ABSTRACT

In Finland, mortality increases steeply in autumn, reaches a peak during the Christmas holidays and declines slowly towards a trough in August. The relative excess in daily mortality (peak vs. trough) is 30% for coronary heart disease, 40% for cerebral vascular accidents and 90% for diseases of the respiratory organs. There is a secondary peak in Midsummer, especially in coronary deaths of working aged men. Mortality is lowest at mean daily temperature of +14°C, and it increases slowly with falling temperature and steeply with increasing temperature. An estimated 2000-3000 extra deaths occur in Finland during the cold season, most of which are people aged 65 years and over but 20% at working age. The number of people dying from high temperatures (over +14°C) in this country in a normal year is 100-200. Heat deaths are mostly certified as being due to cardiovascular or respiratory conditions. Exposure to cold air causes a rise in blood pressure and haemoconcentration which lead to increased tendency to vascular thromboses. In hot weather, haemoconcentration due to sweating and perspiration increases blood viscosity and the risk of thrombosis. Both cold and heat are significant public health hazards which should be taken into account in health care and education of health professionals.  

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INTRODUCTION

The increase in the number of deaths during the cold season of the year was first noted in the 1700’s (1) and a similar increase in cardiovascular mortality was noted in the 1800’s (2). A number of studies were devoted to this issue in the early part of the 1900’s (3). It was usually explained by an increase in respiratory infections common in winter resulting in an extra load on the heart, with an increased cardiovascular mortality, but a direct effect of cold was also entertained as a possible explanation. The availability of daily series of deaths in large population samples since the 1970’s has improved the efficacy of studies, and today, the natural history of cold-related mortality is known reasonably well, although significant questions remain (4). The lack of individual-based data on cold exposure integrated with population data has remained a major difficulty, and interactions between the effects of cold and air pollution present a further problem. Time series studies performed since the 1970’s have also shown that warm weather, not only heat waves, increase mortality from most major causes (5). Despite indisputable evidence on the effects of extreme temperatures on mortality, fewer studies have been devoted to this than to the effects of air pollution.

Physiological responses to environmental temperature changes

Cold causes constriction of skin vessels, thus reducing heat loss, but at the same time, blood pressure will increase and approximately one litre of blood plasma is shifted from skin and legs to central body parts. The extra fluid is removed in urine and part of it is shifted to the extracellular space, which leads to haemodynamic changes. The concentration of red and white blood cells, platelets, cholesterol and fibrinogen and blood viscosity are increased (6-8). On the other hand, the small-molecule protein C, which is an anticoagulant, is shifted to the extracellular space through capillary walls. A rupture of an atherosclerotic plaque in conjunction of a sudden rise of blood pressure or vascular spasm may cause a thrombus (9). During cold exposure, an increase of blood pressure may cause oxygen deficiency in the cardiac muscle, as well as arrhythmias, which may also arise by a reflex mechanism (10). Blood pressure will increase especially in cold-sensitive individuals (11). Even a short-term cold exposure causes a mild systemic inflammatory reaction, which increases thrombotic factors (12). It has been suggested that the reduced intake of vitamin C in winter could increase the acute phase reaction in respiratory infections and thereby increase the risk of thrombosis (13). The immediate increase of deaths after a decrease in temperature could be explained by reflex mechanisms and the changes in blood pressure, and the subsequent increase of deaths 2-3 days later by increased risk of thrombosis. Changes in blood pressure and haematological variables sufficient to cause increased mortality have been observed not only in cold exposure experiments (6) but also in people living normal conditions (7).

As is well known, respiratory infections increase in the cold season and are associated with a sharp increase in mortality which peaks 10-12 days after the decrease in temperature and can last several weeks (14). The underlying mechanisms have remained unclear. Breathing of warm air just before the infection begins will alleviate its course (15). Breathing of cold air may cause a bronchospasm, and
increased numbers of inflammatory cells have been observed during cold exposure (16). The concentration of fibrinogen increases in respiratory infections; this may explain in part why coronary and stroke mortality remains high even after the peak mortality, 2-3 days after the cold exposure.

In hot weather, the heat balance of the body is sustained by enlarging skin vessels and increased sweating which in turn increases the cardiac work and loss of fluid and salt. This leads to haemoconcentration, increased blood viscosity and the risk of thrombosis. In people with congestive heart failure, the extra heat load may lead to fatal consequences (17). Patients unable to sweat due to diabetic neuropathy or use of anticholinergic drugs, are at risk (18). Excessive alcohol consumption during a hot spell will increase dehydration.

