

1998:18

Problems with cold work

Proceedings from an international symposium
held in Stockholm, Sweden, Grand Hôtel Saltsjöbaden,
November 16–20, 1997

Editors:

Ingvar Holmér

Kalev Kuklane

ARBETE OCH HÄLSA VETENSKAPLIG SKRIFTSERIE

ISBN 91-7045-483-3 ISSN 0346-7821 <http://www.niwl.se/ah/>



Arbetslivsinstitutet
National Institute for Working Life

National Institute for Working Life

The National Institute for Working Life is Sweden's center for research and development on labour market, working life and work environment. Diffusion of information, training and teaching, local development and international collaboration are other important issues for the Institute.

The R&D competence will be found in the following areas: Labour market and labour legislation, work organization and production technology, psychosocial working conditions, occupational medicine, allergy, effects on the nervous system, ergonomics, work environment technology and musculoskeletal disorders, chemical hazards and toxicology.

A total of about 470 people work at the Institute, around 370 with research and development. The Institute's staff includes 32 professors and in total 122 persons with a postdoctoral degree.

The National Institute for Working Life has a large international collaboration in R&D, including a number of projects within the EC Framework Programme for Research and Technology Development.

ARBETE OCH HÄLSA

Redaktör: Anders Kjellberg
Redaktionskommitté: Anders Colmsjö
och Ewa Wigaeus Hjelm

© Arbetslivsinstitutet & författarna 1998
Arbetslivsinstitutet,
171 84 Solna, Sverige

ISBN 91-7045-483-3
ISSN 0346-7821
<http://www.niwl.se/ah/>
Tryckt hos CM Gruppen

Foreword

In many countries the cold season of the year comprises climatic conditions well below normal indoor temperatures. Throughout the world the processing and storage of alimentary products require low temperatures, usually at 2 to 10 °C for fresh food and below -25 °C for frozen food. Cold is a hazard to health and represents a risk of getting cold injuries. Cold interferes with work and may impair performance and productivity. The long-term effects of years of exposure to cold as well as the health effects of living and working in cold climates are not readily understood.

The symposium dealt with the problems encountered by people exposed to cold either naturally or in artificial environments.

The symposium was the result of work of many persons. The international program committee and the national organising committee are acknowledged for their contributions, suggestions and work.

Financial support has been given by the National Institute for Working Life, the Council for Work Life Research, the National Board of Health and Welfare, Taiga AB, Triconor and Arbesko.

Solna in September 1998

Ingvar Holmér

First international symposium on

Problems with cold work

organised by
National Institute for Working Life
Solna, Sweden

in co-operation with
National Institute of Occupational Safety and Health, Cincinnati, USA
National Institute of Occupational Health, Moscow, Russia
National Institute of Public Health, Tokyo, Japan

under the auspices of
International Labour Organisation
International Commission on Occupational Health
International Union of Circumpolar Health

International programme committee

Ingvar Holmér, Sweden	Rallema Afanasieva, Russia
George Conway, USA	Barbara Griefahn, Germany
Murray Hamlet, USA	Juhani Hassi, Finland
George Havenith, Netherlands	Bengt W Johansson, Sweden
Desmond Lugg, Australia	Ruth Nielsen, Denmark
Ken Parsons, United Kingdom	Arvid Påsche, Norway
Peter Tikuisis, Canada	Yutaka Tochihara, Japan

National organising committee

Ingvar Holmér, John Abeysekera, Ulf Bergh, Ulf Björnstig, Christina Ekeberg,
Staffan Gyllerup, Anders Kjellberg, Hans Lundgren, Ronnie Lundström..

representing

National Institute for Working Life, Defence Research Establishment, ColdTech,
Technical University of Luleå, University of Umeå.

Table of Contents

Opening session

Cold as a risk factor in working life in the circumpolar regions G. A. Conway, B. J. Husberg, J. M. Lincoln	1
Occupational cold exposure in the offshore environment; development of test methods for protective clothing R. E. Reinertsen	11
Work in artificially cold environments Y. Tochihara	13
Characteristics of cold workplaces in Denmark R. Nielsen	16

Assessment methods and ergonomics

Preventive measures of workers in cooling conditions: hygienic and clinical basis of assessment and development R. F. Afanasieva	19
Influence of the outdoor cold air in winter on the microclimate and reactivity of workers from underground mines H. Herman	26
Use of personal heaters in cold work T. Risikko, H. Anttonen	29
Evaluation of thermal stress in cold regions - a strain assessment strategy I. Holmér	31
The effects of work intensity on thermal responses in calm air and in wind at -10 °C T. Mäkinen, D. Gavhed, Ingvar Holmér, H. Rintamäki	39
Validation of local temperature criteria in ISO TR 10079 D. Gavhed, T. Mäkinen, H. Rintamäki, I. Holmér	42
Estimated insulation of clothing worn in cool climates (0-15 °C) compared to required insulation for thermal neutrality (IREQ) B. Griefahn	45
Working practices in the cold: measures for the alleviation of cold stress K. C. Parsons	48
Effect of a wide hood on facial skin temperatures in cold and wind H. Rintamäki, T. Mäkinen, D. Gavhed	58
A re-examination of the cold stress threshold limit value (TLV) H. Mahar	60
Development of work environment in cold terrain conditions H. Anttonen, J. Niskanen, A. Pekkarinen	63
Case study of cold work in a hospital “plating area” K. C. Parsons	66

Microclimate variations in winter in industrial halls with metal processing by heat	69
H. Herman	
Limits for Cold Work	72
H. Rintamäki, K. Parsons	
Clothing	
Performance criteria for cold protective clothing	75
T. Risikko, H. Anttonen, E. Hiltunen	
The effect of cold, wind and movements on clothing insulation	77
H. Anttonen, E. Hiltunen, I. Holmér, G. Ohlsson	
Thermal properties of three sets of garments measured with a heated sweating mannequin	79
K. Kuklane, I. Holmér, H. Meinander	
Moisture accumulation in sleeping bags	82
G. Havenith, R. Heus	
Physiological study of some protective clothes for cold work	86
H. Herman	
A new winter clothing system for construction workers	89
R. Heus, L. Kistemaker, G. Havenith	
Physiological and hygienic requirements to thermal protective properties indices of headgear	92
R. Afanasieva, O. Burmistrova	
Effect of temperature and gloves on frostbite of hands	94
H. Anttonen, E. Hiltunen	
Reduction of footwear insulation due to walking and sweating: a preliminary study	96
K. Kuklane, I. Holmér	
Development of a new cold protective clothing with phase change material	99
B. Pause	
Cold injuries, hypothermia, cold survival, prediction models	
Prediction of cold responses	101
P. Tikuisis	
The models of cooling effect of wind in cold conditions	108
H. Anttonen, E. Hiltunen, A. Oikarinen	
Solar radiation and cold tolerance	111
K. Blazejczyk	
Clothing insulation at high wind speed	114
H. Nilsson, I. Holmér, G. Ohlsson, H. Anttonen	
Combined effects of dietary salt intake and acute whole body cold exposure on blood pressure	118
O. Arjamaa, L. Turunen, T. Mäkinen, J. Laitinen, J. Leppäluoto, O. Vuolteenaho, H. Rintamäki	

Hazards of cold immersion	120
W. R. Keatinge	
A preliminary comparison of the efficacy of two immersion protection ensembles in Antarctic water	124
S. J. Legg	
Peripheral cold injury	127
M. Hamlet	
Lifetime incidence of frostbite, its association with cold induced white fingers, vibration exposure and outdoor activity in young Finnish men	132
J. Hassi, O. Ervasti, K. Juopperi, H. Rintamäki, R. Pihlajaniemi, T. Linna	
Risk of frostbite	133
U. Danielsson	
Hypothermia, a report from the Swedish National Board of Health and Welfare	136
H. Brändström	
Cold immersion, sustained heat production and survival	137
R. E. Reinertsen	
Mechanisms of inhibition and principles of restoration of brain functions after deadly dangerous hypothermia	140
K. P. Ivanov, Yu. S. Alyukhin, N. K. Arokina, Yu. I. Levkovich, S. V. Shevchenko, N. A. Slepchuk, A. E. Chuikin	
Geographical variation in the lifetime cumulative incidence of frostbite in different thermal zones in Finland	142
K. Juopperi, J. Hassi, O. Ervasti, H. Rintamäki, T. Linna, R. Pihlajaniemi	
Pharmacological correction of hypothermic states	143
A. Smirnov, E. Shustov, V. Varfolomeev	
Human thermal condition restoration at modeling of emergencies after swimming in cold water	145
E. Zhilyaev, A. Chernetsov, A. Azhaev, I. Berzin, V. Grebenkin	
Accidents, adaptation, circulation, health, respiration	
Cold adaptation - its relevance for long term exposure	147
J. H. M. Bittel	
Human adaptability to cold	152
L. Janský, J. Heller, V. Hošek, H. Janáková, I. Lesná, J. Parížková, P. Šrámek, M. Šimecková, B. Ulicný, S. Vybíral, V. Zeman	
Thermodynamics and physiological mechanisms of heat production after acclimatisation to cold	158
K. P. Ivanov	
Seasonal characteristics of physiological and subjective thermal loads in Japanese young adult males during acute cold exposure	161
S. Sawada	
Inhalation of cold air increases the number of inflammatory cells in the lungs of healthy subjects	165
D. Gavhed, G. Tornling, L. Palmberg, C. Müller-Suur, I. Holmér, K. Larsson	

Cold stress and cardiovascular reactions	166
K. J. Collins	
Seasonal changes in finger blood flow in urban citizens.	172
J. Hisdal, R. E. Reinertsen	
Effects of work in and outside a cold storage on circulatory functions	175
I. Morioka, N. Ishii, N. Miyai, K. Miyashita	
The conflicting stimuli of chilling of the face and the forearm on cardiovascular regulation	178
E. Schagatay, J. Andersson, B. Holm	
Heat and cold strain while wearing NBC protective clothing at -25 - +25 °C	182
S. Rissanen, H. Rintamäki	
Breathing in the cold	184
G. Giesbrecht	
Facial cooling and cardio-respiratory interactions	190
K. J. Collins, T. A. Abdel-Rahman, J. C. Easton, P. Sacco, J. Ison	
Effect of ambient temperature on the biofeedback-aided control of motor unit activity in the man	192
Yu. Lupandin, A. Meigal, L. Gerasimova	
Physiological effects of exercise in cold	195
E. Tkatchenko, V. Divert	
Cold climate and regional variation in coronary mortality in Sweden	197
S. Gyllerup	
Slipping and falling accidents on icy surfaces: a case study from northern Sweden	201
J. Abeysekera, Z. Khan	
Quantitative analysis of surface EMG in diphtheric polyneuropathy patients	205
L. Gerasimova, A. Meigal, A. Sergeev, Yu. Lupandin	
Rate and special features of the blood flow in separate capillaries of brain and muscles during deep cooling and rewarming	208
K. P. Ivanov, S. V. Shevchenko, Yu. I. Levkovich	
Differences in cold exposures associated with excess winter mortality	210
W. R. Keatinge, G. C. Donaldson	
Precise motor coordination during cold induced shivering in the man	216
A. Meigal, L. Gerasimova, J. Oksa, H. Rintamäki	
Decrease in muscular performance due to cooling is dependent on exercise type	218
J. Oksa, H. Rintamäki	
Respiratory response to local skin cooling at artificial modulation of skin thermoreceptors	219
T. G. Simonova, T. V. Kozyreva	
Cold environments and health problems	222
H. Lundgren, B. W. Johansson	

Polar medicine, performance, combined effects

Working in Antarctica: current medical practice and human biology research. D. J. Lugg, P. Sullivan	224
Power requirements during skiing with sledges and backpack U. Bergh, U. Danielsson	232
Cold stress and performance A. Enander	235
Subjective sensation during local cold exposure F. Chen, I. Holmér	240
Effects of low temperature on operation efficiency of tree-felling by chain-saw in North China L. Wang	243
Hand dexterity with different gloving in the cold Q. Geng, I. Holmér	246
Cold - its interaction with other physical stressors B. Griefahn	249
Combined effects of cold and other physical factors H. Anttonen, L. Anttonen, H. Virokannas	258
Convection cooling from wind and body motion U. Danielsson	260
Thermal effects of respiration heat-exchanger devices D. Gavhed, W.-F. Zheng, G. Ohlsson, I. Holmér	263
Wind effects on head heat loss G. Ohlsson, E. Hiltunen, H. Anttonen, I. Holmér	266
Medical and biological support of Antarctic expedition E. Zhilyaev, V. Klyuzhev, V. Ardashev, V. Kostritsa, V. Varfolomeev, A. Antonov	269
Authors in alphabetical order	270

Cold as a risk factor in working life in the circumpolar regions

G. A. Conway, B. J. Husberg, J. M. Lincoln

Alaska Field Station, Division of Safety Research, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Anchorage, Alaska, USA.

Geographic distribution of population at risk

While many temperate portions of the earth experience seasonal and intermittent deep freezing temperatures, with resultant work hazards, the polar and circumpolar regions afford the most prolonged and severe periods of these conditions. While the southern Circumpolar region (primarily Antarctica) is very sparsely populated, the northern Circumpolar region is quite variable in its population density, with portions of the Nordic Nations (Norway, Denmark, Sweden, and Finland) and some northern portions of the Russian Federation being sporadically heavily urbanised, while other areas, such as the Canadian north, Siberia, Greenland, and much of Alaska and Iceland, remain sparsely populated. The entire circumpolar regions are immersed in colder temperatures than elsewhere seasonally, but the intensity of this phenomenon varies considerably, with northern Scandinavia, Finland, and Iceland experiencing much more moderate temperatures (due to the influence of the Atlantic Gulf Stream) than those encountered in Greenland, Siberia, northern Canada, and the Alaskan Interior, all of which are regularly exceeded by Antarctic winters. Workers in all regions of the planet are also exposed to substantial cold hazard in cold storage and food freezing and processing operations. The other major categories of workers frequently exposed to very cold temperatures even at temperate latitudes are mountaineers and aviators.

History and popular literature

The fear of the cold is an ancient one, and surfaces frequently in literature. Many accounts have been published of the military impact of the effects of cold, and the frustration of trying to manage the medical consequences of its ravages. Early western written references include the accounts of the decimation of the army of Xenophon (c. 400 BC) and this contemporaneous account in On the Use of Liquids in the Hippocratic collection:

The bones, the teeth, the tendons have cold as an enemy, warmth as a friend; because it is from these parts that come the spasms, the tetanus, the feverish chills, that the cold induces, that heat removes. (Quoted in Majno, 1975, pg. 181).

Larrey's account of Napoleon's retreat from Moscow in the winter of 1812-3, and numerous accounts from the great wars of our own century detail the devastation of the cold and the frailty of the human inadequately clothed and skilled against it (Mills, 1993).

Popular literature abounds with accounts of the cold's insidious dangers: in North America, Robert Service's and Jack London's poetic and prose accounts of the American west and gold rushes, the accounts of the failed Donner expedition, and Farley Mowat's People of the Deer are among the most evocative, while some of Pushkin's winter poems, Pasternak's Doctor Zhivago, and Solzhenitsyn's descriptions of the Soviet Gulag have left millions of readers with lasting impressions of the profound Russian cold. Many of the literary descriptions and historical accounts of the travails of mountaineers and arctic explorers centre on the harsh effects of the cold, exacerbated by remote distances.

