA, differences between urban and rural areas are smaller, which might indicate less access to air conditioning for people living in rural areas than those living in urban areas.[68]

Online heat-related health advice

The table shows the websites of 44 health-related or weather-related organisations retrieved in our internet search for public guidance about heat protection. The most commonly offered advice is shown in panel 1. Aspects of protection emphasised on the websites did not always indicate clearly which issues were of greatest concern, and recommendations were rarely supported by reference citations. The amount and quality of information provided was not necessarily greater in jurisdictions that had previously had a major heatwave than in those that had not. In some situations, recommendations between websites were contradictory. For example, most US websites generally discouraged use of fans, whereas European websites supported it. The likely reason for the difference is the belief that use of fans is counterproductive in high humidity settings because of reduced evaporative cooling. Some websites recommended replacing salt and minerals, whereas others specified avoiding salt tablets.

Evidence base for commonly offered advice

Alcohol has a diuretic effect that varies according to the alcohol content of drinks. Although increases in urinary output of 10 mL/g of alcohol consumed[69] might not be a cause for concern with drinks that have a large fluid-to-alcohol content (such as beer), the bioavailability of fluid content can be attenuated by nearly 50% with drinks containing a high proportion of alcohol (eg, whisky). In addition to impairment of judgment, consumption of large amounts of alcohol diminishes heart contractility and causes peripheral vasodilation, which, in turn, decreases blood pressure and restricts the necessary compensatory increase in cardiac output. A large consumption of alcohol might also inhibit the secretion of antidiuretic hormone.[70] Although alcoholism is a risk factor for heat-related death,[71] the extent of harm caused by moderate consumption of low-alcohol beverages during hot weather is not clear. Similarly, any diuretic effects of caffeinated drinks might not be apparent at moderate intake—no significant differences in hydration status were noted between individuals with a moderate caffeine intake (253 mg per day) and those who drank only water or had a mild caffeine intake (114 mg per day).[72] Any diuretic effect of caffeine is probably modified by habituation, high caffeine content, and hydration status.[69,72]

Thermoregulatory compensation for high ambient temperatures depends mainly on replenishment of fluids lost through perspiration and exhaled breath.[73] If fluid volume is insufficient, metabolic demands are too high, or the heart cannot meet the demands of increased cardiac output, then thermoregulation can fail. Elderly individuals might have a low fluid intake as a result of a decreased sense of thirst.[74] Replacement of water without sodium has been blamed for causing an imbalance in body electrolytes in soldiers.[75]

In areas where air conditioners are commonly used, notably in the USA, evidence from epidemiological studies of heat-related mortality shows a strong protective effect in groups that have access to home air conditioning.[71,76–78] The results of one study have suggested a protective effect of cooling in a dose-response fashion.[71] For the human body to acquire protective physiological changes associated with heat

Panel 1: Most commonly provided heat-protection advice to the general public from the organisations listed in table

1. Avoid drinking alcohol (n=34)
2. Wear lightweight, loose fitting clothing (n=31)
3. Drink regularly without waiting for thirst (n=28)
4. If you have no air conditioning at home, seek out an air-conditioned or cool environment (n=21)
5. Stay indoors in an air-conditioned environment (n=20)
6. Wear a hat (n=18)
7. Avoid or reduce physical activities (n=18)
8. Protect yourself from the sun (n=17)
9. Know the symptoms of heat-associated illness, and know how to respond (n=15)
10. Look in on susceptible people (n=15)
11. Do not leave children in a closed, parked car (n=15)
12. Avoid going out during the hottest part of the day (n=13)
13. Take frequent baths or showers (n=11)

Numbers within parentheses are the number of sources.