**Season and mortality in the north**

In Finland, natural mortality is lowest in mid-August, increases steeply during autumn to reach a peak around Christmas and then falls slowly during the spring (Fig. 1). In the 1930's, mortality was highest in early spring but subsequently, deaths have shifted backwards in calendar, towards the coldest time of the year, perhaps due to more people suffering from milder conditions now surviving, leaving only severe cases to die soon after the coldest time (19). An estimated 2000-3000 extra deaths occur in Finland during the cold season, most which are people aged 65 years and over but approximately 20% at working age. This winter excess mortality is much higher than, for example, mortality from traffic accidents (400 cases a year).

Approximately one third of the excess winter mortality is attributable to coronary heart disease, one fifth to cerebral vascular stroke and one fifth to respiratory causes. The seasonal patterns in various diseases are similar but the amplitude of variation differs. Thus the highest daily mortality from respiratory diseases is 90% higher than the lowest daily respiratory mortality, the respective daily mortality differences being 30% and 40% for coronary heart disease and cerebral vascular accidents respectively.

Deaths from coronary heart disease also increase in June, due to an increase of deaths on Midsummer Day, one day after a similar peak is found in fatal alcohol poisonings. Other indirect effects of temperature include snow shoveling deaths (20). In addition to cold exposure, several other factors during snow shoveling can precipitate acute myocardial infarction or death (21). These include working with arms which especially is known to produce cardiac ischaemia, the upright posture with static legs which causes pooling of blood in the lower extremities, and expiratory strain during strenous lifting.
which causes rapid loading and unloading the cardiac muscle. The rapid rise in cardiac mortality in autumn, compared with the much slower decline in spring, could be attributed to a time lag elapsing while people adopt their behaviour to cold weather.

**Environmental temperatures and daily deaths**

The association of environmental temperature with daily deaths was examined as early as in the 1930’s (22). In the 1970’s, a British study reported that a decline in temperature lasting some days was followed by an increase in coronary heart disease mortality after 1-2 days, the lag being 3-4 days for an increase in cerebral vascular accidents and more than 5 days for the increase in mortality from respiratory diseases (23). A temperature decline lasting two days was enough to cause such an increase in mortality. A more comprehensive picture on the association of temperature and deaths is obtained by a study of entire weather spells instead of individual days. A cold spell lasting 4 weeks in England was followed by a rise in mortality peaking 3 days after the coldest day (14).

The association of air temperature and mortality is U-shaped. On the colder side of the optimal temperature, mortality increases slowly with declining temperatures, and on the warmer side it increases steeply with rising temperatures. In cold countries such as Finland, mortality is lowest at +14°C but in the Mediterranean countries at +22-25°C (24, 25) (Fig. 2). In countries with mild and warm climate the increase of mortality starts at temperatures as high as +20°C and is larger than in colder countries. According

![Figure 2. Daily mortality of people aged 65.74 in relation to mean daily temperatures in regions with the coldest, median, and warmest summer temperatures (May to August). The gray squares indicate the 3°C band of minimum mortality for the region (calculated at 0.1°C intervals) and the horizontal lines show mortality in this band. (Figure modified from Keatinge et al. 2000, ref. 25).](image-url)
to the Eurowinter study, mortality of people aged 50-74 years in Athens started to increase at temperatures below +23°C, by 2 % per 1°C decline in temperature. In London mortality increased by 1.4% / °C decline below optimum, but only 0.3% / °C in Finland (24). In Yakutsk, Siberia, in the coldest region of the world, there is no increase in mortality even at temperatures of -48°C (26).

Air pollution and temperature
The terminal phases of cold spells often coincide with high contents of sulfur dioxide in the air, which makes any assessment of separate effects of cold and pollution difficult. Thus during the period 1976-1995 in London, not only were the polluted episodes colder than average but were preceded by longer than average cold spells (27). When allowance was made for this abnormal weather pattern, there was no effect of SO$_2$ or CO on mortality, just a marginal effect of smoke which the authors believed could reflect the effect of the particulate composition of the atmosphere (PM$_{10}$). This actually questions previous studies on pollution and mortality which have looked at individual days, not entire weather patterns, and have not taken into account the complex multicollinearity of the variables used in their analyses.

Cold protection
In cold countries, people have adapted their behaviour to cold, critical body parts are protected by clothing, and there is effective house heating. Probably, people suffering from heart disease avoid staying outdoors during the coldest weather because cold aggravates cardiac symptoms.

Marked differences exist in the level of cold protection between countries. People living in the south do not recognize cold as a health hazard the way people do in the north. At outdoor temperatures around zero °C or below, the indoor temperature in Finnish homes stays at +20°C or over, while in Greece, for example, homes cool down by several degrees. While being outdoors, the vast majority of Finns but a minority of people in the Netherlands, London or North Italy uses hat and gloves. While outdoors at +7°C few Finns stand stationary but half of people in Greece and Italy do so (24, 28). Consequently, 20-33% of the Greek and Italians report shivering at this temperature but only 5% of Finns.