There is a fascinating literature of ethnographic accounts of aboriginal peoples' adaptations to the cold. One of the most detailed, Richard Nelson's Hunters of the Northern Ice (Univ. Of Chicago, 1969), describes the behavioural and physical adaptations of the Alaska Inuit people, with an extensive account of the Inuit descriptive science of ice and snow (including a glossary of over 90 separate terms for ice and snow types and topography), and accounts of (and wisdom regarding) survival under extreme conditions. One of these adaptations, the excellent properties of Inuit and other indigenous seal- and other skin clothing, has been well described in the literature, and only very recently equalled by modern synthetic materials in function and versatility. These traditions have deep roots in Alaska. Notwithstanding the current international controversy about animal rights and the ethics of trapping and fur hunting, many Alaskans still cherish and trust skins and fur clothing for their beauty and function, preferring them over the less expensive, brightly coloured, but soon gamy (after use) synthetics now on the market. Woven *qiviut* (musk ox wool) goods are also highly prized in modern-day Alaska.

The history of the medical management of cold injury and illness is a fascinating one (including the persistence of Larrey's advice for frictional rubbing of frost-bitten parts with snow, slow rewarming, etc., which was closely heeded into this century, though based on his erroneous extrapolation of his original and very astute observations of injury mechanisms and the compound burn hazards of rewarming near open fires, (Mills, 1993)), but beyond the scope of this article.

Current scientific literature and research

A computer database review of recent publications (1980-1997) on cold exposure, hazards, injury, and disease elicited hundreds of citations, including 92 on "cold physiological effect" alone. This literature represents a very advanced understanding of the physiology, pathophysiology, and management of cold stress, injury, and illness, and a progressively evolving understanding of the underlying cellular and chemical events and human factors involved in these events. The considerable and consistently excellent contributions of this conference's organizer, Dr. Ingvar Holmér of Arbetslivsinstitutet, to this corpus is impressive and requiring acknowledgment, as is that of the Oulu Regional Institute of the Finnish Institute of Occupational Health, due to the enduring efforts of Juhani Hassi and his colleagues there.

While it is beyond the humble powers of this author to adequately distil all of this fine work down to its essence, I have attempted to organise the high points into something readily approachable, via the use of time-phase, or Haddon's, matrices (Haddon, 1972). The most prominent hazards are presented in the first of these (Figure 1), and preventive strategies summarised in the latter (Figure 2).

It is beyond the scope of this article to even summarise current knowledge of and technology for the measurement and understanding of the physiology of human response to the cold. There are numerous excellent reviews available on this subject (e.g., Holmér, 1994, Bittel, 1992, Burtan, 1994).

Figure 1. Risk Factors for Working in the Cold

	Host/Human	Agent/Vehicle	Environment
Pre-event/ Pre-injury	Fatigue/exhaustion, hunger, immobilization, inactivity, poor physical fitness Alcohol, intoxicants, cigarettes, tobacco chewing, prescription drugs Age Endocrine factors Anorexia nervosa Burns, sepsis, uremia Ignorance Occupation	Snowmachine/ snowmobile Boats/vessels Heavy equipment Metallic hand tools Inadequate clothing Aircraft Unheated buildings Entanglement	Cold air Wind Cold water Moisture Thin ice Repeated exposures Remoteness Tobacco smoke Pollutants Poor Visibility
Event/ Injury	Thermal discomfort/pain Impaired performance Poor dexterity Reduced mobility Cold injury - musculoskeletal, neurologic, vascular Exacerbation of underlying conditions	Entanglement Immobilization	Persistence of cold, insult Additional insult (e.g., water immersion)
Post-event	Slow/inadequate response to circumstances Intoxication (alcohol, drugs)	Entanglement Immobilization	Poor/inadequate medical care provided

Figure 2. Prevention and Mitigation of Cold Injury and Disease

	Host/Human	Agent/Vehicle	Environment
Pre-event/ Pre-injury	Adaptation Acclimatization Training Vigorous activity Adequate rest Good/sufficient nutrition	Adequate insulating clothing Improved motor vehicle design, e.g., hand heaters Cold water immersion (survival) suits Radio communication GPS navigation tools	Limits on exposures at lower temperatures Avoidance of rough waters, thin ice
Event/ Injury	Early recognition of symptoms Early response to hazards	Design for easy exit, extrication Cold water immersion suits Radio/tele- communications	Rapid removal from cold environment and placement in suitability warm environment Avoiding/keeping victim from additional insults
Post-event	Early management of symptoms	Design for easy exit, extrication	Availability of emergency medical services

Spectrum of cold hazards to human health

Augmenting the obvious and often synergistic hazards of exposure to cold air, wind, moisture, and water immersion are numerous environmental and human factors which may exacerbate these exposures.

Hypothermia and other cold injury risk may be elevated by exhaustion, immobilisation, or entrapment, and exacerbated by intoxication with ethanol and illicit drugs. Barbiturates, opiates, and other sedatives may impair shivering, as can spinal cord injury (Delaney and Goldfrank in Rom, 1992). Endocrine factors such as hypothyroidism, hypoadrenalism, hypopituitarism, and hypoglycemia may heighten risk, as may anorexia nervosa, certain malignancies, and burns, sepsis, and uremia (Herrington, 1996).

Repeated brief interval exposures (such as meat packers entering and exiting deep freezes or maintenance workers constantly walking between heated buildings and intense cold outside) may have cumulative chilling effects on body temperature (Tochihara, 1995).

Repeated exposures to even moderate cold (between -5 and +15 °C.) may hasten or exacerbate a broad range of illnesses (Griefahn, 1995).

Working and exercising in the cold is preferred by some individuals, and perceived effort is often lower at colder air temperatures. While this effect may beneficially enhance performance in the fit and acclimated, the potential under-reading of physiologic signals by unfit individuals until experiencing symptoms such as profound fatigue or angina pectoris may predispose some individuals to a higher risk of sudden death (Nelson, 1991).

Population at risk

In addition to those mentioned elsewhere in this article, many other occupations in the circumpolar region are at elevated risk of cold injury. Any worker spending more than a few minutes at a time outdoors during the winter months is at risk, as are those working in un- or poorly-heated buildings. These hazards have perhaps been most thoroughly described for military personnel on maneuvers or in bivouac conditions (Sampson, 1983, Taylor, 1992, and Bandopadhyay, 1996).

Public and commercial transportation in the circumpolar regions is inherently more hazardous than elsewhere, due to complementary factors: winter environmental conditions often promote icing on airplane wings and helicopter rotors; visibility is often poor, with whiteout, ground blizzards, and ice fog all posing unique hazards; snow can obliterate many natural landmarks, making visual navigation more challenging; if a crash or equipment failure does occur, the hazards of the cold are present, and help is often far away. Rescuers face the same risks in trying to recover injured victims or bodies. Flying in small aircraft in the Alaskan bush is among the most hazardous of occupations, partially because of these environmental factors (CDC, 1997).

Arctic petroleum exploration and production workers and winter surface hard rock and coal miners are among those consistently facing the harshest conditions. The petroleum industry has built a large base of empirical knowledge on how to keep people working productively in extremely cold, and now, in the late phase of these operations in Alaska, does so with relatively low rates of fatal and hospitalised worker injuries

(CDC, 1997 - ATR, at press), via a combination of suitable clothing, rotational outdoor work schedules, and a mature and experienced workforce.

Subsistence activities, such as hunting, fishing, and gathering, often expose rural people to cold air and water environments, as does trapping. The hazards faced by Alaskan commercial fishermen and strategies for mitigating these are described near the end of this article.

Recent/emerging hazards: the growth of outdoor recreational and practical uses of snowmachines (snowmobiles), as well as their rapidly increasing speed and range, have opened new frontiers for wind-chill injury and being stranded in the cold far from help. The recent advent of this type of motorised transport in reindeer herding has increased the risk of frostbite among Saami and Finnish herders (Ervasti, 1991).

The growth of extreme skiing and winter mountaineering and the rescues often necessitated by their results (particularly when novices have gone beyond their training and capabilities) pose substantial cold hazards. The very recent growth of “adventure travel” has placed sometimes inexperienced guides and often inexperienced tourists in harm’s way, from treks in the deep Himalayas and South American ascents (Horowitz, 1996) to white water rafting on remote Alaskan rivers, as have new artificial challenges such as a man-made waterfall for ice-climbing in Ouray, Colorado (Grout, 1997). Among some groups of Canadian Inuit, the eight warmest weeks of summer are now often referred to locally as the “silly season” because of the frequency of modern “explorers” attempting to reach the North Pole, an otherwise unappealing destination, with all manner of conveyances (dog sled, airplane, helicopter, skis, and motorcycle), often requiring rescue due to poor preparation or knowledge (Kalman, 1988).

The recent rapid expansion of human residential developments outside of established North American cities (including in Alaska and northern Canada) and suburbs place increasing numbers of construction, road service, and utility workers in more sparsely populated areas, and can make for very hazardous commutes for all workers in the cold, with regionally prevalent road hazards such as black ice, caribou, and moose.

Sudden dips in temperature in more temperate regions may also pose substantial hazard in unprepared and unacclimated populations: A cluster of incident frostbite, some of it quite severe, was described in Oxfordshire, United Kingdom, during the unusually severe winter of 1981-1982 (Bishop, 1984); a recent landmark study (Eurowinter Group, 1997) showed a significant mortality increase with falling temperatures in regions with generally warm winters, populations with inadequately heated homes, and among inactive and inadequately clothed persons.

The reliability of human cold response may deteriorate with age (Inoue, 1992), but it is unclear if this is inevitable or associated with lowered overall physical fitness.

Range of pathophysiology and deleterious effects of cold exposure on humans

Holmér (1994, II) has aptly summarized many of the problems associated with cold exposure:

- *thermal discomfort and pain sensation - in particular, from the extremities;*
- *impaired manual performance, caused by cold and/or gloved hand;*
- *impaired mobility and operational capacity due to weight and bulk of clothing and/or environmental conditions (ice, snow, etc.);*
- *deterioration in physical work capacity with muscle and body cooling;*
- *risk of cold injury with extreme exposures; and*

- *initiation and aggravation of symptoms associated with certain diseases....*

Serious cold-related injuries include frostbite, hypothermia, both generally acute events related to acute exposures, and trench foot, which is more likely to result from prolonged exposures to cold, wet conditions. A recent epidemiological study has demonstrated a possible relationship between recurrent exposure to extreme low temperatures and an increased risk for testicular cancer, in addition to the previously-described hazard associated with heat exposure (Hang, 1995).

Recent work has detailed the decrement in anaerobic performance with cold exposure in military servicemen (Hackney, 1991).

Frequent or prolonged exposure to moderate cold has been demonstrated to precipitate or exacerbate shoulder and extremity pain, lumbago, rheumatism, respiratory infections, and hearing loss (Griefahn, 1995) and chilblains (perniosis), trench, and immersion foot (Herrington, 1996).

Cold exposure may also result in a variety of other, less severe, occurrences: mild decrease in core body temperature results in shivering, which some individuals find unpleasant, and rhinorrhea may occur on re-entry to heated rooms from the cold. Muscle and tendon tears may also be more likely in cold environments. Raynaud's syndrome and the related white finger syndrome cause severe arterial vasoconstriction with digital blanching, and severe cases may lead to ulceration and tissue loss (Lloyd, 1994). Smoking tobacco can greatly exacerbate these symptoms. Frostnips, wherein chilled skin blanches painfully while remaining pliable, have historically been regarded as self-reversing harbingers of frostbite, benign in themselves. However, individuals with a history of many frostnips may undergo less severe versions of the distal digital and tarsal joint atrophy, contractures, and peripheral neurologic changes associated with frostbite (Hassi, personal communication, 1996).

Respiratory effects of cold range from acute cold-induced bronchospasm (asthma if recurrent) and increased risk for respiratory infections, to a chronic illness with chronic obstructive pulmonary disease (COPD) features, complete with many of the spirometric, radiographic, and cardiac changes seen in other forms of COPD. This latter syndrome, dubbed "Eskimo Lung", has been described in the Canadian arctic among older individuals with a long history of working hard out of doors, but may also be attributable in part to smoking (Giesbrecht, 1995) and/or persistent poor indoor air quality due to heating or cooking fires.

Adaptation and primary prevention and mitigation of harmful exposures to cold

Bittel (1992) has described different types of cold adaptation:

Metabolic adaptation (Alacaluf Indians, Arctic [American] Indians [and] Eskimos);

Insulative adaptation (coastal Aborigines of tropical northern Australia);

Hypothermic adaptation (bushmen of the Kalahari desert, Peruvian Indians); and

Insulative hypothermic adaptation (Central Australian Aborigines, nomadic Lapps [Saami], Korean and Japanese diving women).

Burtan (1994) defined adaptation as "those changes occurring during a period of several generations" and acclimatisation as "those changes occurring in the responses of the organism produced by continued alterations in the environment." Bittel (1992) also noted that "the habituated person is able to function more efficiently in the cold while being able to better resist cold injury through an improved cutaneous blood flow."

Countermeasures should include training, encompassing: 1) a description of the hazard and its effects on the individual, 2) individual hygiene practices, 3) recognition and first aid treatment of hazard-related disorders, and 4) descriptions and training related to specific countermeasures that are in place.” (from Dukes-Dobos, 1996, pp. 285). Some authors advocate screening for workers having pre-existing autonomic dysfunction or vascular disease or who must use prescription drugs that impair thermoregulation (Delaney and Goldfrank in Rom, 1992).

Holmér (1993) asserts that “a rationally based set of limit values should be useful for planning and organisation of work in cold regions and for control of exposure under extreme conditions” and outlines a rough framework for these, down to -55 degrees C.

Planning for work regimes to include persistent or frequent physical activity while working out of doors in the cold is important. Sir William Osler noted that lumberjacks could work protractedly in cold, wet conditions for weeks at a time without injury, which he attributed to their high activity level. In this century’s two World Wars and the Korean conflict, the troops suffering the most cold injuries were those experiencing general body chilling during bivouacs and while confined to unheated vehicles, trenches, or foxholes (Burtan in Zenz et al., 1994). Even the modern vapour-barrier boots and high-tech mittens may not be sufficient to overcome the combined insults of deep cold and enforced inactivity.

The placement of infrared heaters in strategic locations to heat workers and sensitive machinery has been proposed and evaluated (Anttonen, 1995)

Alaskan experiences

Some of the results of our work in describing nonfatal acute cold injuries in Alaska are presented below. We have also accumulated an extensive dataset on deaths related to cold water drowning and hypothermia in Alaska, and have gained some insight into how to prevent and mitigate these events, and present that as well.

Cold-related non-fatal injuries in Alaska

We have conducted comprehensive surveillance for non-fatal injuries requiring hospitalization for 1991 forward via the Alaska Trauma Registry. We consider the following ICD-9-CM classifications to be cold injuries: E-codes: 901.00 (excessive cold weather), 901.8 (excessive cold, other), and 901.9 (excessive cold, nonspecific); and/or n-codes: 991.6 (hypothermia), 991.00-991.3 (frostbite), 991.5 (chilblains), and 991.4 (immersion foot).

During 1991-1995, 327 persons were hospitalised for cold-related injuries in Alaska. Male victims numbered 251, female 76. The mean age of victims was 34 years. Among those injured while working (n=40): 20 (50 %) were active-duty military, and 14 were professional fishermen, hunters or trappers; 19 (48 %) were white, 12 (30 %) black (versus 4 % of the Alaska population), and 8 (20 %) Alaska Native, disproportionate in rate only for black workers. For those injuries not meeting a strict case definition for work-related events (n=287), 147 (51 %) of the victims were Alaska Native, in contrast to the 16 % of Alaska residents who are Alaska Native. The most common cause for hospitalisation was hypothermia (150, 46 %), followed by frostbite of the foot (138, 42 %) or hand (62, 19 %) or face (13, 4 %). Immersion foot accounted for 10 (3 %) of the hospitalisations. Alcohol consumption was implicated in 88 (27 %) of these events.