Panel 2: Possible modes of action of drugs on risk of heat-associated illness, and drug classes expected to be of greatest risk

Possible modes of action:

- Dehydration caused by diuretics and angiotensin-converting enzyme (ACE) inhibitors might reduce visceral blood flow to the liver and kidneys, reducing clearance of drugs and toxins. Moderate to severe dehydration is associated with a risk of hypovolaemia and orthostatic hypotension, causing falls and increasing heart rate.
- Antianginal drugs and β blockers decrease heart rate or contractility.
- Drugs that antagonise water retention (eg, morphine), have laxative effects (eg, lactulose), or cause vomiting or diarrhoea (eg, colchicine) can lead to electrolyte disturbances by shifting the fluid balance.
- Antipsychotic (anticholinergic and tricyclic antidepressant) drugs are associated with a reduction in sweat production through a reduction in autonomic input to the parasympathetic system in patients at risk of drug-induced movement disorders. These patients are often given anti-Parkinsonian drugs to combat side-effects that might act synergistically with antipsychotic drugs.
- Dopamine antagonists (elevate the set point of the hypothalamus), neuroleptics, and serotonin agonists interfere with thermoregulation.
- Sympathomimetics and antihistamines, particularly H_1 antagonists, cause vasoconstriction. The reduction in the peripheral blood flow leads to modification in sweat gland activity.
- Sympathomimetics and thyroxine increase metabolic heat production.
- Sedatives, painkillers, and drugs of abuse reduce alertness, judgment, and perception of heat.
- Non-steroidal anti-inflammatory drugs (NSAIDs), ACE inhibitors, angiotensin receptor blockers, sulphonamides, and indinivir reduce renal function; NSAIDs, aspirin, and paracetamol are contraindicated for the treatment of heatstroke.
- Concentrations of lithium and digoxin can increase as a result of dehydration.

High-risk drugs:

- Diuretics
- Anticholinergics
- Neuroleptics

Panel 3: **Recommendations**

Advice supported by scientific evidence:

- Generally, increase fluid intake during periods of hot weather. Elderly individuals should drink water frequently without waiting for thirst, and carers should be alert to the fluid status in individuals who are unable to care for themselves (eg, bedridden patients, children, cognitively impaired individuals).
- Susceptible people should stay in a cool or air-conditioned environment during periods of hot weather. Although, our review of epidemiological evidence supports the benefits of increased time spent in such an environment, individuals might not be able to adequately acclimatise. Wear loose-fitting clothes and take frequent showers or baths.
- Reduce normal activity levels during hot weather. Metabolic heat production varies with fitness level, acclimatisation, age, and body type. People should be aware of the inherent risks of activity during hot weather, and the symptoms of heat exhaustion and heatstroke.
- Patients taking drugs that can potentially impede heat loss should be given preseasonal recommendations by their physicians about how to monitor themselves (eg, regular bodyweight measurements to monitor hydration status).

Advice not well supported by scientific evidence:

- Electric fans should not be used because they increase the rate of dehydration.
- Avoid consumption of alcohol. This advice is probably overemphasised, and should distinguish between moderate consumption of low-alcohol beverages (when evidence does not strongly support a diuretic effect) and spirits, which should be avoided.
- Avoid consumption of even small amounts of coffee, tea, and other caffeinated drinks because of possible diuretic effects.

Panel 4: **Recommendations for further research activities**

- Elderly or infirm individuals with hydration needs that might differ drastically from active, healthy people have been assessed in few studies. Controlled studies are needed to assess how various hydration protocols, including replenishment of sodium and other electrolytes, can mitigate the adverse effects of heat in elderly people.
- Information about how environmental heat affects drug use is largely theoretical. Studies are needed to investigate how fluid status is affected by some common drugs (notably diuretics) and medical conditions (such as diabetes and heart failure).
- Not all psychiatric drugs have similar risks. Also, how much risk is attributable to the drug and how much to the underlying disease might be impossible to assess on the basis of the available evidence. Epidemiological studies of drug use in cases of heat-related mortality, including an assessment of drug compliance, are needed to address these issues.

acclimatisation, exposure to heat is necessary. In healthy individuals, these changes can be obvious within a few days.[79] Habituatation to air-conditioned homes, workplaces, and motor vehicles is speculated to endanger this physiological acclimatisation and perhaps also threaten behavioural adaptation.[8,80] So far, the issue of deacclimatisation by use of air conditioning specifically in relation to elderly individuals does not seem to have been addressed.

