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IMPACTS OF COLD CLIMATE ON HUMAN HEAT BALANCE, PERFORMANCE AND HEALTH IN CIRCUMPOLAR AREAS

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ABSTRACT

In circumpolar areas the climate remains cool or thermoneutral during the majority of the days of the year spite of global warming. Therefore, health consequences related to cold exposure represent also in the future the majority of climate-related adverse health effects. Hot summers may be an exception. At ambient temperatures below +10 – +12°C, humans experience cold stress of varying degree. Man can compensate a 10°C change in ambient temperature by changing metabolic heat production by 30-40 W m⁻² or by wearing an additional/taking off ca. 0.4 clo units (corresponding to one thick clothing layer). Cold ambient temperature may be a risk for human health and cause varying levels of performance limitations. The impacts of cold exposure on health and wellbeing cause a burden to many societies in terms of lowered productivity and higher costs related to health care systems as well as public health planning and management. In order to provide preventive and protective public health actions for cold-induced adverse health effects, it is important to recognize cold related injuries, illnesses and symptoms and their turn-up temperatures, and to identify the most at-risk population subgroups and factors that increase or decrease the health risks posed by cold ambient temperatures. The majority of cold-related harmful health impacts can be prevented or managed by correct preventive and protective actions. Rapid unpredictable changes are more difficult to compensate because of lack of experience (affecting attitude and skills), preparedness (vehicles, garments, supplies, logistics etc.) and/or acclimatization. (*Int J Circumpolar Health* 2005;64(5):459-467.)

Keywords: thermal environment, heat balance, cardiovascular responses, immune responses, hormonal responses, cold injury, cold-related illnesses, symptoms, prevention

INTRODUCTION

There is scientific consensus that global warming is particularly evident in the circumpolar north. Climate change during the 21st century is predicted to be rapid and large. A special feature of this change is the variability of future climate and the occurrence of extreme conditions. These include anomalously high and low temperatures, precipitation and wind speeds. Even in the circumstances of climate warming, extreme cold spells will be present in the future and would cause damage. Based on the predicted increase in environmental temperature during the coming 50 years, health consequences related to exposure to cold in circumpolar areas remain common and represent the majority of climate-related adverse health effects.

Seasonal changes in human health are remarkable and have been recognized for more than 2000 years (1). Special attention has in recent decades been given to excess winter mortality in Europe (2, 3). Deaths by cold weather are epidemiologically quantified (4). Figures based on monthly, rather than daily, statistics underestimate problems related to cold climate (5). Excess winter morbidity is well known, but the association with climatic cold has been controversial. Some recent studies have reported other health problems than mortality related to cold weather (6, 7).

There are great individual differences in the ability to cope with stressful thermal environments. In general, small children, the elderly, individuals with health problems and those with poor physical fitness or those who are poorly prepared have higher risk of deleterious effects of high or low temperatures. Furthermore, an increased risk to adverse health effects of cold

climate is present in subjects having chronic obstructive pulmonary disease, respiratory asthma, conjunctivitis or allergic rhinitis, earlier frostbite, diabetes, hypertension, coronary heart disease, chronic neurological diseases, Raynaud's phenomenon, cold urticaria, history of hand vibration or current smoking.

Little attention has been given to public health actions to prevent the negative health impacts of cold climate (8). In evaluating the need for preventive and protective public health actions, it is important to recognize the effects of cold stress, cold-related health and performance limitations, illnesses, injuries, as well as the excess mortality related to cold climates.

This paper focuses on cold-induced injuries, illnesses (excluding infections), physiological cold stress and cold-related performance limitations.

HEAT BALANCE, PERFORMANCE AND HEALTH IN THERMAL ENVIRONMENTS

Maintenance of body heat balance in thermal environments

Human body heat balance depends on thermal environment (air temperature, air moisture, air velocity and radiative heat gain), thermal insulation of clothing and the rate of physical work producing heat. In the thermoneutral zone (width ca. 4°C), body heat balance is adjusted by changes in circulation in the skin, arms and legs. In temperatures above the thermoneutral zone, heat loss is increased by sweating, and below the zone, heat production is increased by muscular work or by shivering. Criteria for thermal strain are presented in Table I.