Cold-related injury remains a tangible and potentially serious hazard in Alaska, particularly for military and outdoor workers and Alaska Natives. While Alaska Natives constitute 16 % of the overall Alaskan population, they are the majority population in the Alaskan Bush (off the road system), and thus likely at a much higher population-specific exposure level to prolonged outside activities. The apparent higher risk for cold injury experienced by black military servicemen also requires further investigation, including a determination of whether the observed increased cold injury rates in this group of Alaskan workers are attributable to lack of acclimatisation, or to other human factors.

Careful attention to wearing proper clothing, particularly gloves or mittens and boots or mukluks, as well as limiting sustained exposure times, should be encouraged in all areas with similar climates. Specialised training in cold preparedness and injury prevention should be considered for all workers and persons conducting subsistence activities in cold environments.

Preventing hypothermia and cold-water drowning in Alaska's commercial fishing industry

There is a high occupational fatality rate (200/100,000/ year in 1991-1992) among Alaska's commercial fishermen. Over 90 % of these deaths have been due to cold-water drowning or drowning with hypothermia, following vessel capsizing and sinking. The Arctic and subarctic waters of Alaska provide a very hazardous work setting, with great distances, seasonal darkness, very cold waters, high winds, brief fishing seasons, and icing.

We established comprehensive surveillance for commercial fishing occupational fatalities during 1991 and 1992 in Alaska. During 1991 through 1994, the U.S. Commercial Fishing Vessel Safety Act of 1988 required the implementation of post-event injury prevention and mitigation measures for all fishing vessels in offshore cold waters, including heat-conserving immersion suits, survival craft (life rafts), emergency position-indicating radio beacons (EPIRBs) and crew training in emergency response and first aid.

During 1991-1996, there has been a substantial decrease in Alaskan commercial fishing-related deaths, from 36 in 1991 to 35 in 1992, 22 in 1993, 11 in 1994, 18 in 1995, and 24 in 1996. While man-overboard drownings and some other categories of deaths (falls, fires) have continued to occur, the most marked progress has been in vessel-related events, with virtually all of the remaining mortality in the winter crab fisheries:

Year	Vessels Lost	Persons on Board	Persons Killed	Case-Fatality %
1991	39	93	25	27 %
1992	44	113	26	23 %
1993	24	83	14	17 %
1994	36	131	4	3 %
1995	26	106	11	10 %
1996	38	114	13	11 %

Specific measures (e.g., heat-conserving survival suits) tailored to prevent cold water drowning and hypothermia in vessel capsizing and sinking in Alaska's commercial fishing industry have been very successful so far for near-shore fisheries, but not for the winter king crab fisheries. Additional efforts should be made to reduce the frequency of

vessel events (particularly capsizing related to overloading and icing) and to prevent man-overboard events and the hypothermia and drownings associated with them (CDC, 1997, at press).

Conclusions

Exposure to the cold is a common hazard in the circumpolar regions. Careful planning, training, and equipment can greatly mitigate these hazards.

References

1. Anttonen, Hannu, and Niskanen, Juhani: "Prevention of the Adverse Health Effects of Cold by Using Infrared Heaters." *Arctic Medical Research*. 54:S2, pp. 55-59, 1995.
2. Bandopadhyay, P. And Selvamuirty, W.: "Clinical Observations on Tropical Men During Their Sojourn Over the Arctic Region." *J. Assoc. Physicians India*, 44(4): 248-51, 1996.
3. Bishop, H.M., Colin, J., Wood, R.F.M., and Morris, P.J.: "Frostbite in Oxfordshire: The Impact of a Severe Winter on an Unprepared Civilian Population." *Injury*. 15: 379-380, 1984.
4. Bittel, J.: "The Different Types of General Cold Adaptation in Man." *Int. Journal of Sports Medicine*. 13:S172-S176, 1992.
5. Burtan, Rupert C.: "Work Under Low Temperatures and Reactions to Cold." *Occupational Medicine, Third Edition*, C. Zenz, O.B. Dickerson, and E.P. Horvath, editors, Mosby-Year Book, St. Louis, MO, 1994, pp. 334-342.
6. Delaney, Kathleen A. and Goldfrank, Lewis R.: "Hot and Cold Work Environments." *Environmental and Occupational Medicine*, ed. by William N. Rom, Little, Brown and Co., Boston, MA, 2nd ed., pp. 1153-1164, 1993.
7. Dukes-Dobos, F.N. and Bernard, Thomas E.: "Problematic Issues in Prevention of Injuries and Illnesses Resulting from Exposure to Heat and Cold Stress." *Appl. Occup. Environ. Hyg.* 11(4): 282-287, 1996.
8. Ervasti, O., Virokannas, H., and Hassi, J." "Frostbite in Reindeer Herders." *Arctic Medical Research*. 50: Suppl. 6: 89-93, 1991.
9. Eurowinter Group: "Cold Exposure and Winter Mortality from Ischaemic Heart Disease, Cerebrovascular Disease, Respiratory Disease, and all Causes in Warm and Cold Regions of Europe." *Lancet*. 349:1341-1346, 1997.
10. Giesbrecht, Gordon G.: "The Respiratory System in a Cold Environment." *Aviation Space Environmental Medicine*. 66:890-902, 1995.
11. Grout, Pam: "A Slippery Slope." *Outside*. P.158, November, 1997.
12. Griefahn, B., Mehniert, P., Brode, P., Forsthoff, A.: "Health Hazards and Work in Moderate Cold." *Proc. Of International Symposium: From Research and Prevention - Managing Occupational and Environmental Health Hazards*, 20-23 March, 1995, Helsinki, Finland; Finnish Institute of Occupational Health, Helsinki, 1995.
13. Hackney, A.C., Shaw, J.M., Hodgdon, J.A., Coyne, J.T., and Kelleher, D.L.: "Cold Exposure During Military Operations: Effects on Anaerobic Performance." *Journal of Applied Physiology*. 71(1): 125-130, 1991.
14. Haddon, W. Jr.: "A Logical Framework for Categorizing Highway Safety Phenomena and Activity." *Journal of Trauma*. 12:197-207, 1972.

15. Herrington, Thomas N., and Morse, Linda H.: "Temperature Related Disorders." *Occupational Injuries: Evaluation, Management and Prevention*. Mosby, St. Louis, MO., pp. 381-394, 1996.
16. Holmér, Ingvar: "Cold Stress: Part II -- The Scientific Basis (Knowledge Base) for the Guide." *International Journal of Industrial Ergonomics*. 14:151-159, 1994.
17. Holmér, Ingvar: "Work in the Cold." *International Archives of Occupational and Environmental Health*. 65:147-155, 1993.
18. Horowitz, Adam. "Trekking: Buried at the top of the World." *Outside*. P24, February, 1996.
19. Inoue, Y., Nakao, M., Araki, T., and Ueda, M.: "Thermoregulatory Responses of Young and Older Men to Cold Exposure." *European Journal of Applied Physiology*. 65: 492-498, 1992.
20. Kalman, Bobbie: *The Arctic Land*. Crabtree Publishing Co., Toronto, Ontario, Canada, 1988.
21. Lloyd, Evan L.: "Temperature and Performance in Cold." *British Medical Journal*. 309: pp. 531-534, 1994.
22. Majno, Guido: *The Healing Hand: Man and Wound in the Ancient World*. Harvard University Press, Cambridge, Massachusetts, 1975.
23. Mills, William J., O'Malley, James, and Kappes, Bruno: "Cold and Freezing: A Historical Chronology of Laboratory Investigation and Clinical Exposure." *Alaska Medicine*. Volume 35, Number 1, pp89-116, 1993.
24. Nelson, T.M., McIntyre, W.R., LaBrie, I.G., and Csiky, A.: "Self-Perception of the Ability to Work in the Cold." *Behavioural Medicine*. 17:15-23, 1991.
25. Nelson, Richard K. *Hunters of the Northern Ice*. University of Chicago Press, Chicago, 1969.
26. Tochihara, Y. and Ohnaka, T.: "Effects of Repeated Exposures to Severe Cold Environments on Thermal Responses of Humans." *Ergonomics*. 38:987-995, 1995.
27. Zang, Zuo-Feng, Velva, John E., Zielezny, Maria, et al.: "Occupational Exposures to Extreme Temperature and the Risk of Testicular Cancer." *Archives of Environmental Health*. 50(1): 13-18, 1995.

Occupational cold exposure in the offshore environment; development of test methods for protective clothing

R. E. Reinertsen

SINTEF Unimed, Division of Extreme Work Environment, N-7034 Trondheim, Norway

People working in the offshore environment in northern regions are exposed to harsh climatic conditions. As petroleum activities move further north in the Norwegian part of the North Sea, platform workers are being increasingly exposed to extreme cold conditions. Fishermen are usually less well equipped than the oil workers. Crews often consist of quite a few people and the distance to the nearest rescue base may be at the limits of the practical working range of its helicopters. Land-based and offshore military personnel are also exposed to cold conditions. Ferry passengers are in a special situation that require different solutions from those designed for people working offshore on a regular basis.

Environmental conditions are characterised not only by low air and water temperatures, but also by wind, high humidity, rain and snow. Furthermore, changing weather conditions make it difficult to select optimal clothing for long work sessions. Since cold is a stress producing factor, the frequency of occurrence of unsafe actions increases as the ambient temperature decreases. Cold also leads to concentration deficiency, impaired short-term memory, ineffective execution of procedures and instructions, inaccurate or slow recall of emergency actions and inability to take innovative action in unexpected situations.

When accidents do occur, both the probability of being found alive and the chances of survival are critically dependent on the properties of protective garments and buoyancy devices as well as on local rescue policy. Although survival suits have indeed saved lives, there are numerous reports of equipment that has not performed as expected under emergency conditions. This is partly due to the design of current test methods which typically focus on product performance against specific hazards rather than on the human factors aspects of protective clothing. In order to improve safety standards and rescues of people working offshore in northern areas, more knowledge of the critical exposure factors and of the human factors relevant to protective clothing is required.

Test methods should provide accurate measures of protective clothing performance under conditions as they occur in the “field”. Each test should attempt to simulate field microenvironment and the actual work tasks of the wearer. Furthermore, the test persons should be selected according to the characteristics of the actual workers (e.g. age, fitness, measurements of body dimensions). Average and worst case types of exposure should be considered for the evaluation of the properties of the protective clothing. Furthermore, the testing should address the performance of the overall product or the clothing concept. Manikin tests can be used for prediction of thermal performance.

Manned tests should be used for testing related to product use, in terms of comfort and function since acceptance by end users will depend on thermal comfort during changing work intensities, mobility, dexterity, burden and sizing.

Our laboratory has compared the performance of immersion protective equipment during realistic North Sea conditions with that predicted by routine testing for certification. A group of 6 subject undertook two immersions wearing standard insulated survival suits. The routine testing was identical with the IMO standard testing while the North Sea conditions introduced 50 cm waves, periodic surface spraying, 5 m·s⁻¹ wind, and -5 °C air temperature. While all test persons carried out the 6 hours IMO test, the North Sea condition experiment had to be terminated after 90 minutes due to low skin temperatures. For this condition, shivering was evoked at an early stage of the immersion, but the increased heat production was not sufficient to balance the heat loss from the body. Also for the IMO test condition the body temperatures continued to fall after shivering onset, but rectal temperature was well above 35 °C and none of the skin temperatures were below 10 °C during the 6 hours immersion. During an emergency situation in the North Sea the victim will be exposed to more severe conditions than those described in the IMO standards. This will result in increased rates of heat loss due to more flushing of water, lower air temperature and higher levels of water leakage. Due to prevailing weather conditions, darkness during the winter months and distance, rescue may not reach the victim within the predicted 6 hours. Our results demonstrate that current test methods overestimate the performance of immersion protective clothing. The present standards do not provide any accurate prediction of likely actual survival time during accidents in conditions of differing adversity. To do this, testing should be more linked to the environmental conditions during an accident. The tests should also include physiological measures for prediction of survival during immersion.

Development of standards and test methods must involve participation of end users, manufacturers, testing laboratories, research institutions and the authorities. Since end users are the experts on the requirements related to everyday use of protective clothing, they should participate throughout the process of standard development, test method design and product manufacturing. This will probably improve the quality of the protective clothing and the acceptance by end users in general.

Work in artificially cold environments

Y. Tochiara

Department of Ergonomics, Kyushu Institute of Design, 4-9-1 Shiobaru, Minami-ku, Fukuoka 815, Japan

Introduction

There are two types of cold workplaces. One is the outside workplace in winter ; the other is artificially cold environments. Work in the outside in winter is done after the workers are acclimatised to the cold. On the other hand, work in artificially cold environments is done in all seasons. Therefore, work in artificially cold environments except winter season may be more stressful to the workers.

Cold storages are the most common workplaces of artificial cold work environments. There are about 4,000 cold storages in Japan, and 85 % of them are kept at a temperature below -20 °C. We did several surveys to investigate the work loads of workers in cold storages with questionnaires and time studies (1-3). We also did experimental studies with climatic chambers to simulate work in cold storages (4-8). In this paper, the characteristics of work in cold storages are summarised from our several field studies and experimental studies.

Surveys

Survey 1

The survey with questionnaires was addressed to the workers in 377 cold storages and was conducted to investigate their working environments and conditions (1).

The most common temperature in cold storages is -20 °C to -30 °C. There are about 30,000 to 40,000 workers in cold storages in Japan. As the set temperature of cold storage rooms is made lower, the shorter the working time in cold. The extreme coldness and large temperature difference between the inside and the outside of cold storages should also be considered as a cause of health problems, in addition to the working conditions.

Survey 2

Subjects were 10 forklift-truck workers (Group R) in two cold storages and eight forklift-truck workers (Group C) working in a general storehouse. From the start to end of the working day, the investigators followed the workers. They checked the time in cold storage and the number of cold exposure, etc. Skin temperatures were also measured every minute during work (2). Hand tremor, handgrip strength, pinch strength, counting task, flicker value and blood pressure were measured five times (before work, at 10 a.m., before lunch, at 3 p.m., and after work) per day (3).

Mean cold exposure time for Group R in a day was 125 minutes. The mean frequency to enter the cold storages in a day was 73 times which was much greater than reported

earlier. Although cold exposure time per each stay was very short (almost less than 5 minutes), workers entered the cold storages very frequently, skin temperatures of the peripheral parts decreased remarkably. The mean values of the lowest skin temperatures at finger and toe for Group R were 11.0 °C and 15.1 °C, respectively. These values were significantly lower than those of Group C (Figure 1). There were no significant differences in handgrip strength, pinch strength, counting task, flicker value between Group R and C. However, changes in hand tremor and diastolic blood pressure for Group R were significantly greater than those for Group C. The actual forklift work in these cold storages did not cause a distinct reduction in manual performance, but caused an increase in stress which would be expressed as an increase in catecholamine excretion.

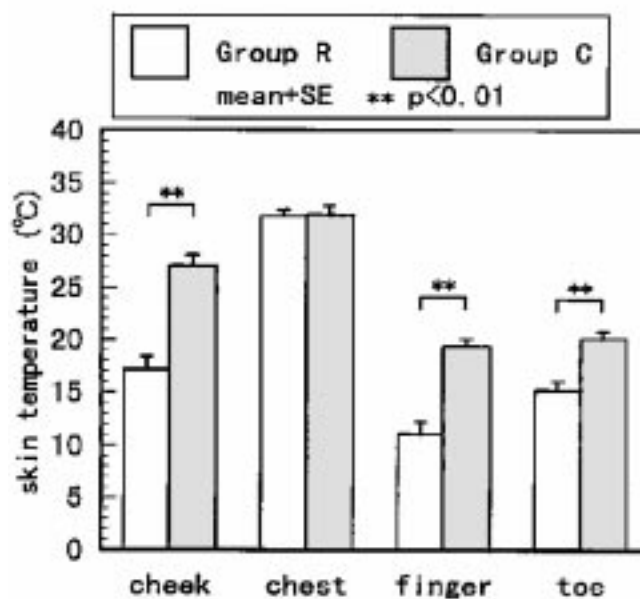


Figure 1. Averages of the lowest skin temperatures at 4 points for both groups.