Another issue of uncertainty is the use of electric fans as cooling devices. Conflicting arguments are that sweat production in an individual has an evaporative cooling effect in the presence of winds, even at high humidities,[81] but that electric fans are not effective at reducing the risk of heat-associated illness during hot weather because moving air currents must be cooler than body temperature to be helpful.[82] Generally, no significant protective effect has been noted with the use of fans on heat-related mortality in case-control studies done in the USA.[51,52,57,71] Again, little experimental evidence exists about the cooling effects of fans on elderly and other high-risk individuals. Light garments and frequent showers or baths were highly protective during the 2003 heatwave in Paris, France, with a clear exposure-response association between washing infrequently and increased risk of death associated with hot weather.[54]

In hot weather, the advice might be to restrict physical activity, participation in sports, and potentially strenuous tasks such as gardening, or at least to do them during the coolest periods in the day. As little as a 3°C increase in core body temperature can threaten life.[83] Therefore, the risk of heat illness is often compounded by physical activity; and in people who are very active (eg, soldiers in training, athletes) heatstroke might occur at moderate ambient temperatures. Physical activity among elderly people is much higher in summer than in winter.[84]

Prescription and over-the-counter drugs can affect hydration status, electrolyte balance, haemodynamics, thermoregulatory set point, and alertness.[85] Anti-cholinergic drugs can also interfere with sweat production.[86] Heat exposure can affect drug absorption and pharmacokinetics.[87] Although the results of many epidemiological studies show increased heat risk in people with some illnesses (eg, cardiovascular and respiratory problems),[8] drug use specifically has been investigated in few studies. Raised mortality risks have been noted in people taking some drugs (eg, tranquillisers) during heatwaves in the USA and France, although few reached conventional levels of significance.[71,88] To what extent the increased risk is due to drug use and not to the underlying disease being treated is unclear. The few heat-related experimental studies of absorption, metabolism, and elimination of drugs have generally been done with short, intense heat exposures (sometimes in saunas)—conditions that do not replicate an urban heatwave.[87,89]

Evidence and recommendations

Effects of heat on morbidity are generally smaller in magnitude and less consistent than those on mortality, supporting evidence that the effects of heat happen quickly and often before people come to medical attention.[25] Although in most plans for protection against hot weather, this situation is taken into consideration by use of outreach strategies to protect people within the community, the advice given to the general public might not always be based on clear evidence.

Drug use is often cited in the plans as a potential risk factor for heat-related illness, but practical advice for appropriate action or adjustment of treatment regimens is rarely provided to readers, other than to check with their doctor. The extent to which health professionals are informed about how to adjust the doses of drugs for a patient during hot weather is unclear. Panel 2 shows how some drugs might add to the heat burden, and the drug types that might be particularly high risk on the basis of available evidence.

We emphasise that, in many countries, there was a clear pressure to introduce plans after recent deadly heatwaves, and so their development was necessarily rapid. As an increasing number of countries are introducing such plans, we recommend that the contents of these plans should be consistently developed as information about the efficacy of interventions accumulates. On the basis of our findings, we make recommendations to public health practitioners (panel 3) about the commonly promoted methods that we believe are supported by medical evidence, and also those that we feel are not well supported.

Much confusion remains about the use of electric fans during hot weather. Results of most physiological studies support the use of air currents for cooling, but do not specifically address the issue of household fans. Certainly, there is little to recommend the use of a fan when other, effective, methods are available, such as taking a cool shower. In view of the high energy use of air conditioners and massive electric failures during periods of excessive hot weather in North America, clarification of the usefulness of electric fans, and how that varies in different climates would be prudent.

A potentially valuable issue that has been given little attention is the notion of gradual acclimatisation to heat in elderly people to build up their physiological defences. Although advice to stay in an air-conditioned environment is well supported by evidence, avoidance of outdoor temperatures and strenuous exercise might deprive elderly individuals of the opportunity to train their sweat glands.[90] So far, little is known about the extent to which people in their 70s and 80s, and those with chronic medical conditions, can attain such acclimatisation. Advice about activity should draw on experimental evidence available from sports, military, and occupational settings, in which techniques to make activity during hot weather safe have been identified—eg, precooling the body before activity. Panel 4 shows our recommendations for future research activities to inform the further development of protection methods.

Conclusion

With rises in temperatures expected in the coming decades, use of evidence-based health protection during hot weather by the general public and public health practitioners will have a key role in determining future heat burdens.

Contributors

SH and TK conceived the idea for the Review. All authors reviewed the published literature, and MOC did the internet searches. SH and TK wrote the Review, with contributions from MOC.