Table 1. Approximate thermal strain criteria for some physiological parameters (45).

	Comfort	Discomfort	Performance degradation	Tolerance	Health effect
Mean skin temperature (°C)	33	<31 >35	30 36	25	<15 >45
Finger temperature (°C)	27-34	<20	<15	5	-2<<15
Toe temperature (°C)	27-34	<17	<13	5	-2<<15
Rectal temperature (°C)	37	38	<36.0* >38.2	<35 standing >38.0 work 2 h 38.8	28 41-42
Body heat loss (J g ⁻¹)	0	4	6	12	20

* performance can decrease even without any decrease in rectal temperature

Cold-induced vasoconstriction in the skin, arms and legs decreases thermal conductance and heat loss of the superficial and peripheral parts of the body. In winter, exposure to cold increases systolic and diastolic blood pressure by 20-40 mmHg in young subjects. Plasma volume decreases by 3-7% and blood viscosity increases. Whole body cooling increases the heart rate, while facial cooling decreases it.

The net increase in daily energy expenditure has been shown to increase by 105 - 156 kJ when ambient temperature decreases 1°C

(9-11). Below the thermoneutral zone a 1°C change in ambient temperature corresponds to 5.5 - 8.0 W m⁻² in metabolic rate when clothing insulation is 1 - 2 clo (Fig. 1), and a 1°C change in temperature corresponds to a 0.1 clo change at rest and 0.03 clo in heavy work.

Thyroid hormones regulate the level of metabolic activity. Short exposure to cold does not affect thyroid hormones, but in winter serum total T3 and free T3 levels as well as TSH secretion increase (12, 13). Cortisol and aldosterone levels increase both during acute and long-term severe exposure to cold, together with an increase in ACTH. However, during typical wintertime cold exposure these hormones are not affected. The plasma noradrenaline level increases during acute exposure to cold. Noradrenaline also increases in winter in hypertensive patients. On the contrary, the adrenaline level does not increase in cold. Cold exposure does not seem to depress immune functions (14).

Both psychological and physiological (whole body and local) acclimatization develops when the thermal environment changes. Full acclimatization can take 10 days. In cold, the usual signs of acclimatization are blunted responses in heart rate, blood pressure and heat production (shivering). The cold-induced vasoconstriction in hands is

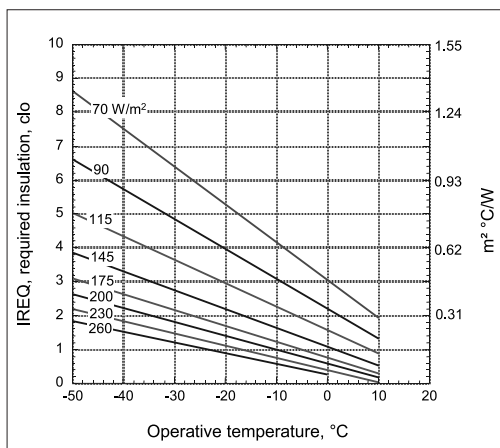


Figure 1. $IREQ_{min}$ as function of ambient operative temperature at eight levels of metabolic heat production. The operative temperature is the integrated value of the air temperature and mean radiant temperature weighted according to values of the convective and radiation heat transfer coefficients, respectively. $IREQ_{min}$ shows the amount of clothing to ensure thermal balance with low thermal strain (thermal sensation "slightly cool") (46).

also attenuated in acclimatized subjects. Heat acclimatization increases the sweating rate, and sweating also starts earlier.

Injuries in cold

Cooling injuries are linked to body cooling, but unintentional main injuries are associated with a more complex relationship with environmental cold. The rate of slip and fall injuries, for example, has been shown to increase with decreasing temperatures. Increasing rates of these injuries are seen at 0°C and colder environmental temperatures (15). Cold environment is often a contributing cause of injury, and perhaps not recorded in statistics.