Experiments

Experiment 1

The study was conducted to investigate the effects of different exposure rates on thermal responses with the total cold exposure time the same under each of the conditions. After resting in a warm room (25 °C) for 10 minutes, six male students wearing standard cold protective clothing entered an adjoining cold room (-25 °C). Each 5-, 10- and 20-minute cold exposure was repeated 12, 6 and 3 times, respectively. Each cold exposures was followed by a similar duration of rest at 25 °C. Total cold exposure time was the same under the three conditions.

At the end of the cold exposure skin temperatures in the shorter exposures were higher than those in the other conditions, except on the foot. However, there were no differences among the three conditions in the fall of rectal temperature and urinary excretion of 17-OHCS, which are good indices of cold stress. Moreover, increase in blood pressure and decrease in counting task due to cold were not different among the three conditions. Even though the cold exposure time for each stay was short, when cold exposures were repeated frequently, cold stress of the whole body and decrease in manual task performance were the same as in the longer exposure.

Experiment 2

Since there are a lot of frozen fish in cold storages, the workers have to do night work in order to deliver them to the markets which open in the early morning. Thirteen male students were exposed to severe cold in the afternoon (3-5 p.m.) and at night (3-5 a.m.). The subjects were kept in a severely cold room (-25 °C) for 20 minutes, thereafter, they were placed in another room (10 °C) for 20 minutes. This pattern was repeated three times, the total cold exposure time amounting to 60 minutes. Rectal temperature, skin temperatures, manual dexterity, blood pressure and thermal comfort were measured during the experiments (8).

At the beginning of the experiment, rectal temperatures in the afternoon were significantly higher than at night due to the subject's circadian rhythm. The fall in rectal temperature during cold exposures at night was significantly greater than that in the afternoon. Although there were no significant differences in mean skin temperature between afternoon and night, finger skin temperature at night was significantly higher. This higher skin temperatures on the peripheral parts of the body would increase heat loss.

Conclusions

From these field and experimental studies, we are able to measured the physiological strain placed on cold storage workers, and to evaluate their work environments. However, more studies, such as a precise epidemiological study, and a study on seasonal differences in the physiological strains to severe cold, are needed.

References

1. Tochihara Y. et al. Work in cold storage warehouse. *J of the Society of heating, Air-Conditioning and Sanitary Engineering of Japan (in Japanese)* 1979: 53: 47-51.
2. Tochihara Y. et al. A survey on work loads of forklift-truck workers in cold storages. *Bull Inst Public Health* 1990: 39: 29-36.
3. Tochihara Y. et al. Physiological reaction and manual performance during work in cold storages. *Appl Human Sci* 1995: 14: 73-77.
4. Tanaka M. et al. Thermal reaction and manual performance during cold exposure while wearing cold-protective clothing. *Ergonomics* 1983: 26: 141-149.
5. Tochihara Y. et al. Effects of repeated exposures to severely cold environments on thermal responses of humans. *Ergonomics* 1995: 38: 987-995.
6. Tochihara Y. et al. Comparison of thermal responses with and without cold protective clothing in a warm environment after severe cold exposures. *J Therm Biol* 1993: 18: 639-642.
7. Ozaki H. et al. The thermal responses from repeated exposures to severe cold with intermittent warmer temperatures. *Environmental Ergonomics*. London: Freund Publishing House, 1996: 107-110.
8. Ozaki H. et al. Thermal responses to repeated exposures to severe cold at night. Unpublished

Characteristics of cold workplaces in Denmark

R. Nielsen

Danish Working Environment Service, Dyregaardsvej 5, DK-2740 Skovlunde, Denmark

In this paper characteristics of occupational cold exposure in Denmark are described. Information has been collected from cross-sectional interview studies on larger population groups, from questionnaire studies in selected cold branches, and from studies measuring and describing the significant thermal factors in some cold branches.

Recently, a population study based on interviews with approx. 6000 wage earners from many different branches and job types were published (1). The wage earners at average reported being exposed to cold 9 % of their working time and to draught 12 % of their working time. Men were more exposed to cold than women (13 % vs. 5 %), whereas there was no gender difference in exposure to draught (13 % vs. 12 %). This means that men either are exposed to cold for a larger part of the working day compared to women or that more men are exposed to cold. 2.2 % of the wage earners were exposed to cold almost all the time, 1.6 % were exposed $\frac{3}{4}$ of the time, 5.3 % were exposed $\frac{1}{2}$ of the time, 8.9 % $\frac{1}{4}$ of the time, 14.8% were exposed seldom or very little and 66.9% were never exposed to cold.

Comprised in the job types exposed to cold $\frac{3}{4}$ of the day are 33 % of the butchers, 26 % of the construction workers, 20 % of wage earners in agriculture and fishing, 17 % among women factory workers, 16 % among carpenters, dock and warehouse workers. Workers exposed extensively to cold can be divided in groups according to exposure characteristics.

Work in cold indoor environments

Employes in artificially cooled, frozen or non-heated rooms includes workers in cold stores, in slaughterhouses, in the fishing industry, in dairies and some female factory workers.

More than 20.000 persons are working in the cold rooms of *slaughterhouses*. 75 % are employed with cutting, sausage making, packing and other jobs at +5 - +12 °C. 20 % are working at room temperatures from +2-5 °C, with cutting of long-life products, slicing and storage in refrigeratory rooms. Only few employees are working in cold storage rooms with temperatures down to -25 °C. Cold exposure comes from the air, machines, packing and cutting tables, meat etc. Kristensen & Christensen (2) reported that 63 % of slaughterhouse workers were exposed to cold and 73 % to draught. Complaints of draught increased with decreasing room temperature. Occurence of draft is due to mainly two reasons. First there are air movements rising close to doors and openings to the outside or to rooms with lower and higher temperatures. The other main cause to draft problems in the cool rooms in slaughterhouses are cold air falling down

from inadequate cooling systems under the ceiling and from high walls and windows (3). The air velocity has been measured to 0.15 - 0.2 m/s at shoulder height. Christensen and Kristensen (2) reported that significantly more persons being exposed to draft reported having a cold and feeling pain in the upper back area.

In the *fishing industry* approx. 2500 persons are working in cold rooms (4). The majority of workers are working in rooms with temperatures of +12-16 °C. Few people work in the icing rooms at 0-2 °C. Many rooms do not have good heating systems. Infrared heaters are often used for heating, and it is not unusual to see them in inefficient positions, pointed in a wrong direction or placed far from work places. The large amount of ice and water used on the cutting tables causes cold air to fall towards the floor. Vertical temperature differences of 2 - 4.5 °C/m have been measured in the cutting rooms. The factories are often placed in old buildings close to the sea allowing the wind to get in through openings and doors. For a number of industries including the fishing industry, the most frequent causes for draft are open doors to the outside (73 %), open doors to other rooms (53 %), air flow from ventilation systems (16 %) and cold air falling down (14 %) (5).

Work in *cold stores* in Denmark are normally being performed with trucks from a heated cabin. Only few jobs involves manual work. Normal temperatures in cold stores are in the range from -16 to -25 °C. In a few cold stores with special products temperatures of -55 °C are necessary and even manual work. When manual work are being performed in cold stores, it is normal practice, that ventilators are turned off, and breaks in warm rooms are frequent.

Work intermittently indoor/outside.

This group comprises persons working intermittently indoor and outdoor as for example agricultural workers, dock workers and warehouse workers. Warehouses in harbours are normally unheated and it is common with large open gates allowing for frequent truck driving in and out. Most trucks does not have a closed cabin. Therefore, truck drivers are exposed to the outdoor climate, the indoor warehouse climate, and increased air velocities arising from the driving, from air movements in the warehouses or from wind. Air velocities in warehouses with two open gates fluctuate very much and the velocity are normally considerably higher than in an office environment (6). Air velocities up to 1.5 m/s have been reported. Closing of one door/gate and use of plastic curtains reduces draft and air movements considerably. Delivery men and lorry drivers are other groups intermittently being exposed to warm indoor and cold outdoor environments.

Outdoor work

This group comprises outdoor workers as construction workers, carpenters, fishermen, road workers, postmen and garbage collectors. Compared to 1990 less wage earners reported in 1995 being exposed to cold and draught. However, e.g. the construction industry has been expanding its construction activities in wintertime. This means that workers are exposed to the outdoor environment and in wintertime typical temperatures in the range from -5 to +5 °C. To this adds the impact from the humid and windy danish weather. A large part of the construction work takes place in open constructions or on the outside of buildings. High wind, turbulence and draft are common exposures for

persons working here. For other outdoor workers, e.g. fishermen, the cold air exposure is increased by a wet environment.

References

1. Borg V, Burr H. Danish wage earners working environment and health 1990-95. Copenhagen: National Institute of Occupational Health, 1997 (in danish).
2. Christensen TS, Kristensen FL. Slaughterhouse work. Copenhagen: Danish Working Environment Fund, 1983 (in danish).
3. Nielsen R. Work Clothing in Cold rooms - A physiological evaluation. Ph.D. Thesis. University of Copenhagen 1984 (in danish).
4. Nielsen R, Toftum J. Development of clothing for cold work places. Copenhagen: Danish Working Environment Fund, 1992 (in danish).
5. Toftum J. Draught in the industrial working environment. Technical University of Denmark 1993 (in danish).

Preventive measures of workers in cooling conditions: hygienic and clinical basis of assessment and development

R. F. Afanasieva

RAMS Institute of Occupational Health, Moscow, Russian Federation

Research on cold and its influence on humans remain of immediate importance in Russia due to the different climatic conditions of the Russian territories. The work done in this area is extensive and multiple. In this overview there is no room for citing all publications and work relating even to the recent stages of development.

Proper protection of a man working in cold environments is important from the point of view of health protection, promotion of performance, and efficient labour organisation. It is important to solve this problem by studying the different body reactions and functional effects in response to acute and chronic cold exposure and to develop assessment criteria for application of effective prevention measures.

A brief overview of areas of research is given in Figure 1. The most important locations and institutes for this research have also have been cited.

Many researchers in Russia have chosen as a priority solving the problems related to the first area [2;3;5;7;9;10;12;13;14;16;18]. Some aspects will be reported at this symposium. Of particular practical and scientific significance are the studies where development of assessment criteria for cold exposure is proposed (Figure 2). Recommendation of criteria depends on the concrete situation by which they are to be applied. In particular, selection is determined by the duration of stay in a cold environment (continuous per working shift), physical activity, allowable degree of cooling, the risk of performance reduction, and development of pathologies.

Standard requirements for the parameters of the indoor and industrial microclimate in order to prevent body cooling. For this purpose criteria for the heat state of the worker during the work shift are and two levels of strain are identified; an optimal and an admissible one. Both domestic and foreign research support the approach for the optimal state. However, for the assessment of admissible cooling the picture is not so clear. Figure 3 shows the most important criteria optimal heat state of a man with regard to the level of physical load. Figure 4 depicts industrial indoor microclimatic parameters that should preserve this heat state. The maintenance of the heat state at by high physical loads is most problematic due to intensive sweating and high skin wettedness.

The relation between mean skin temperature and level of physical activity for different values of body thermal sensation are presented by Maistrakh [2]. The data of Fanger [6] and Holmér [7] have been cited for comfort levels. Admissible criteria levels for the heat state of a man during a work shift [1;2] are those which:

- do not cause unpleasant sensations that are expressed in a wish to leave the workplace for warming or to increase the clothing insulation (> 1 clo);

- do not significantly change manual performance during operations that demands co-ordination of movements. It is anticipated that in 20 % of the individuals the performance may be reduced by 10 %;
- do not lead to increased risks of adverse health effects.

Figure 1. Main areas and locations of research on problems related to cold workplaces.

- Investigation of mechanisms for the control of temperature homeostasis, thermoregulatory reactions, adaptation, functional state and health status in acute and/or chronic cold exposures (*Petersburg, Petrozavodsk, Novosibirsk, Moscow, Ivanovo, Arkhangelsk*);
- Study of combined effects of cold and other environmental factors (hypoxia, hand-arm vibration, whole body vibration, noise, non-ionising radiation, chemicals etc.) (*Moscow, Kirovsk, Ivanovo, Petersburg*);
- Determination of assessment criteria for the influence of cold on adapted and non-adapted workers (*Moscow, Petersburg, Novosibirsk*);
- Elaboration of preventive measures for workers in cold (*Moscow, Petersburg, Kirovsk*);
- Hygienic requirements on microclimatic parameters when using convective and radiation/convective heating systems (*Moscow, Petersburg*);
- Hygienic requirements on personal protective measures (clothing, shoes, caps, gloves) including those with active heating (*Moscow, Petersburg, Kirovsk*);
- Prediction of the heat balance of workers in the cold considering the severity of the cold environment, physical activity, exposure duration (uninterrupted during work-shift) and thermal insulation of clothing ensemble (*Moscow, Petersburg, Novosibirsk*).

Figure 2. Definitions of the two levels of human heat state (according to Methodological Recommendations No. 5168 approved by Russian Health Ministry, 1990)

The human heat state is defined by the heat content and heat distribution in deep (“core”) and surface (“shell”) tissues and by the degree of strain on the thermoregulatory responses. Thermoregulatory strain is determined by the level of activation of the specific systemic functions for the maintenance of temperature homeostasis.

Optimum human heat state is characterised by the absence of general and local discomfort sensations, minimum strain on thermoregulatory reactions as defined by indices and criteria given in [2], This is a precondition for high work efficiency for a long periods.

Admissible human heat state is characterised by some but insignificant general and/or local discomfort sensation, preservation of thermal balance of the body during whole work-shifts with only moderate strain of the thermoregulatory responses in accordance with indices and criteria in Figure 3. Temporal fall in performance ability (during the work-shift) may take place, but the health state is not affected (in the course of the whole work shift).

Short stay in a cold environment may result in more significant cooling of the body only if it is combined with another part of the work shift performed in microclimatic conditions contributing to the establishment of a normal heat balance. It means that the admissible mean work shift criteria for the body heat state are maintained. Criteria for admissible body cooling for three hours per work shift or less are given in [2]. This level of cooling is likely to be accompanied by a 20 % reduction of performance related to co-ordination of movements, if the temperature of the back of the hand drops to 22 – 24 °C, and the body heat deficit is about 4.82 kJ/kg.

Figure 3. Criteria for optimum human heat state (approved by Health ministry No. 5168, 1990)

Physiological factor	Energy loss, W/m ²				
	69	87	113	145	177
Body temperature, t _r , °C	37.1-37.2	37.2-37.3	37.3-37.4	37.4-37.5	37.5-37.7
Mean skin temperature, t _s , °C	32.5-33.5	32.1-32.8	31.6-32.5	30.9-32.0	30.2-31.4
Mean body temperature, t _b , °C	35.3-35.8	35.3-35.8	35.3-35.8	35.3-35.8	35.3-35.8
Heat content change, kJ/kg, (kcal/kg)	± 0.87 (± 0.2)	± 0.87 (± 0.2)	± 0.87 (± 0.2)	± 0.87 (± 0.2)	± 0.87 (± 0.2)
Heart rate increase, beats/min	6	7-10	11-18	19-25	26-32
Water losses, g/h	80	100	120	150	180
Heat sensation, T _s , point	4.0	4.0	4.0	4.0	4.0
Difference between temperatures of breast and foot skin, °C	2-4	2-4	not typical	not typical	not typical

Figure 4. Optimum values for microclimatic parameters at workplaces for the warm season (sanitary rules and norms No. 2.2.4.548-1996, approved by Russian Health Ministry)

Work category by level of metabolism, W	Air temperature, °C	Surface temperature, °C	Relative air humidity, %	Air velocity, m/s
Ia (≤ 139)	23 - 25	22 - 26	60 - 40	0.1
Iá (140 - 174)	22 - 24	21 - 25	60 - 40	0.1
IIà (175 - 232)	20 - 22	19 - 23	60 - 40	0.2
IIá (233 - 290)	19 - 21	18 - 22	60 - 40	0.2
III (≥ 290)	18 - 20	17 - 21	60 - 40	0.3

Dependence of recommended duration of work on the ambient temperature has been elaborated. Our data show that our emergency situation criteria (ECI) of cold endurance corresponds to the subjective refusal to withstand the cooling environment. The results support the fact that the ECI values are determined by the rates of cooling that depend in turn on different ambient temperature. Recommendations for the admissible level of body cooling are to be verified by the results of medical examinations.