Conflicts of interest

We declare that we have no conflicts of interest.

Acknowledgments

SH is funded by a Wellcome Trust Research Career Development Fellowship (076583/Z/05/Z); MOC was funded by the Research Institute of the McGill University Health Centre, Montreal, QC, Canada; and TK is funded by the British Columbia Centre for Disease Control, Vancouver, BC, Canada.

References

1 Intergovernmental Panel on Climate Change (IPCC) 2007. Climate change 2007: impacts, adaptation and vulnerability. Working group II contribution to the fourth assessment report of the intergovernmental panel on climate change. Cambridge and New York: Cambridge University Press, 2007.

2 Hajat S, Armstrong B, Baccini M, et al. Impact of high temperatures on mortality: is there an added heat wave effect? *Epidemiology* 2006; **17:** 632–38.

3 Basu R, Samet JM. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiol Rev* 2002; **24:** 190–202.

4 Huq S, Kovats RS, Reid H, Satterthwaite D. Reducing risk to cities from disasters and climate change. *Environ Urban* 2007; **19:** 3–15.

5 Heatwave plan for England 2009. http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_099015 (accessed June 1, 2009).

6 Keatinge WR. Death in heat waves. *BMJ* 2003; **327:** 512–13.

7 Kovats RS, Ebi KL. Heatwaves and public health in Europe. *Eur J Public Health* 2006; **16:** 592–99.

8 Kovats RS, Hajat S. Heat stress and public health: a critical review. *Annu Rev Public Health* 2008; **29:** 41–55.

9 Luber G, McGeehin M. Climate change and extreme heat events. *Am J Prev Med* 2008; **35:** 429–35.

10 Sessler DI. Thermoregulatory defense mechanisms. *Crit Care Med* 2009; **37** (7 suppl): S203–10.

11 Kenney WL, Munce TA. Aging and human temperature regulation. *J Appl Physiol* 2003; **95:** 2598–603.

12 Pandolf KB. Aging and human heat tolerance. *Exp Aging Res* 1997; **23:** 69–105.

13 Donoghue ER, Graham MA, Jentzen JM, Lifschultz BD, Luke JL, Mirchandani HG. Criteria for the diagnosis of heat-related deaths: National Association of Medical Examiners. Position paper. National Association of Medical Examiners Ad Hoc Committee on the Definition of Heat-Related Fatalities. *Am J Forensic Med Pathol* 1997; **18:** 11–14.

14 Kilbourne EM. Heat waves and hot environments. In: Noji E, ed. The public health consequences of disasters. New York: Oxford University Press; 1997: 245–69.

15 Steadman RG. A universal scale of apparent temperature. *J Clin Appl Meteorol* 1984; **23:** 1674–87.

16 Kalkstein LS, Greene JS. An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change. *Environ Health Perspect* 1997; **105:** 84–93.

17 Dear K, Ranmuthugala G, Kjellstrom T, Skinner C, Hanigan I. Effects of temperature and ozone on daily mortality during the August 2003 heat wave in France. *Arch Environ Occup Health* 2005; **60:** 205–12.

18 Ren C, Williams GM, Morawska L, Mengersen K, Tong S. Ozone modifies associations between temperature and cardiovascular mortality: analysis of the NMMAPS data. *Occup Environ Med* 2008; **65:** 255–60.

19 Argaud L, Ferry T, Le QH, et al. Short- and long-term outcomes of heatstroke following the 2003 heat wave in Lyon, France. *Arch Intern Med* 2007; **167:** 2177–83.

20 Kalkstein LS. Health and climate change. Direct impacts in cities. *Lancet* 1993; **342:** 1397–99.

21 Le Tertre A, Lefranc A, Eilstein D, et al. Impact of the 2003 heatwave on all-cause mortality in 9 French cities. *Epidemiology* 2006; **17:** 75–79.