Hypothermia

Hypothermia is defined as deep body temperature below 35°C. Hypothermia is often caused by cold-water immersion, or after immersion by thoroughly wet clothing. Hypothermia can also develop in cold air. The factors increasing the risk are moisture, wind and insufficient thermal insulation due to inadequate or wet clothing. Hypothermia develops very rarely in healthy active subjects in cold air; the risk of hypothermia is increased in sedentary subjects or in subjects lying on the ground: heat production is minimal and conductive heat loss to the ground large. Groups at risk include people abusing narcotics or alcohol and patients using drugs that affect the central nervous system and behaviour. Accidental hypothermia is known to be a hazard to elderly people in temperate and cold climates (16). The typical victim of outdoor hypothermic death in Finland is an elderly person forgetting his/her way back home when walking in cold weather. Hypothermic deaths are also seen as a special consequence of unsatisfactory dwellings: body

cooling develops so slowly that the thermal sensations do not give any warning signals.

Frostbite

Frostbite is a common cold injury in the average circumpolar population. Frostbites are most usual among young people working or staying continuously in cold environments. Repetitive frostbites in the same individuals are common. The treatment of severe frostbites is difficult and requires a long hospital treatment period. Complications related to frostbites are common and can lead to persistent function limitations and disability.

The annual average incidence of hospital-treated frostbite is 2.5/100 000 persons in Finland (17). According to the FINRISK 2002 questionnaire survey, the annual incidence of self-reported blister severity frostbite is 0.9% among the Finnish population (men = 1.4%, women = 0.4%). Among teenagers the annual self-reported incidence of frostbite in northern Finland is 4.1% in boys and 2.4% in girls. Lifetime experience of frostbite by men entering military service is 44% in all severity classes and 12% in blister-grade or more severe classes (7). Late symptoms of hand frostbite are common, present on average in 60% of the

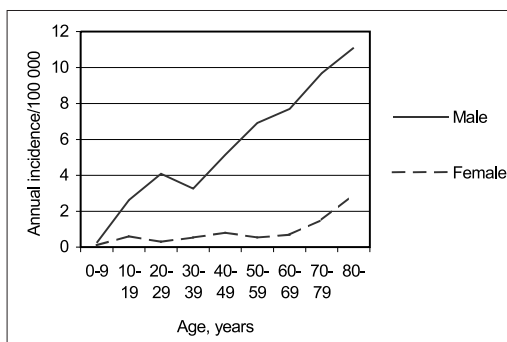


Figure 2. Average annual incidence of hospital-treated frostbite per 100 000 inhabitants by age and sex (17). Permission to reproduce the illustration from Int J Circumpolar Health.

cases (18). In Finland, the annual incidence of hospital-treated frostbite increases almost linearly with age, and the incidence is higher in northern than in southern Finland (17) (Fig. 2).

Individual risk factors of frostbite are Raynaud's phenomenon, i.e. periodical attacks of white fingers, hand vibration and smoking (7). Fatigue, low physical activity, dehydration and use of alcohol (19) increase the risk of frostbite. Appropriate winter clothing protects from frostbites. Wind-proof and dry clothing should be preferred. Travelling in an open vehicle or not wearing a hat with earlaps or a scarf and the use of facial ointment were independent risk factors for developing face and ear frostbite (20). Exercise leading to exhaustion should be avoided during periods of inactivity. Heat loss should be minimized by additional thermal insulation of clothing or by using shelters. Extra metabolic heat production by increased muscular work is an effective protection tool against frostbite. Adequate nutrition and hydration protects against frostbites. Use of ointments or washing the face with strong detergents is not recommended prior to cold exposure. Frostbites related to contact cooling may be prevented by insulating contact surfaces. Smoking should be avoided before and during cold exposure. All individuals should be aware of the early signs of frostbite and be educated on how to protect themselves.

Unintentional injury

Unintentional injuries occur least frequently at a temperature of about +20°C and increase at lower and higher ambient temperatures (21). Unintentional main injuries are associated with a more complex relationship with environmental cold (Fig. 3).