In a real industrial environment a worker, as a rule, avoids too much body cooling. He compensates the increase of heat loss by “behavioural” thermal regulation, for instance, by the increase of clothing thermal insulation, though in this case reduction of performance may occur due to restriction of movements. However, in some cases both general and local significant cooling may sometimes occur in persons with temperature sensitivity reduction, which impairs adequate assessment of actual heat status. This is observed in workers, for instance, in contact with cool fish, meat, dock workers, miners exposed both to cold and vibration. It is important, thus, for the prevention to establish

what levels of cooling (general and/or local) contribute to the development of pathologies.

Unfortunately data on quantitative interrelations are scarce, though persuasive results have been obtained for correlation of cooling values with the development of pathologies. These data have been cited in several papers [5;14;16]. Detailed morbidity analysis of subjects exposed to cold has been done Hassi (presented at this symposium).

Figure 5. Complaints of female workers at manual frozen fish processing. Air: $t_a=13.9\pm1.5$ °C; RH=88 %; $V_a=0.17$ m/s; Fish: $t_{surf}=7-12$ °C; $t_{water}=22-32$ °C; Skin: $t_{mean}=29.4\pm1.1$ °C; $t_{hand}=26.8\pm2.0$ °C (N=30, age 18–42 years, mean service length 4.2)

Complaints	n (out of N = 30)
Pains in hands	11
Chilliness of hands	7
Tiredness of hands	5
Numbness of hands	3
Blanching of fingers	1
Oedema of hands	1

Neurological status of examined group of workers

Symptoms	Number
Decreased skin temperature of hands	22
Oedema of hands	17
Cyanosis of hands (of different degrees)	11
Disorders of temperature and tactile sensitivity on skin of hands	8
Pains in hand and arm muscles	3

Figure 5 shows data on prevalence of some forms of symptoms in female workers in contact with cold fish. The most frequent symptoms are cold hands; they are pale, and with cyanosis, which indicates local peripheral vegetative impairment, or angiodystonial syndrome. In females exposed to general and local cooling, some decrease of general and local temperature sensitivity is observed. This is manifested by lower mean skin temperature (29.4 ± 0.15 °C) and lower back hand temperature (26.8 ± 0.38 °C) found at a level of comfortable thermal sensation. Corresponding skin temperatures of individuals not adapted to cold were 33.5 °C - 32.5 °C and 29.5 °C – 28.5 °C, respectively. This can partly be explained by the adaptation to cold and is confirmed by some researchers [10]. However, the development of pathologies in these persons does not allow the assessment of positive cold adaptations of this kind.

Significant skin temperature reduction was registered in miners of Murmansk exposed to combined effects of cold and vibration [15]. It seems important that in this case, workers' complaints to cooling were registered at lower skin temperature and greater heat deficit than in persons not adapted to cold. This reduction of temperature sensitivity in miners should be viewed in light of the development of pathologies resulting from supercooling. Data obtained by work at our institute support the finding that combined effects of cold and local vibration significantly decrease time during which pathologies due to vibration develop (Figure 6). They are found mainly in the form of vegetative-sensory polyneuropathy in combination with white finger symptoms. Therefore, it is advisable to assess environmental cooling effects by heat state criteria for persons not adapted to cold (Figure 2-3) [2].

The body heat state criteria given previously, are also the basis for a relevant calculation and assessment of clothing thermal insulation. To calculate thermal insulation for a set of clothes, the value of mean skin temperature is used with regard to admissible level of body cooling and the energy losses rate [2].

Figure 6. Combined effects of cold and hand-arm vibration (HAV)

Parameters	Mine	
	1	2
Metabolism rate, W/m ²	150	113
Air temperature, °C	5.0 ±1.4	12.8 ±1.7
Air velocity, m/s	0.7 ±0.1	0.8 ±0.1
Relative humidity, %	30 ±0.5	80 ±4.5
HAV weighted acceleration, a_{hw8} , m/s ²	4.8 ±1.9	1.9 ±0.2
Thermal sensation	comfort	slightly cool
Mean skin temperature, °C	27.5 ±0.2	26.9 ±0.5
Heat deficit, kJ/kg	3.7	5.3
Diagnosed class of vibration disease (N= 415)	91	173

Neurological status of workers (N= 415)

Neurological symptoms	Incidence rate, %
Pain in hands	27.2
Cyanosis of upper extremities	26.4
Hyperhydrosis	31.0
Hypothermia of hands ($t_{skin} = 25.7 - 26.7^{\circ}C$)	34.5
Blood flow velocity decrease	30.0

Figure 7. State standard GOST 29335-92 “Men’s clothes for low-temperature protection. Specifications.”

	Climatic zone			
	IA Arctic sea coast	IB East Siberia	II West Siberia and Ural	III Central
Thermal insulation, °C·m ² /W *	0.73	0.80	0.64	0.50
Air penetration of material package, dm ³ /m ² ·s	7 – 10	10 – 40	10 – 40	7 – 10
Permissible uninterrupted duration of stay in cold, hrs	1	1	2	2

*) in relatively calm air; insulation of cloth ensemble

Requirements for clothing insulation are determined in the Russian Federation by the State Standard (Figure 7) and consider the different climatic regions of the country [4]. To maintain performance of workers, required clothing insulation must allow a time for continuous stay at the cold. In regions II and III work time is less than two hours and in regions in IA and IB - one hour. It is assumed that moderate work is performed.

Problems of cold protection in different occupational situations are solved in accordance with the methodology, developed in our institute and approved by the Ministry of Health of the Russian Federation (Figure 8).

An appropriate heat balance of a worker exposed to different meteorological conditions considering also the type of job and metabolic rate, is ensured by relevant design of clothing having for example warm removable layers, ventilation etc. Figure 8 also lists a standard concerning a method for determination of total clothing thermal resistance with the participation of a man.

Figure 8. “Hygienic and physiological evaluation of clothing for protection against cold”
(Recommendations approved by Russian Health ministry, No. 5189 – 1990)

—Method for calculation of total thermal resistance of clothing (thermal insulation of ensemble);
—Method for determination of total thermal resistance of clothing with participation of a man (State standard GOST 12.4.185 – 96);
—Evaluation of the insulative function of clothing in conditions simulating occupational activity;
—Hygienic and physiological tests of clothing in situ.

Comparative assessment of clothing thermal insulation values and trials performed on volunteers and on a manikin (ISO/DIS 9920) showed similar results: the difference did not exceed 6 % [4a].

References

1. Afanasieva R, Burmistrova O. Physiological and hygienic requirements to clothes for workers' protection against cold on open air territories of North regions. *J Occup Med and Indust Ecol* 1996;6:10-15 (in Russian).
2. Afanasieva R, Repin G, Bessonova N, Babajan M. Problem of rating of microclimate at working places in industrial premises. *J Occup Med and Industr Ecol* 1996;12:14-18 (in Russian).
3. Afanasieva R. Heat loss rate from human body surface and heat state indices corresponding to subjective tolerance to cooling. In: *Problems of Medical Geography of the North*. Murmansk, 1986: 3-17 (in Russian).
4. Afanasieva RF. *Hygienic principles of clothing projection for cold protection*. Legkaya Industria, Moscow, USSR, 1977.
- 4a. Anttonen H, Hassi J, Mäkinen H, Afanasieva R, Basargina L. Assessment of heat resistance determination methods for clothes against cold. *J Industr Hygiene and Occup Diseases* 1990: 9: 18-21 (in Russian).
5. Dedenko I, Oustjushin B, Litkin B, Shmonin A, Ivanova T. Occupational health and heat exchange peculiarities of man during work on open air in Extreme North. In: *Problems of Medical Geography of the North*. Mourmansk, 1986: 57-64 (in Russian).
6. Fanger P. *Thermal comfort*. Copenhagen: Danish Technical Press, 1970:244pp.
7. Holmér I. *Work in cold environments*. Solna: National Institute of Occupational Health, 1994: 118 pp.

8. Ivanov K. The principles of energetics in organism: The general energetics, heat exchange, thermoregulation. Leningrad: Nauka, 1990: vol.1: 307 pp.
9. Kandror I, Demina D, Ratner E. Physiological principles of sanitary and climatic ranking of territories in the USSR. Moscow: Meditsina publishers, 1974: 175 pp (in Russian).
10. Kozireva T, Yakimenko M. On the temperature sensitivity of man to cold. *Physiol J USSR* 1978: 4: 220-225 (in Russian).
11. Koshcheev V. Physiology and hygiene of individual protection of man against cold. Moscow: Meditsina publishers, 1981: 288 pp.
12. Maistrakh E. Pathological physiology of man's cooling. Leningrad: Meditsina publishers, 1975: 215 pp.
13. Minut-Sorokhtina O. The physiology of thermoreception. Moscow: Nauka, 1972: 227 pp (in Russian).
14. Sidorenkov O, Lous E, Medvedev G. Clinical manifestations of chronic cold trauma. In: Problems of medical geography of the North. Mourmansk, 1986: 36-41 (in Russian).
15. Suvorov G, Afanasieva R, Losik T, Babajan M. Physiological and hygienic substantiation of requirements to the individual protective devices against cold for workers under exposure of hand-arm and whole-body vibrations. *J Occup Med and Industr Ecol* 1996: 5: 19-23 (in Russian).
16. Tarasova L, Komleva L, Doumkin V, Losik T. Peculiarities of peripheral neurovascular disorders between ore miners under cooling microclimate. *J Occup Med and Industr Ecol* 1994: 12: 14-17 (in Russian).
17. Tkachov A, Bojko E, Gubkina L, Ramenskaja E, Sukhanov S, ed. by Roshchevsky M. Endocrine system and metabolism of man in North. Siktivkar: Komi centre of Ural division of Russian Academy of Science, 1992: 156 pp.
18. Velichkovsky B, Chashchin V. Health care and some hygienic problems of work activity in North and Eastern regions of the USSR. In: Problems of medical geography of the North. Mourmansk, 1986: 3-17 (in Russian).

Influence of the outdoor cold air in winter on the microclimate and reactivity of workers from underground mines

H. Herman

Institute of Hygiene, Public Health, Health Services and Management, Bucharest, Romania

Introduction

Our studies made in the underground coal mines from point of view of occupational hygiene and health have showed that the microclimate is one of the most important factors of the working environment in this industrial sector. There are many differences between the meteorological conditions of the surface and the underground microclimate of the mines, which has a great influence on the health and work capacity of the human organism. The closed relation between the microclimate of the mine and the morbidity of miners, their thermal comfort during work and the number of accidents has been evidenced by some studies. We present in this paper an aspect of the underground microclimate in the coal mines, respectively the influence of the outside cold air in winter on this microclimate and the reactivity of workers, under the condition of the continental excessive climate.

Methods

Research methods included:

- Characterisation of workplaces, of access and transport ways, and work analysis.
- Measurement of microclimate factors outside and underground (in workplaces and galleries): air temperature, relative humidity, speed of air movement.
- Investigation on thermal state of body in 100 underground workers by skin temperature measurement on central (forehead, sternum) and peripheral (nose top, ear lobule) zones and by determination of thermal sensation according to the following notation: well, cool, cold, warm, very warm.
- Investigation of influence during the time of the microclimate conditions on the human body by statistic analysis of the morbidity with temporary disability for the diseases favoured by cooling (acute infections of the upper respiratory ways, angina, influenza, neuralgia, rheumatic state) of the underground and surface workers of the mines in a period of 2 years.

Results and Discussion

In the underground coal mines the galleries are access ways to and from the workplaces for the workers and transport ways for tools, materials, coal and sterile by trains with trucks. The main gallery between the entrance into the mine and the shaft platform has a length of about 2,000 m or more. For the engine mechanic of the train the transport galleries are the workplace of the whole workday. He makes shifts between the exterior and the shaft with the trucks empty or filled (5-10 shifts in a workday). The miners go through the main gallery by train or walking at the beginning and the end of the workday to and from their workplaces. The time of this passing is about 20-30 minutes. After the main gallery the miners go through other galleries, descend or mount by the shaft lift, by stairs. The workplaces are workings of coal deposits or advances into sterile. The work is manual (shovelling), manual-mechanised (excavating the rocks by pneumatic hammer) and mechanised.

In winter in the main and transport galleries there are great variations of temperature, humidity and air speed. The outside cold air penetrates by the mine opening into these galleries determining hard air currents of high speed (5-7 m/s) and low temperature (under and about 0 °C) till a distance of 1,000 m. Then the air speed begins to decrease and the air temperature increases. After the distance of 2,000 m the influence of the cold outside air is low and begins to vanish. The relative air humidity rises progressively from the mine entrance till 80-90 % at 1,500 m increasing the cold level of the microclimate.

Therefore the workers who make activities (coal transport, repairs) or go to and from the workplaces in these galleries are exposed to great microclimate variations, to cooling. The physiological investigation showed a great decrease of the skin temperature on the forehead and the sternum, under the normal value of about 32.5-33 °C, till 24.3 °C on the forehead, till 26.5 °C on the sternum, and also on the peripheral zones (under 18 °C). The thermal sensation was “cool”, “cold” and “very cold”. The engine mechanic of transport train was exposed at every transport from the shaft to exterior and at the return to great differences of air temperature, till 20-30 °C. At the work end the exposure to this microclimate condition is especially unfavourable for the miners who work in places with high temperature (till 30 °C). They go through these galleries warmed and sweaty because of the warm microclimate and the intense muscular effort. They may sicken of the diseases favoured by cooling because of the quick contact with the low air temperatures and the great air currents of the main gallery. Of course the workers' clothing has a great importance in response of the organism to the action of this microclimate.

It is known that the heat brakes the centres of thermoregulation and the whole thermoregulation mechanism regarding the production and the keeping of the heat in the body. Hence when the warm stimulus is quickly replaced by the cold stimulus, the thermoregulation mechanism does not react so promptly. Therefore the body should be exposed more easily to the cooling in absence of an adequate physiological reaction.

The statistic analysis of the morbidity showed a high percentage of the diseases favoured by cooling in winter, especially in the months of December, January and February, when in the main galleries of the mines there are the lowest temperature and the greatest air speed. The index of the specific weight (cases) of these diseases was in these months 28.6-29 %; in the warm months (June, July, August) this index was 18.8-23 %. The indices of frequency and of gravity for the cooling diseases were higher in winter for the underground workers than for the surface workers of the mine: frequency of 52-58 % and gravity of 264-286 % in the first case, respectively of 17 % and 167 %

in the second case. Regarding the acute infections of the upper respiratory ways, their frequency and gravity exceeded about 3-4 times for the underground workers (13.8-14.8 % and respectively, 51.5-52.7 %) the values of the surface workers (3.6 % and respectively, 14.8 %). This situation is very important for the health of the miners, especially for those who work in advances into sterile, with dust with free crystalline silicium dioxide. These diseases may favour the noxious action of the respective dust on the organism intensifying the possibility to produce silicosis.