22 Kaiser R, Le Tertre A, Schwartz J, Gotway CA, Daley WR, Rubin CH. The effect of the 1995 heatwave in Chicago on all-cause and cause-specific mortality. *Am J Public Health* 2007; **97** (suppl 1): 158–62.
23 Toulemon L, Barbieri M. The mortality impact of the August 2003 heat wave in France: investigating the 'harvesting' effect and other long-term consequences. *Popul Stud (Camb)* 2008; **62**: 39–53.
24 Hajat S, Armstrong BG, Gouveia N, Wilkinson P. Mortality displacement of heat-related deaths: a comparison of Delhi, Sao Paulo, and London. *Epidemiology* 2005; **16:** 613–20.
25 Kovats RS, Hajat S, Wilkinson P. Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK. *Occup Environ Med* 2004; **61:** 893–98.
26 Linares C, Diaz J. Impact of high temperatures on hospital admissions: comparative analysis with previous studies about mortality (Madrid). *Eur J Public Health* 2008; **18:** 317–22.
27 Michelozzi P, Accetta G, De Sario M, et al. High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. *Am J Respir Crit Care Med* 2009; **179:** 383–89.
28 Semenza JC, McCullough JE, Flanders WD, McGeehin MA, Lumpkin JR. Excess hospital admissions during the July 1995 heat wave in Chicago. *Am J Prev Med* 1999; **16:** 269–77.
29 Schwartz J, Samet JM, Patz JA. Hospital admissions for heart disease: the effects of temperature and humidity. *Epidemiology* 2004; **15:** 755–61.
30 Koken PJ, Piver WT, Ye F, Elixhauser A, Olsen LM, Portier CJ. Temperature, air pollution, and hospitalization for cardiovascular diseases among elderly people in Denver. *Environ Health Perspect* 2003; **111:** 1312–17.
31 Ebi KL, Exuzides KA, Lau E, Kelsh M, Barnston A. Weather changes associated with hospitalizations for cardiovascular diseases and stroke in California, 1983–1998. *Int J Biometeorol* 2004; **49:** 48–58.
32 Knowlton K, Rotkin-Ellman M, King G, et al. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. *Environ Health Perspect* 2009; **117:** 61–67.
33 Nitschke M, Tucker GR, Bi P. Morbidity and mortality during heatwaves in metropolitan Adelaide. *Med J Aust* 2007; **187:** 662–65.
34 Hansen AL, Bi P, Ryan P, Nitschke M, Pisaniello D, Tucker G. The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia. *Int J Epidemiol* 2008; **37:** 1359–65.
35 Hansen A, Bi P, Nitschke M, Ryan P, Pisaniello D, Tucker G. The effect of heat waves on mental health in a temperate Australian city. *Environ Health Perspect* 2008; **116:** 1369–75.
36 Dolney TJ, Sheridan SC. The relationship between extreme heat and ambulance response calls for the city of Toronto, Ontario, Canada. *Environ Res* 2006; **101:** 94–103.
37 Cerutti B, Tereanu C, Domenighetti G, et al. Temperature related mortality and ambulance service interventions during the heat waves of 2003 in Ticino (Switzerland). *Soz Praventivmed* 2006; **51:** 185–93.
38 Leonardi GS, Hajat S, Kovats RS, Smith GE, Cooper D, Gerard E. Syndromic surveillance use to detect the early effects of heat-waves: an analysis of NHS direct data in England. *Soz Praventivmed* 2006; **51:** 194–201.
39 Golden JS, Hartz D, Brazel A, Luber G, Phelan P. A biometeorology study of climate and heat-related morbidity in Phoenix from 2001 to 2006. *Int J Biometeorol* 2008; **52:** 471–80.
40 Claessens YE, Taupin P, Kierzek G, et al. How emergency departments might alert for prehospital heat-related excess mortality? *Crit Care* 2006; **10:** R156.
41 Bassil KL, Cole DC, Moineddin R, et al. Development of a surveillance case definition for heat-related illness using 911 medical dispatch data. *Can J Public Health* 2008; **99:** 339–43.
42 Josseran L, Caillere N, Brun-Ney D, et al. Syndromic surveillance and heat wave morbidity: a pilot study based on emergency departments in France. *BMC Med Inform Decis Mak* 2009; **20:** 9–14.
43 McMichael AJ, Wilkinson P, Kovats RS, Pattenden S, Hajat S, Armstrong B, et al. International study of temperature, heat and urban mortality: the 'ISOTHURM' project. *Int J Epidemiol* 2008; **37:** 1121–31.
44 Baccini M, Biggeri A, Accetta G, et al. Heat effects on mortality in 15 European cities. *Epidemiology* 2008; **19:** 711–19.