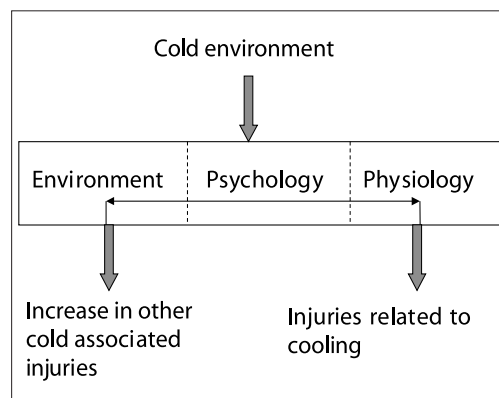


Figure 3. Associations between environmental cold and unintentional injuries.

The injury rate may change as a consequence of the direct or indirect effects of cold exposure. Causal relationships between different injury sources and accident types, the nature of the injury and the degree of disability sustained from the injury may have different pathways. The majority of occupational outdoor cold exposure injuries occur during the few coldest winter days in USA. Wind speed strongly increases the injury rate. Freezing, strains and sprains are commonly represented among the cold exposure injuries. Cold exposure injuries have a strong negative relationship with temperature (22). Occupational slips and falls exhibit a similar negative correlation with temperature. The higher rates were linked to temperatures of 0°C or colder in the US mining industry (15). Unintentional injuries occur less frequently at a temperature of about +20°C and increase at lower and higher ambient temperatures (21). Cold environmental temperature is usually a contributing factor in cases of injury. Cold exposure injuries are repeated with much higher frequencies in questionnaire studies than in records, which tend to underestimate this type of injury.

Cold-related illnesses and symptoms

Many types of diseases including cardiovascular diseases, respiratory diseases, diseases in peripheral circulation, musculoskeletal diseases and skin diseases are affected by cold exposure. Symptoms induced by cold temperatures are diverse and they originate from various organs of the human body (23). The rate of cooling in different sites of the body during cold exposure may also be intensified by the pathophysiological functions associated with these symptoms. The responses to cold and symptoms associated with cold exposure depend on several factors, including the type and duration of cold exposure (2, 24) and the biological, physiological, behavioural, health and medical characteristics of the individual (25).

Exposure to cold temperatures causes additional problems for those suffering from

cardiovascular diseases (26-28), musculoskeletal and peripheral nervous systems disorders, Raynaud's phenomenon (29, 30) and various skin diseases (31). Cold environmental temperatures also aggravate respiratory symptoms and increase the susceptibility to respiratory infections in individuals suffering from asthma and chronic obstructive pulmonary disease (COPD) (32, 33). Cold exposure may also increase perceived symptoms of those diseases and may worsen their clinical development.

Prevalence of cold-induced symptoms is relatively high among the adult population in Finland (34). Approximately half of population reported cold-induced symptoms during the winter 2002. Women are more susceptible to symptoms than men. The most common symptoms are shortness of breath, increased extraction of mucus from the lungs, extended cough or cough attacks and white fingers. The occurrence of cardiac symptoms is rather rare. Multiple symptoms in the same individuals were common. The occurrence of symptoms increases among those with a pre-existing chronic disease.

The median of the self-reported turn-up temperatures of the cold-related symptoms is -15°C in Finland (34). The temperature range in which the symptoms start to appear varies between the main symptom categories (Fig. 4). When the temperature falls, cardiovascular symptoms are the first to appear, followed by respiratory symptoms, white fingers, peripheral circular and musculoskeletal symptoms. Finally, outdoor activity becomes difficult or even restricted in extreme cold (below -25°C) due to increased symptoms and other complaints.