Conclusions

The penetration of the outside cold air into the main and transport galleries of the underground coal mines in winter produces hard air currents of low temperature and great speed associated with a high air humidity, creating the condition of cooling for the body. The organism's reaction shows immediate effects, on the thermoregulation mechanism which has a tendency to cooling. In time the appearance of the diseases favoured by cooling has been evidenced, their frequency and gravity having greater values in winter than in summer, in the underground workers than in the surface workers. The personal protective clothing against this microclimate is very important for preventing the disorders, and of course the education of the workers regarding this problem is important. The obtained results are also an example of the appearance of the cooling and of its influence on the human body in the industrial work.

Use of personal heaters in cold work

T. Risikko, H. Anttonen

Oulu Regional Institute of Occupational Health, FIN-90220 Oulu, Finland

Introduction

Manual tasks in cold are often done with the bare hands or wearing thin gloves. Cold decreases manual performance and dexterity. In tasks involving low heat production, the feet and the central body are also cooled. Personal heating systems using combustion and chemical or electrical energy, have been developed (3, 4). Heat may also be transported (5). This study focused on the effects of heating on the hands and the whole body.

Table 1. The evaluated heaters and their target skin areas.

Heater	Energy	Target area
Bag filled with solid metal powder, reaction with water	chemical	fingers
Bag filled with solid metal powder, reaction with air	chemical	fingers
Bag filled with saline solution	chemical	fingers
Large heat bag filled with saline solution, belt	chemical	central body
High voltage wired glove (9.6 V * 0.52 A = 5 W)	electrical	hand / back
Low voltage wired glove (1.5V * 0.67A = 1 W)	electrical	fingers
Low voltage wired socks (1.5 V * 0.67 A = 1 W)	electrical	toes
Charcoal burner, distribution tubes	combustion	central body

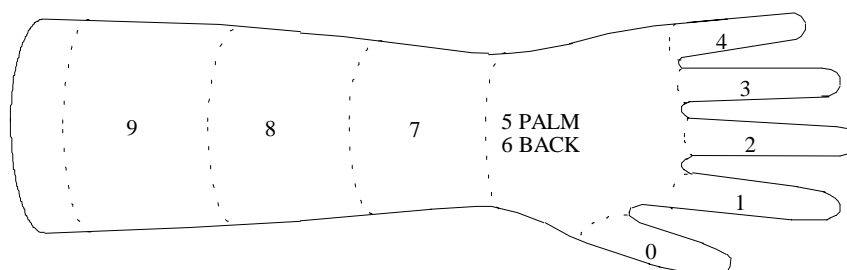


Figure 1. The measuring zones (0-6) and guard rings (7-9) of the hand model (2).

Materials and methods

The evaluated heating systems are shown in Table 1. The effect of heating on the heat loss of the hand was measured using a hand model (2) in a climatic chamber ($T_a = -10$ °C, $v=1$ m/s). The thermal hand has seven zones in which the surface temperature is kept at +20 °C (Figure 1). The thermal insulation of the reference glove and mitten was $0.25 \text{ m}^2 \text{ K/W}$ (1.6 clo). The effect of external heating on mean skin temperature and

rectal temperature was evaluated by using test subjects. The test subjects did light work (110 W/m^2) in a climatic chamber ($T_a = -20 \text{ }^\circ\text{C}$, $v = 1 \text{ m/s}$). The skin temperatures and the rectal temperature were recorded.

Results

Depending on the system, the heated area was 10-40 % of the surface of the hand model. The decrease in heat loss of the target zone was maximally 100 % (Table 2). The temperature of the hand rose in the cases where excessive heat was transferred from the heater to the hand.

Heaters that distributed the heat over a large skin area were best for central body heating. Heating of the extremities only did not affect the mean skin temperature.

Table 2. The maximum decrease in the heat loss ΔP (%) caused by the hand heaters, average of 10 minutes. Measurements with thermal hand ($T_a = -10 \text{ }^\circ\text{C}$, $v = 1 \text{ m/s}$).

Heater	target area	ΔP (%) middle finger	ΔP (%) palm	ΔP (%) back	ΔP (%) whole hand
Heat bag (metal powder + water)	fingers	100	32	0	36
Heat bag (metal powder + air)	fingers	100	33	3	41
Bag filled with saline solution	fingers	100	83	3	52
High voltage wired glove (5 W)	hand / back	39	70	100	64
Low voltage wired glove (1 W)	fingers	37	0	10	34

Discussion

In order to warm up the human hand efficiently, a minimum power of 5-6 W is needed per hand, as also shown in previous studies (1). Due to the higher core temperature, warming of the central body is relatively more efficient. By heating the central body and hands, the climatic utility range of the clothing may change temporarily by $10 \text{ }^\circ\text{C}$ in light work (110 W/m^2) according to the IREQ index. The results show the benefit of external heating, although the heaters still need to be developed further.

References

1. Clark, R. P. & Edholm, O. G. Man and His Thermal Environment. London, 1985.
2. EN 511. Protective gloves against cold. CEN, 1994: 10 p.
3. Haisman, M. F. Physiological Aspects of Electrically Heated Garments. Ergonomics 1988; 31(7): 1049-1063.
4. Madnick H, Goldman R.F. Cold-weather hand covering having selectively-shaped chemical heating element receiving chamber. Patent. Multi-Tech Corporation, England, 1988.
5. Martini S et al. The Effect of Auxiliary Heating of Hands and Body during Cold Exposure on Soldier Marksmanship on Anti-armour Weapons (TOW) under Field Conditions. Proceedings of the 6th Int. Conf. of Environmental Ergonomics; 1994. Montebello, 1994: 264-265.

Evaluation of thermal stress in cold regions - a strain assessment strategy

I. Holmér

Department of Occupational Medicine, National Institute for Working Life, Solna, Sweden

Introduction

Exposure to cold environments comprises a significant hazard with risks of adverse effects on human comfort performance and health. The many different effects of cold on the human body are the subject of this symposium and have been reviewed by several authors (4-8, 10, 12-14, 20-23, and 27)

Cold acts in many ways resulting in different types of cold stress, each representing a specific effect on the human body as a whole or locally (13). This paper presents a general strategy for assessment of the different types of cold stress.

Types of cold stress

Figure 1 illustrates the different types of cold stress and the associated environmental climatic factor (13). The most pronounced and serious effect is general body cooling (hypothermia). The different types of local cooling can develop without any significant threat to the whole body.

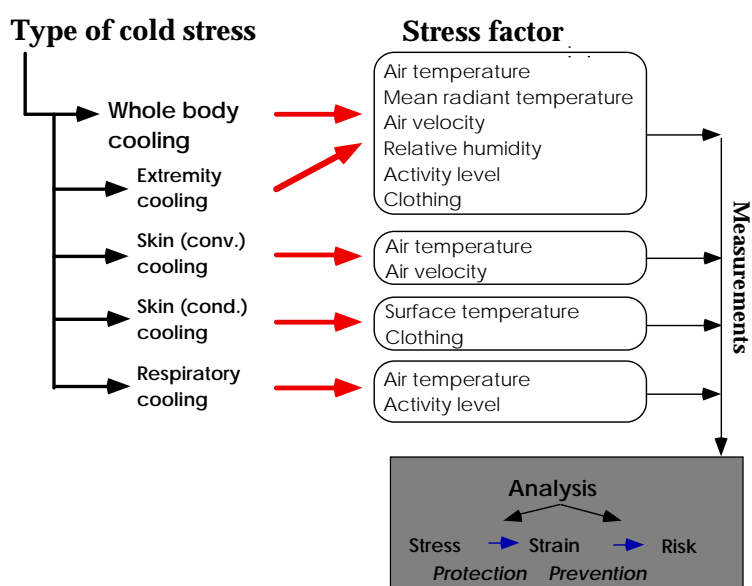


Figure 1. Different types of cold stress and the associated environmental climatic factors.

Effects of cold stress

The primary effect and common pattern of each type of cold stress is tissue cooling. Depending on the extent and intensity of tissue cooling a sequel of effects develops. Most, if not all, of them are associated with all types of cold stress. Figure 2 gives an indication of the components of this sequence of effects. It is likely that the first response to a mild cold stress is thermal discomfort. It is also likely that mental effects dominate with light cold stress and cold injuries with severe cold stress. For some of the effects, such as cardio-respiratory effects and non-freezing cold injury the aetiology becomes more complex. Circulatory and respiratory effects appears to be very acute and may be triggered also by low levels of cold stress, partially as function of poor individual protection (11, 17-19). The sequence shown in Figure 2 is indicative. Depending on type of cold stress the order of effects may change. It is likely, for example, that cooling due to contact with very cold metals results in local frostbite within few seconds (1).

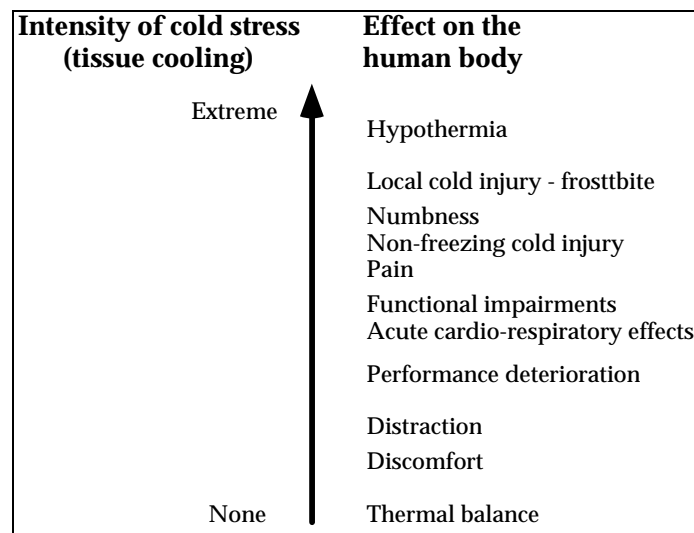


Figure 2. Effects of cold stress on humans.

Risk and strain assessment

The purpose of a risk assessment strategy is to analyse in a systematic way the possible risk of defined effects to occur under given exposure conditions. The strategy should contain

- a particular, measurable effect (e.g. frostbite or pain sensation)
- a dose-response relation between effect and cold stress
- a distribution of individual variation in the population

Risk assessment is usually associated with health effects - the probability of developing a symptom or a disease under given exposure conditions. For most types of cold effects representative samples of the "population" and, accordingly, distribution curves are missing. The technique, however, can be used for assessment of the "risk" of developing discomfort, pain sensation, functional impairment, performance decrement and, eventually, cold injury. The "risk" level is then expressed in terms of type of effect (or **strain**) found (or expected) in the average individual, rather than in number of persons (probability) showing defined symptoms under given exposure conditions - **strain assessment**. Figure 3 gives an illustration of the effect assessment strategy. At

very low levels of cold stress there is a minimal risk of developing symptoms (others than discomfort). However, some effects are observed at much lower levels of stress than others are. The risk (or probability) of seeing these effects can be very high also at moderate levels of cold stress (e.g. discomfort). A risk of developing hypothermia is only associated with very severe cold stress.

In the following a procedure for general evaluation of cold stress is presented based on defined cold effects (levels of strain). Three levels of strain are identified, representing a no, medium and high strain, respectively. The levels are

Level 1: no strain - comfort for the average, discomfort for some individuals

Level 2: medium strain - performance degradation, functional imbalances (e.g. tissue cooling)

Level 3: high/severe strain - injuries (e.g. hypothermia, frostbite)

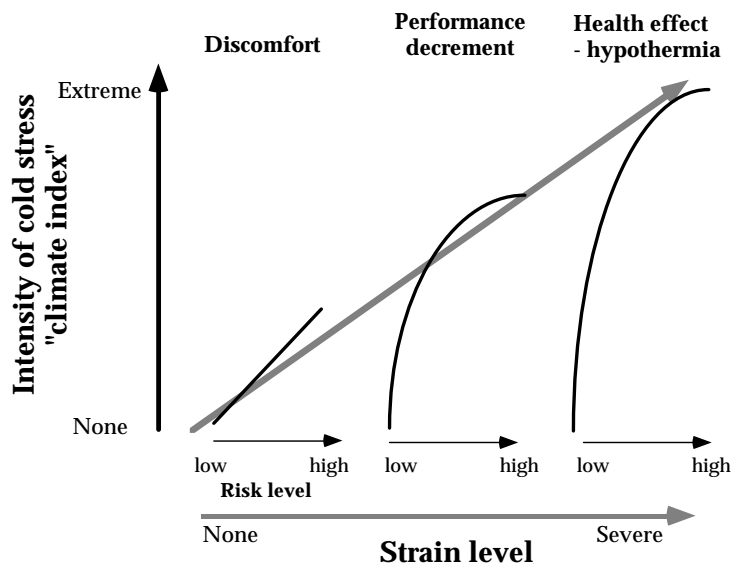


Figure 3. Schematic illustration of the terms risk level and effect level. The relations are not necessarily of the form indicated by the curves.

Whole body cooling

Whole body cooling results from an imbalance between the heat production of the body (mainly determined by physical activity level) and its heat losses. The climatic factors and the properties of available clothing determine heat losses. When heat production cannot match the progressively increasing heat losses, superficial tissue cooling starts and develops into body core cooling, leading to low and, eventually, fatal body temperatures (12). The process can be analysed with a heat balance equation. ISO/TR 11079 (15) describes such an equation. The equation calculates the required clothing insulation (IREQ) for preserving heat balance at defined levels of physiological strain.

Two types of evaluation can be done

1. based on required clothing insulation
2. based on available clothing insulation

Figure 4 shows the required insulation level for the maintenance of heat balance for the three levels of criteria (no, medium and severe strain). The lines apply to one activity level (100 W/m^2). The main purpose of this kind of information is to provide an estimation of the safety requirements (amount of clothing insulation) associated with

the different effects. Time is an important factor for strain to develop. The graphs in figure 4 provide an estimation of the requirements for the maintenance of body heat balance at the defined levels of strain for infinite time.

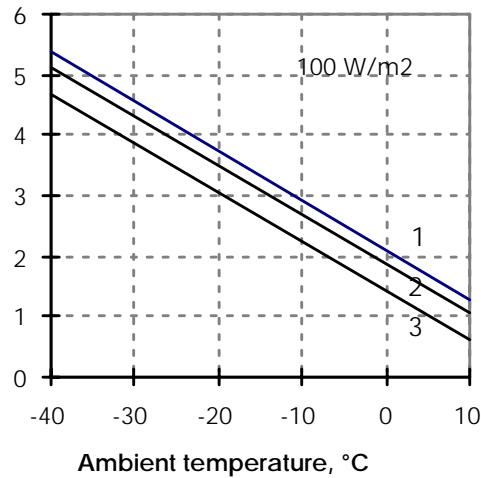


Figure 4. Required insulation calculated for three levels of physiological strain.

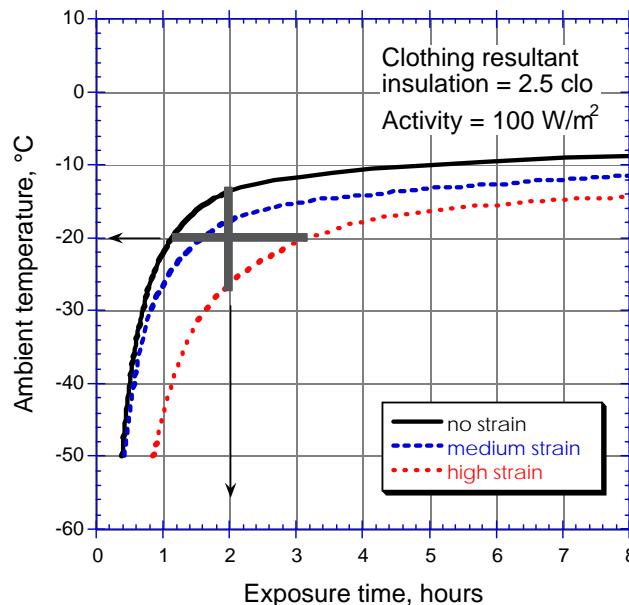


Figure 5. Time limited cold exposure based on three levels of physiological strain.