45 Smargiassi A, Goldberg MS, Plante C, Fournier M, Baudouin Y, Kosatsky T. Variation of warm season mortality as a function of micro-urban heat islands. *J Epidemiol Community Health* 2009; **63:** 659–64.
46 Rocklov J, Forsberg B, Meister K. Winter mortality modifies the heat-mortality association the following summer. *Eur Respir J* 2009; **33:** 245–51.
47 Stafoggia M, Forastiere F, Michelozzi P, Perucci CA. Summer temperature-related mortality: effect modification by previous winter mortality. *Epidemiology* 2009; **20:** 575–83.
48 Bouchama A, Dehbi M, Mohamed G, Matthies F, Shoukri M, Menne B. Prognostic factors in heat wave related deaths: a meta-analysis. *Arch Intern Med* 2007; **167:** 2170–76.
49 Basu R, Ostro BD. A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California. *Am J Epidemiol* 2008; **168:** 632–37.
50 Schuman SH. Patterns of urban heat-wave deaths and implications for prevention: data from New York and St Louis during July, 1966. *Environ Res* 1972; **5:** 59–75.
51 Semenza JC, Rubin CH, Falter KH, et al. Heat-related deaths during the July 1995 heat wave in Chicago. *N Engl J Med* 1996; **335:** 84–90.
52 Naughton MP, Henderson A, Mirabelli MC, et al. Heat-related mortality during a 1999 heat wave in Chicago. *Am J Prev Med* 2002; **22:** 221–27.
53 Schwartz J. Who is sensitive to extremes of temperature?: A case-only analysis. *Epidemiology* 2005; **16:** 67–72.
54 Vandentorren S, Bretin P, Zeghnoun A, et al. August 2003 heat wave in France: risk factors for death of elderly people living at home. *Eur J Public Health* 2006; **16:** 583–91.
55 Bark N. Deaths of psychiatric patients during heat waves. *Psychiatr Serv* 1998; **49:** 1088–90.
56 Worfolk JB. Heat waves: their impact on the health of elders. *Geriatr Nurs* 2000; **21:** 70–77.
57 Kaiser R, Rubin CH, Henderson AK, et al. Heat-related death and mental illness during the 1999 Cincinnati heat wave. *Am J Forensic Med Pathol* 2001; **22:** 303–07.
58 Jokinen E, Valimaki I, Antila K, Seppanen A, Tuominen J. Children in sauna: cardiovascular adjustment. *Pediatrics* 1990; **86:** 282–88.
59 Martinez BF, Annest JL, Kilbourne EM, Kirk ML, Lui KJ, Smith SM. Geographic distribution of heat-related deaths among elderly persons. Use of county-level dot maps for injury surveillance and epidemiologic research. *JAMA* 1989; **262:** 2246–50.
60 O'Neill MS, Zanobetti A, Schwartz J. Modifiers of the temperature and mortality association in seven US cities. *Am J Epidemiol* 2003; **157:** 1074–82.
61 Michelozzi P, de Donato F, Bisanti L, et al. The impact of the summer 2003 heat waves on mortality in four Italian cities. *Euro Surveill* 2005; **10:** 161–65.
62 Stafoggia M, Forastiere F, Agostini D, et al. Vulnerability to heat-related mortality: a multicity, population-based, case-crossover analysis. *Epidemiology* 2006; **17:** 315–23.
63 Hajat S, Kovats RS, Lachowycz K. Heat-related and cold-related deaths in England and Wales: who is at risk? *Occup Environ Med* 2007; **64:** 93–100.
64 O'Neill MS, Zanobetti A, Schwartz J. Disparities by race in heat-related mortality in four US cities: the role of air conditioning prevalence. *J Urban Health* 2005; **82:** 191–97.
65 Stafoggia M, Forastiere F, Agostini D, et al. Factors affecting in-hospital heat-related mortality: a multi-city case-crossover analysis. *J Epidemiol Community Health* 2008; **62:** 209–15.
66 Hashizume M, Wagatsuma Y, Hayashi T, Saha SK, Streatfield K, Yunus M. The effect of temperature on mortality in rural Bangladesh—a population-based time-series study. *Int J Epidemiol* 2009; published online Jan 30. DOI:10.1093/ije/dyn376.
67 Oke TR. City size and the urban heat island. *Atmos Environ* 1973; **7:** 769–79.
68 Sheridan SC, Dolney TJ. Heat, mortality, and levels of urbanization: measuring vulnerability across Ohio, USA. *Clim Res* 2003; **24:** 255–65.
69 Stookey JD. The diuretic effects of alcohol and caffeine and total water intake misclassification. *Eur J Epidemiol* 1999; **15:** 181–88.