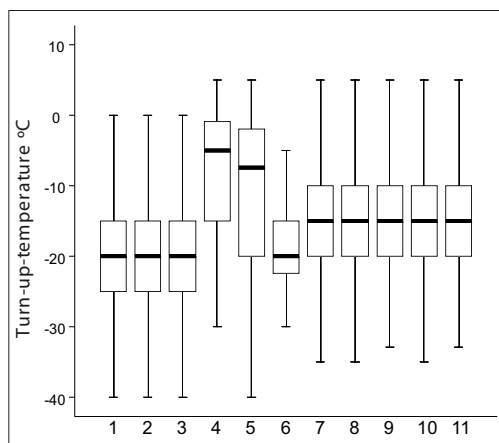


Figure 4. The turn-up-temperatures of selected cold-induced symptoms among working-age population in Finland (34). 1 = shortness of breath, $n=820$; 2 = Extended coughing, $n=545$; 3 = Wheezing of breath, $n=323$; 4 = Increased extraction of mucus from the lungs, $n=610$; 5 = Chest pain, $n=126$; 6 = Cardiac arrhythmia, $n=43$; 7 = Circulation disturbances in hands or feet episodic, $n=531$; 8 = White fingers, $n=564$; 9 = Pain in head, neck and shoulders, $n=481$; 10 = Finger pain, $n=839$; 11 = Pain in foot or ankle, $n=529$.

Respiratory effects of cold weather

Respiratory responses in cold are reviewed in short, excluding mortality and communicable diseases.

Exercise and cold weather may provoke respiratory symptoms and pulmonary obstruction; these findings may be used as a diagnostic tool particularly in asthma (35). Respiratory symptoms increase in cold weather, especially with age, smoking, atopy or obstructive pulmonary conditions. In northern Finland 47% – 78% of adult asthmatics reported shortness of breath in cold weather, while the corresponding figures for healthy adults were 3% – 13% (36). Current smokers reported respiratory symptoms 1.5 – 2 times more often than non-smokers (6).

Respiratory symptoms and pulmonary obstruction provoked by cold may lead to decline in working capacity in cold. Although short-term exercise in the cold did not affect respiratory capacity in healthy persons (37, 38), a decrease in lung function occurred after a marathon run in cold weather (39). Patients with chronic obstructive pulmonary disease had 9% lower maximal oxygen uptake in -20°C than in normal room temperature (40). A similar finding was reported after a speed skating competition (41). Thus, in subjects with obstructive respiratory conditions, worsening of symptoms and obstruction in cold weather leads to decline in working capacity and in extreme conditions this may occur in healthy persons as well.

Spirometry results from the general population in Finland reveal higher values than pan-European reference values (42-44).

This may reflect an adaptation to cold environment: a population living in cold climate may have larger lung volumes.

Clothing may give effective protection against many harmful effects of cold weather, but it does not protect the respiratory system. Adequate regular treatment for respiratory disease may help to minimize cold-induced breathing problems, but persons with known susceptibility to cold should avoid extreme conditions. Respiratory limitations in cold should be taken into account individually in tasks where working or staying in cold weather is essential.

RECOMMENDATIONS

Research has in recent years focused on a variety of harmful health impacts of cold exposure in everyday life in circumpolar areas. More research is needed to study these impacts in more detail at the level where their results can effectively be used in everyday self and health care. Active development of models for health care against harmful impacts of the cold should be generated.

Governments and local authorities should provide information practices for extreme cold periods aimed especially at risk groups. Collaboration between weather broadcasting and health specialists offers one useful path for new practices. Vocational education of health care personnel and basic information for pupils in comprehensive schools is needed. Southern visitors should be informed and trained at the beginning of their experience of winter wilderness or other type of outdoor recreation.

Effective protection from cold weather and regular treatment for chronic respiratory disease and other chronic diseases sensitive to cold exposure may help minimize the majority of health problems in the cold, but persons with known susceptibility to cold should avoid extreme conditions. Health limitations in the cold should be individually taken into account in tasks where working or staying in cold weather is essential.

Appropriate winter clothing protects against the harmful health impacts of cold exposure. Windproof and dry clothing should be preferred; wearing a hat with earlaps or a scarf is also (20). Extra metabolic heat production by increased muscular work, adequate nutrition and hydration are effective protection tools against cooling and associated cold impacts. Clothing does not protect the respiratory system from the harmful effects of cold weather. Increased muscular work in cold exposure may exacerbate the harmful respiratory responses of cold exposure.

Smoking should be avoided before and during cold exposure. All individuals should be aware of the early signs of frostbite and be educated on how to protect themselves. Correct behaviour, including using available shelters, is on the whole the cornerstone for living and working in cold circumpolar environments.

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