Once the available clothing insulation value is known, it is possible to calculate a time limited exposure on the basis of the difference between required (IREQ) and available insulation. This can be done for the three levels of strain discussed before. However, a more realistic and useful approach is to assume that exposure starts from "comfortable" conditions (no strain). When available clothing insulation is insufficient, tissue cooling will follow and the level of strain is determined by the amount of cooling developed with time. A short exposure will cause discomfort at most, whereas more severe will occur with progressive tissue cooling.

Figure 5 shows an example. The three curves represent three levels of strain:

- no body heat debt
- 40 Wh/m² heat debt
- 80 Wh/m² heat debt

Two interpretations can be made:

- At -20 °C the defined conditions will result in different levels of strain after 1, 2 and 3.2 hours, respectively.
- A 2-hour operation will result in the three levels of strain at temperatures of -13, -20 and -26 °, respectively.

Extremity cooling

The local heat balance determines extremity cooling. Heat input by circulating blood and heat loss mainly by convection, radiation and conduction. Heat input is largely determined by the general thermal status of the body and metabolic rate. The worst condition occurs with low activity and vasoconstriction. Heat losses depends mainly on air temperature, wind and protective insulation (gloves, boots).

Some limit values for hand cooling are suggested in ISO/TR 11079. The three levels of strain are proposed as follows:

Level 1: no strain - finger skin temperature at 24 °C (discomfort for some individuals)

Level 2: medium strain - finger skin temperature at 15 °C (pain, performance degradation, functional imbalances, e.g. tissue cooling)

Level 3: high/severe strain - finger skin temperature at 8 °C (pain, numbness, and non-freezing cold injury)

Shitzer has proposed a model for prediction of finger cooling ((25). Figure 6 shows calculation of exposure times for level 3 for a cold person (low activity) and a warm person (high activity). Predictions apply to still wind conditions and warm gloves (3.2 clo). The importance of activity is readily shown in longer stay times and lower temperatures of infinite exposures.

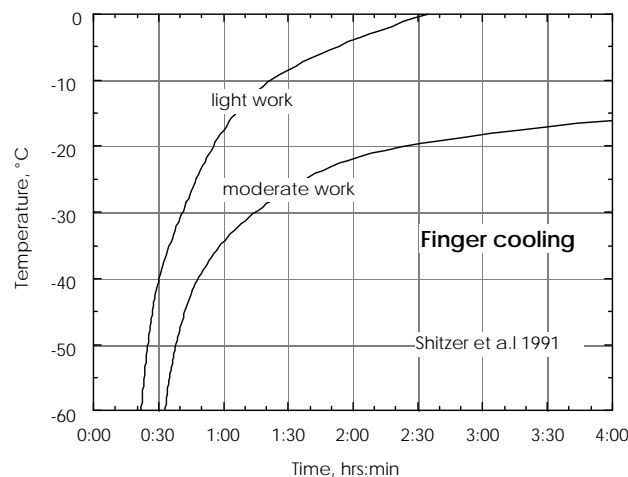


Figure 6. Example of time limited exposure for finger cooling.

Convective skin cooling - wind chill

Wind chill is probably the most common cold effect experienced by people. The classic wind chill index - WCI (26) has long served the purpose of warning people staying outdoors for the high heat losses associated with low temperatures and wind. The method applies to bare skin, only, and the most susceptible area is the face. The simplicity of the approach to evaluate the risk by a “chilling temperature” has made it popular and used world-wide. The rationale behind the WCI has been criticised (3, 16).

The WCI is insensitive to very high wind speeds (even decreases cooling!) and indicates a slightly lower risk at moderately cold environments. Nevertheless, the standard table for chilling temperature can be used as a “first” estimate of the cooling effect (Table 1). However, more research can provide better background for the suggested criteria.

Level 1: no strain - skin temperature above 20 °C (discomfort for some individuals)

Level 2: medium strain - skin temperature at 10 °C (pain, sensory loss)

Level 3: high/severe strain - skin temperature below 0 °C (cold injury, frostbite)

Table 1 shows the temperature under calm conditions (chill temperature) that results in the same heat loss as the actual temperature and wind conditions. Detailed information about relation between the chill temperature and level 1 and 2 effects is not readily available and requires more investigation. The critical temperatures (-30 and -60 °C) correspond to risk of frostbite and are strongly time dependant.

Table 1. Cooling effect of wind at low temperatures, expressed as a chilling temperature. A risk of frostnip emanates at a chill temperature of -30 °C and frostbite may occur in a few minutes at -60 °C and lower.

Wind m/s	Air temperature, °C					
	0	-5	-10	-15	-20	-25
2	-2	-7	-12	-17	-23	-28
7	-11	-17	-25	-32	-38	-45
11	-16	-23	-31	-38	-46	-53
16	-18	-26	-34	-42	-49	-57
20	-19	-28	-36	-43	-52	-59

Contact cooling

A cold environment comprises many occasions for skin contact with cold objects - intentional or accidental. In particular, contact with metal surfaces by bare skin causes rapid cooling of the skin area in contact. Models for prediction of skin temperature in contact with cold (or hot) surfaces are under development (1, 2, and 24).

Important physical factors for contact cooling are surface temperature of the material, material mass and heat conductance, contact pressure and size of contact area. Tissue properties, temperature at the onset of contact and heat input are important physiological factors. Based on available empirical studies the following criteria are suggested. However, much more investigations with different materials are necessary to develop a general model.

Level 1: no strain - skin temperature above 15 °C (discomfort for some individuals)

Level 2: medium strain - skin temperature at 7 °C (pain, sensory loss)

Level 3: high/severe strain - skin temperature below 0 °C (frostbite)

Respiratory cooling

A specific and local type of cold stress is the inhalation of cold air. The human respiratory tract is an effective heat exchanger. However, at very low and/or at high ventilation rates cold air may penetrate deep into the lung (14). Anecdotes from northern Siberia say that children can play outside for 20 minutes at -45 °C, but get injured at -55 °C. The ACGIH limits for cold work recommends 30 minutes at -38 °C

and no exposure at -55 °C. Recent findings (9) indicate that inhalation of cold air may cause inflammatory responses of the mucosal membrane.

One conclusion is that cooling of the respiratory tract may be harmful when the cooling power reaches a defined level -presently unknown. With light work the ambient temperature may be very low (less than -40 °C), but at high activity levels it should be as high as -20 or -15 °C. A support for this conclusion is that endurance event in winter sports do not take place at temperatures below -18 to -20 °C. One reason is the anticipated severe cooling that will take place due to the very high ventilation volumes with endurance work (14).

Conclusions

Cold environments present a multi-factorial stress situation. General hypothermia is the imminent hazard with severe cooling conditions, but several types of local cold stress may develop under moderately cold conditions.

A rational approach to the assessment of cold stress must identify and quantify all types of effects of cold stress.

Existing models for prediction of cold effects can be used, but suffer from limitations in terms of validity and relevance.

Type of effect or strain can be based on the severity of effect from none or low strain to high or severe strain. The criteria associated with different levels of strain can be identified but more research is needed to validate them and to quantify risk levels.

The approach may be useful as a first estimate of possible effects of different exposure scenarios.

Acknowledgement

Supported by grants from the Swedish Council for Work Life Research.

References

1. Chen F, Nilsson H, Holmér I. Cooling responses of finger pad in contact with an aluminum surface. *Am Ind Hyg Assoc J* 1994;55:218-222.
2. Chen F, Nilsson H, Holmér I. Finger cooling by contacting cold aluminium surfaces - effect of pressure, mass and whole body thermal balance. *European Journal of Applied Physiology* 1994;69:55-60.
3. Danielsson U. Wind cooling. *Journal of Applied Physiology* 1994;:164-165.
4. Ellis HB, Wilcock SE, Zaman SA. Cold and performance: The effects of information load, analgesics, and the rate of cooling. *Aviat Space Environ Med.* 1985;56:233-237.
5. Enander A. Performance and sensory aspects of work in cold environments: a review. *Ergonomics.* 1984;27(4):365-378.
6. Enander A. Sensory reactions and performance in moderate cold [Doctoral]. National Institute of Occupational Health, 1986.
7. Fanger PO. Thermal comfort. Copenhagen: Danish Technical Press, 1970
8. Francis TJR. Non freezing cold injury: A historical review. *Journal of Royal Navies Medical Services* 1984;70:134-139.

9. Gavhed D, Palmberg L, Holmér I, Müller-Suur C, Tornling G, Larsson K. Airway inflammation in healthy subjects following inhalation of cold air. In: Holmér I, Kuklane K, ed. Problems with cold work. Stockholm: Arbetslivsinstitutet, Arbete och Hälsa., 1997:
10. Granberg P-O. Cold physiology and cold injury. In: Lotens WA, Havenith G, ed. Proceedings of the Fifth International Conference on Environmental Ergonomics. Maastricht, the Netherlands: , 1992: 54-55.
11. Gyllerup S. Cold as a risk factor for coronary mortality [Medical Doctor]. University of Lund, 1992.
12. Hamlet MP. Human Cold Injuries. In: Pandolf KB, Sawka MN, Gonzales RR, ed. Human Performance Physiology and Environmental Medicine at Terrestrial Extremes. U.S. Army Research Institute of Environmental Medicine, 1988: 435-466.
13. Holmér I. Work in the cold. Review of methods for assessment of cold stress. *Int Arch Occup Environ Health* 1993;65:147-155.
14. Horvath SM. Exercise in a cold environment. *Exercise and Sports Sciences Reviews* 1981;9:221-263.
15. ISO/TR-11079. Evaluation of cold environments - Determination of required clothing insulation (IREQ) [Technical Report]. International Standards Organisation, 1993.
16. Kaufman WC, Bothe BS. Wind chill reconsidered, siple revisited. *Aviat Space Environ Med.* 1986;57:23-26.
17. Keatinge WR, Donaldson GC. Eurowinter1. 1997;.
18. Keatinge WR, Donaldson GC. Eurowinter2. 1997;.
19. Lassvik C. Angina pectoris in the cold. Effects of cold environment and cold air inhalation at exercise tests [Medical Dissertation No 67]. Linköping university, 1979.
20. Litchfield P. Manual performance in the cold: a review of some of the critical factors. *J Roy Nav Med Serv* 1987;73:173-177.
21. Meese GB, Kok R, Lewis MI, Wyon DP. The effects of moderate cold and heat stress on the potential work performance of ind workers. Performance of tasks in relation to air temp under eight environmental conditions. CSIR research report 381/2. , 1981:
22. Mills WJ. Cold injury. *Alaska Medicine* 1991;35:1.
23. Oksa J. Cooling and neuromuscular performance in man [Doctoral]. University of Jyväskylä, 1998.
24. Parsons KC. Contact between human skin and hot surfaces equivalent contact temperature (T_{ceq}). In: Lotens WA, Havenith G, ed. The Fifth International Conference on Environmental Ergonomics. Maastricht: TNO Institute for Perception, Soesterberg, The Netherlands, 1992: 144-145.
25. Shitzer A, Stroschein A, Santee WE, Gonzalez RR, Pandolf KB. Quantification of conservative endurance times in thermally insulated cold-stressed digits. *J Appl Physiol* 1991;71(6):2528-2535.
26. Siple PA, Passel CF. Measurements of dry atmospheric cooling in subfreezing temperatures. *Proc American Philosophical Society* 1945;89(1):177-199.
27. Wilkerson JA, Bangs CC, Hayward JS. Hypothermia, Frostbite and other Cold Injuries. Seattle, Washington: The Mountaineers, 1986

The effects of work intensity on thermal responses in calm air and in wind at -10 °C

T. Mäkinen, D. Gavhed, I. Holmér*, H. Rintamäki*

Oulu Regional Institute of Occupational Health, Aapistie 1, FIN-90220, Oulu, Finland.

*National Institute for Working Life, S-171 84 Solna, Sweden.

Introduction

In cold ambient conditions wind increases heat loss. Physical exercise, although it increases heat production, also decreases insulation of clothing (1, 2). Through body movements the convection between clothing surface and air increases. At the same time air movements increase inside the clothing by the pumping effect, which also increases convection. Wind may compress the clothing and reduce the insulation, and through sweating the clothing can get wet. The effects of physical exercise and the exercise intensity, on thermal responses in cold and windy conditions are not fully known. The aim of this study was to investigate the effects of wind on thermoregulatory responses during two different work levels in the cold.

Methods

Eight young, healthy, men volunteered as test subjects. Their mean (\pm SD) age was 23 ± 2 years, height 179 ± 4 cm, weight 73 ± 7 kg, and body fat 14 ± 3 %. Before the wind exposure the test subjects were exposed for 60 minutes to "thermoneutral" temperature ($+20$ °C) in the climatic chamber.

During a 60 min wind exposure the subjects walked on a treadmill at a speed of $2.8 \text{ km}\cdot\text{h}^{-1}$ in a wind tunnel. The work level was adjusted by changing the inclination of the treadmill between 0° (lighter work level, energy expenditure 138 W, LW) and 6° (higher work level, energy expenditure 232 W, HW), thus keeping the same walking speed in all experiments. Moreover, the work levels were light enough not to produce heat load and sweating. The temperature in the wind tunnel was -10 °C, and the wind speed was 0.2 ("calm") or $5 \text{ m}\cdot\text{s}^{-1}$. Subjects wore a standard Finnish military winter clothing, which consists of a three-layer clothing made from synthetic and semi-synthetic fabrics (basic insulation 2.2 clo). Skin (18 sites) and rectal temperatures, heart rate, and oxygen consumption were measured.

Results

Rectal temperature (T_{re}) was higher at the end of HW than LW both at calm air and at $5 \text{ m}\cdot\text{s}^{-1}$ wind (Table 1). Increased wind velocity did not have effects on rectal temperature. The mean skin temperature (T_{sk}) was lower at $5.0 \text{ m}\cdot\text{s}^{-1}$ than in calm air (Table 1). An

interaction between exercise and wind was only observed for the skin temperatures of the hand, lower arm and finger; The temperature was highest in calm air during HW compared to the other tested conditions.

Table 1. Temperatures at the end of wind exposures. Values are means of the eight subjects.

	LW		HW	
	0.2 m·s ⁻¹	5.0 m·s ⁻¹	0.2 m·s ⁻¹	5.0 m·s ⁻¹
T _{re}	37.1	36.9	37.5	37.4
T _{sk}	28.7	25.7	29.0	26.1
T _{ant}	31.0	27.5	31.1	27.3
T _{post}	29.0	28.6	29.8	29.4

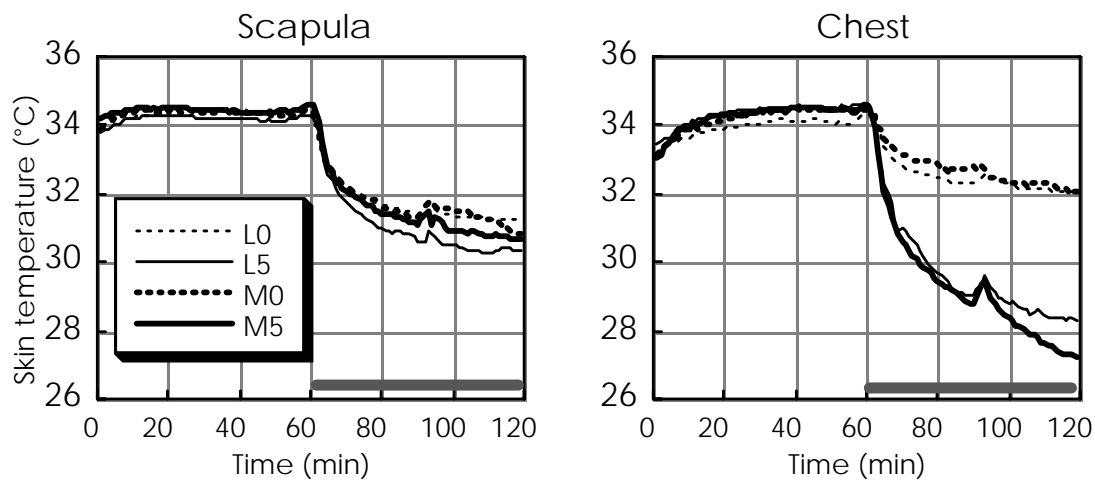


Figure 1. Average scapula and chest skin temperatures of eight subjects. L0 = lighter work at calm air, L5 = lighter work at 5 m·s⁻¹, H0 = higher work at calm air, H5 = higher work at 5 m·s⁻¹. The grey bars show the duration of the cold exposure.