Clothing is associated with variations of mortality between countries. In the Eurowinter study, high mortality during cold spells was linked with low proportions of people wearing hats, gloves and scarves, all clothing items protecting peripheral body parts (28). Coronary heart disease mortality was relatively high in regions where women preferred to wear skirt while outdoors in cold weather (24, 28). Available studies suggest that appropriate information and advice given by mass media can reduce cold-related mortality (29).

Hypothermia and mortality
Among the general public, cold deaths are usually felt to be deaths from hypothermia which, however, are rare. In the 1990’s, there were approximately 70 such cases annually in Finland which is not more than 0.15 % of annual deaths. The number of cases has increased since the 1960’s when only 20 cases were recorded annually. Not surprisingly, most cases occur in winter, but a few occur in
summer. Mortality from hypothermia increases significantly with temperatures sinking below +5°C. A majority of deaths in this circumstance are attributable to an underlying disease which causes the fatal event (30). Paradoxically, the association of declining temperature with deaths from hypothermia is weakest in the coldest area, northern Finland.

The effect of warm weather and heat waves
Heat causes an increase in mortality even in countries where heat is not recognized as hazardous. Especially in cold regions, the effect of heat on mortality begins at relatively low temperatures and the effect on increasing mortality is greater than in warm areas. In Finland, the increase of deaths starts at +14°C, and marked excess mortality is seen with mean daily temperature staying at +20°C for 1-2 weeks (19). In the Mediterranean countries mortality does not increase until above +25°C and in Taiwan only above +32°C (31). In Finland, mortality increases steeply with rising temperature (3% increase in mortality for each °C) but as the number of hot days in a normal year is small, heat has less significance than cold on mortality.

However, the number of deaths caused by heat waves in Finland is significant. During the heat wave of 1972, for example, an estimated 800 people died as a consequence of heat (19). The extra deaths are certified as being due to most major causes, such as coronary heart disease, cerebral vascular accidents and respiratory diseases. Mortality similarly increased during later, somewhat milder heat waves in 1973, 1978, 1988, 1995 and 1997. The heat-related mortality has decreased over the years, but during the 1990’s in Finland there were still 100-200 extra deaths related to temperatures higher than +14°C. This is not more than 0.2-0.4% of all annual deaths; the percentage was 1.5-2.0% in the 1970’s. This paradoxical decline in heat mortality with warming climate has been attributed to more widespread use of air conditioning and increased prosperity which is supposed to offer better opportunities for avoiding heat stress. The total burden of heat mortality is also reduced by physiological and other adjustments which will cause the threshold temperature for increasing mortality to increase by 1-3°C, thus reducing the number of hazardous days in the year (32). It is therefore expected that the warming climate will not cause dramatic increases in mortality in the near future. Cold spells or influenza epidemics which may have proven fatal for frail individuals in the preceding year, may spuriously decrease the effect of heat waves.

Prevention of mortality from extreme temperatures
In cold regions people protect themselves against cold effectively. Protection of peripheral body parts by clothing prevents vasoconstriction caused by cold exposure (28). Those who live in the arctic know that one has to keep moving while in cold. Paradoxically, winter is less dangerous to people living in the north than to those living in the south. Hypothermia is not a significant factor in overall mortality. Heat mortality can be prevented by provision of adequate fluid supply, especially among the elderly. The mechanisms underlying mortality during extreme temperatures need more research but even now a reduction of cold exposure by interventions will yield significant public health gains. The global warming
will reduce the excess winter mortality in the arctic, mainly due to reduction of cardiovascular and respiratory deaths, assuming that the standards of cold protection, including individual behavioral factors, are followed.

Conclusions

Environmental temperature is closely associated with population mortality. Optimum temperature with the lowest population mortality, differs between warm and cold regions, with increases in mortality when the temperature rises, or falls.

Factors involved with increased mortality include increasing rates of myocardial infarction, stroke, respiratory disease and infection.

Physiologic mechanisms include intravascular fluid shifts, reflex blood pressure changes, and changes in blood viscosity, thrombotic activity, and inflammatory factors.

The interaction of air pollution with temperature related mortality is poorly defined, and needs further research.

Public health advice regarding protective and adaptive measures during cold and hot spells could significantly decrease the impact of environmental temperature on morbidity and mortality.

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Simo Näyhä, M.D., Professor
Department of Public Health Science and General Practice
University of Oulu
P.O. BOX 5000
FIN- 90014 University of Oulu
Finland
Email: simo.nayha@oulu.fi