70 Zakhari S. Overview: how is alcohol metabolized by the body? *Alcohol Res Health* 2006; **29:** 245–54.
71 Kilbourne EM, Choi K, Jones TS, Thacker SB. Risk factors for heatstroke. A case-control study. *JAMA* 1982; **247:** 3332–36.
72 Grandjean AC, Reimers KJ, Bannick KE, Haven MC. The effect of caffeinated, non-caffeinated, caloric and non-caloric beverages on hydration. *J Am Coll Nutr* 2000; **19:** 591–600.
73 Johnson SJ. Fluid loss can lead to heat stress, though replenishment offsets effects. *Occup Health Saf* 1993; **62:** 65.
74 Mack GW, Weseman CA, Langhans GW, Scherzer H, Gillen CM, Nadel ER. Body fluid balance in dehydrated healthy older men: thirst and renal osmoregulation. *J Appl Physiol* 1994; **76:** 1615–23.
75 O'Brien KK, Montain SJ, Corr WP, Sawka MN, Knapik JJ, Craig SC. Hyponatremia associated with overhydration in US army trainees. *Mil Med* 2001; **166:** 405–10.
76 Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA. Temperature and mortality in 11 cities of the eastern United States. *Am J Epidemiol* 2002; **155:** 80–87.
77 Kilbourne EM. Heat-related illness: current status of prevention efforts. *Am J Prev Med* 2002; **22:** 328–29.
78 Anderson BG, Bell ML. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. *Epidemiology* 2009; **20:** 205–13.
79 Ellis FP. Heat illness: III. Acclimatization. *Trans R Soc Trop Med Hyg* 1976; **70:** 419–25.
80 Ellis FP. Mortality from heat illness and heat-aggravated illness in the United States. *Environ Res* 1972; **5:** 1–58.
81 Steadman RG. The assessment of sultriness. Parts I and II. *J Appl Meteorol* 1979; **18:** 861–84.
82 Blum LN, Bresolin LB, Williams MA. From the AMA Council on Scientific Affairs. Heat-related illness during extreme weather emergencies. *JAMA* 1998; **279:** 1514.
83 Keim SM, Guisto JA, Sullivan JB. Environmental thermal stress. *Ann Agric Environ Med* 2002; **9:** 1–15.
84 Sumukadas D, Witham M, Struthers A, McMurdo M. Day length and weather conditions profoundly affect physical activity levels in older functionally impaired people. *J Epidemiol Community Health* 2009; **63:** 305–09.
85 Albert C, Proulx R, Richard P. Chaleaur accablante et usage de medicament: etude exploratoire en Estrie. *Bulletin d'Information en Sante Publique du Quebec* 2006; **17:** 5–8.
86 Kwok JS, Chan TY. Recurrent heat-related illnesses during antipsychotic treatment. *Ann Pharmacother* 2005; **39:** 1940–42.
87 Vanakoski J, Seppala T. Heat exposure and drugs. A review of the effects of hyperthermia on pharmacokinetics. *Clin Pharmacokinet* 1998; **34:** 311–22.
88 Ledrans M, Pirard P, Tillaut H, et al. The heat wave of August 2003: what happened? *Rev Prat* 2004; **54:** 1289–97.
89 Kukkonen-Harjula K, Kauppinen K. Health effects and risks of sauna bathing. *Int J Circumpolar Health* 2006; **65:** 195–205.
90 Stoops JL. A possible connection between thermal comfort and health. 2004. Lawrence Berkeley National Laboratory. http://escholarship.org/uc/item/9j03d7kq (accessed March 1, 2009).