As expected, the cooling effect of wind was more pronounced in skin temperatures for the frontal parts of the torso than for the posterior parts (Figure 1). This was also reflected by the calculated mean of all anterior (T_{ant}) and mean of all posterior (T_{post}) skin temperatures (Table 1). At the back side of the body, the wind induced decrease in skin temperatures was smaller than at the front (Figure 1). The average skin temperatures of the front part of the legs were higher at the higher work level in both air velocities.

The heat produced in HW at calm condition effectively prevented the cooling of the hands compared to LW (Figure 2). During HW at 5 m·s⁻¹ wind the hands cooled at the same rate as they did in calm conditions. The oxygen consumption (VO₂) was 2.4 ml·min⁻¹·kg⁻¹ higher (24 %) at 5 m·s⁻¹ wind than at calm conditions during LW. An explanation could be that the energy cost of walking is increased when the muscles are cooled. During HW the corresponding increase was 1.0 ml·min⁻¹·kg⁻¹ (7 %). The average heart rate was higher during HW (85 S.E. 5) than at LW (73 S.E. 3), but unaffected by wind speed.

Conclusions

Wind decreased the skin temperature of most parts of the body. However, the wind-induced decrease in skin temperatures was most pronounced in the frontal parts of the torso due to direct effects of the wind.

The higher work level resulted in a heat production enough to prevent large skin cooling of the hands at calm conditions and shivering. However, at $5 \text{ m}\cdot\text{s}^{-1}$ wind the convective cooling of hands was too large to maintain a stable hand skin temperature and shivering occurred.

The effect of wind on hands and tibial temperature in the cold was affected by the exercise intensity.

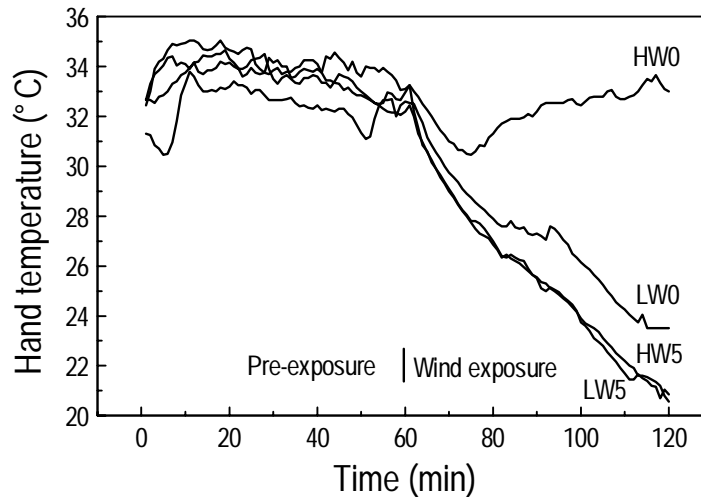


Figure 2. Back of the hand skin temperature of one test subject. LW0 = lighter work at calm air, LW5 = lighter work at $5 \text{ m}\cdot\text{s}^{-1}$, HW0 = higher work at calm air, HW5 = higher work at $5 \text{ m}\cdot\text{s}^{-1}$.

Acknowledgement

Supported by grants from the Finnish Work Environment Fund and the Swedish Council for Work Life Research.

References

1. Havenith, G., Heus R. & Lotens WA. (1990): Resultant clothing insulation: a function of body movement, posture, wind, clothing fit, and ensemble thickness. *Ergonomics* 33: 67-84.
2. Nielsen R., Olesen BW. & Fanger PO. (1985): Effect of physical activity and air velocity on the thermal insulation of clothing. *Ergonomics* 28: 1617-1631.

Validation of local temperature criteria in ISO TR 10079

D. Gavhed, T. Mäkinen¹, H. Rintamäki¹, I. Holmér

Department of Occupational Medicine, National Institute for Working Life, S - 17184 Solna, Sweden

¹Oulu Regional Institute of Occupational Health, FIN-90220 Oulu, Finland

Introduction

Heat production is particularly important to maintain heat balance in cold conditions. However, many occupational tasks imply low physical work loads and thus at low metabolic rates, e.g. guarding and surveillance and truck driving in cold stores. In those conditions, problems with cold extremities are common. The larger the cooling of the body, the larger becomes the negative effects for the individual, ranging from discomfort to impaired performance to pain. Impaired performance and pain is unacceptable at occupational work, both from human aspects and from productivity aspects.

To prevent unacceptable cooling the IREQ/DLE method, described in the international standards organisation (ISO) technical report 11079 (1) was developed. IREQ predicts the required insulation in a cold environment and is based on calculations of the heat balance at the actual conditions.

If, the existing insulation is too low for the actual conditions, an acceptable exposure time, DLE (duration limited exposure), can be calculated. The purpose of DLE is to prevent progressive body cooling. DLE may be calculated for two levels of strain, a low strain and a higher strain. The lowest strain (DLE_{neutral}) assumes cooling from a thermoneutral level, the highest from a slightly cool level. The net heat debt during the cold exposure is assumed to be approximately 40 Wh/m².

Methods

A validation of DLE_{neutral} was made on data from eight healthy male subjects in a cold chamber. The subjects had no history of cold injury. All subjects performed four experiments, three times standing at three air velocities (0.2, 1, 5 m/s) at -10 °C for 30 min, and one sitting at -5 °C in calm air for 60 min. The subjects were dressed in winter clothing. The standard basic insulation of the clothing was 2.2 clo. This was not enough to maintain thermoneutrality according to IREQ. The experimental time corresponded to the calculated DLE_{neutral} time for the actual conditions.

Rectal temperature, mean skin temperature, hand and finger skin temperature were measured continuously at 1 min intervals throughout the experiment. The subjects also rated body thermal sensation and pain sensations. Moreover, acceptance of these sensations during a full working day was rated.

Results and discussion

At the start of exposure, the subjects rated ‘thermoneutral’ or warmer in 29 out of 32 experiments. The mean skin temperature (T_{sk}) was at this point at average 32.9 °C, which is about 1 °C less than calculated by the comfort equation by Fanger (2). T_{sk} at DLE was at lowest, 26.6 °C, at 5 m/s and -10 °C.

The rectal temperature was maintained within 0.3 °C throughout the exposure in all conditions. The hand temperature was significantly lower at 5 m/s than at lower air speeds ($p < 0.05$). The thermal sensations were predominantly cold or very cold at DLE. Half of the subjects only accepted 0.2 m/s “at several occasions a working day”, but not continuously. Notably, seven subjects reported pain sensations in the face in 5 m/s at DLE. Pain sensations in the face were more common and stronger with higher wind speeds. Consequently, the frequency of acceptance decreased with higher wind speed. Wind had also a significant effect on the thermal responses.

The average hand temperatures were above the recommended minimal temperature, 24 °C, at DLE in all conditions, which has been suggested in ISO TR 10079 (Figure 1). However, in three individuals the hand temperatures went below 24 °C at DLE. Moreover, fingers were much colder than the hands, the average finger temperature being 15-18 °C at DLE (Figure 1). Such low temperatures are not acceptable for safely performing manual work tasks, since manual function is known to be impaired when finger temperatures are lower than 20 °C (3) and at 15 °C the deterioration is substantially decreased.

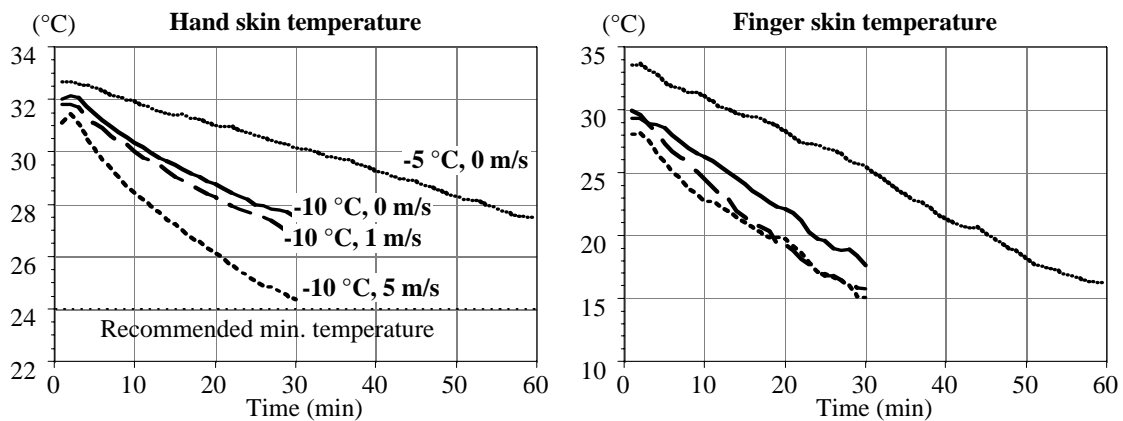


Figure 1. Average hand and finger temperature of eight subjects at cold exposure. The exposure ended at $DLE_{neutral}$

Conclusions

$DLE_{neutral}$ predictions of minimum hand temperature fitted well with the average values of the experimental data, i.e. the recommended levels were not passed. However, the wind effect seemed to be slightly underestimated in IREQ calculations, since some subjects had lower hand temperatures than recommended at 5 m/s.

DLE should prevent hand cooling of most individuals at least at the 24 °C level. Therefore we suggest that 95 % of the thermal responses to cold exposure of the normal working population should be included to protect the majority of exposed persons to severe hand cooling and that the wind effect must be considered in IREQ.

A minimal finger temperature, as the coldest site, may constitute a better criteria for extremity cooling and replace the hand temperature in the recommendations in ISO

10079. The criteria levels should also possibly be dependent on the type of work, i.e. in situations where manual performance is demanded. Also subjective responses as pain should be considered in the criteria of the index.

Subjective stress (thermal sensation and pain) should also be considered in the index. Corrections based on these conclusions would thus result in a shorter DLE at least for windy conditions.

Acknowledgement

Supported by grants from the Swedish Council for Work Life Research and the Finnish Work Environment Fund.

References

1. ISO/TR-11079, Evaluation of cold environments - Determination of required clothing insulation (IREQ), International Standards Organisation, Geneva, 1993
2. Fanger, P. O. *Thermal comfort*. Copenhagen, Danish Technical Press, 1970
3. Enander A. Performance and sensory aspects of work in cold environments: a review. *Ergonomics* 1984;27(4):365-378.

Estimated insulation of clothing worn in cool climates (0-15 °C) compared to required insulation for thermal neutrality (IREQ)

B. Griefahn

Institute for Occupational Physiology at the University of Dortmund, Ardeystr. 67, D-44139 Dortmund, Fed. Rep. Germany

Introduction and objectives

As an analytical index for cold stress that integrates the effects of air and mean radiant temperature, humidity, velocity, and metabolic rate $IREQ_{neutral}$ defines the insulation required to maintain thermal equilibrium at a normal level that is no or minimal cooling of the body.

To proof the applicability of the IREQ-model for men and women, for air temperatures above +10 °C, and for transient conditions due to changes of temperatures and workloads clothing insulations worn by workers in moderate cold were compared with the corresponding insulation calculated as prescribed by the IREQ-model.

Methods and material

The study concerned 75 workers (16 women, 59 men, 16 - 56 yrs) who were daily exposed to air temperatures between 0 °C and 15 °C and observed during a shift each. Their clothing insulation and metabolic rates were estimated (ISO 9920, ISO 8996, resp.). Air temperature, humidity and velocity at the individual workplaces were measured (ISO 7726); stays in different climates were documented and $IREQ_{neutral}$ was calculated (ISO/TR 11079).

The recorded parameters were height and weight of the subjects, general thermal sensation (7-point scale), skin temperatures at the scapula (YSI 427), for 39 subjects skin temperatures at the chest and at the lower back, rectal temperatures (depth 10 cm, YSI 401), and heart rates were registered as well.

The subjects were grouped according to exposure pattern and mean air temperatures: 32 persons worked in air temperatures between 0 and 10 °C, 33 worked in 10 to 15 °C, and 10 experienced frequent temperature changes ($T_a \approx 10$, individual range 13 °C). Another grouping concerned workload and the cutpoints were taken from ISO 8996: 8 persons worked at less than 100 W/m², 50 worked at 100 to 164 W/m², and 17 persons worked at 165 W/m² or more.

Results and discussion

Methodological aspects. Estimation of clothing insulation and metabolic rates

Estimation of clothing insulations and metabolic rates are susceptible to errors which may result in differences between estimated and calculated clothing insulations. Estimated metabolic rates were in accordance with the literature but I_{cl} deviated from $IREQ_{neutral}$ by about 35 % which is not unusual even for experienced appraisers. Due to the systematic deviation and the highly reliable appraisal the data were standardised to $IREQ_{neutral}$ which still did not affect the relations between the data and allowed to analyse several influences on the applicability of the IREQ-model.

Influences on the applicability of the IREQ-model

Concerning general thermal sensation that varied between less than slightly warm and slightly cold, skin temperatures which indicated thermal comfort, core temperatures and heart rates that averaged 37.6 °C and 95.2 bpm the workers were adequately dressed.

Analyses of variance revealed that air temperatures and age did not affect the deviations between estimated and calculated insulation but gender and workloads had a significant effect.

Gender:

Women wore significantly lower insulations than men ($\Delta I_{cl,stand.} = -0.24$ vs. 0.02 clo), which might be explained by a better physiologic insulation due to their subcutaneous fatty tissue. The asymmetric distribution of the data revealed that IREQ is not equally applicable for both genders, probably because it was primarily developed and validated for male subjects. To extend its applicability to women requires directed studies where clothing insulation and metabolic rates should be measured.

Cold stress:

The differences between $IREQ_{neutral}$ and estimated I_{cl} were the same for the 3 groups determined by their cold stress, suggesting that the IREQ-model is valid for temperature changes of 13 °C and for air temperatures of up to 15 °C.

Workloads:

The symbols in Figure 1 indicate the 3 categories for metabolic rates. Where workload did not constitute a distinguishing mark for clothing habits between the 2 groups working at less than 165 W/m², estimated insulations of persons with higher workloads (empty circles) deviate systematically and considerably from $IREQ_{neutral}$ (0.5 clo, $p < 0.01$).

Clothing insulation varies due to body posture, intensity and type of activity, moisture content and wind. So, ISO/TR 11079 takes into account a loss of insulation, i.e. 20 or 10 % for metabolic rates of more or less than 100 W/m². As the reduction may reach 50 % and even more, another parameter labelled as IREQ(50) was calculated which admits a loss of insulation of 50 %.

Even when standardised clothing insulations of 12 out of 17 persons with the heaviest workloads exceeded this limit. The asymmetric distribution reveals a limit of the applicability of the IREQ-model. As high metabolic rates are almost necessarily accompanied by large ranges ($r = 0.68$, $p < 0.01$), an improvement is scarcely attainable

as currently available clothing material cannot provide protection within these large ranges ($\approx 200 \text{ W/m}^2$).

These workers are apparently clothed for occupational activities of rather low metabolic rates, if not for the short pauses due to uneven workflow. The most likely explanation is that the larger means and the ranges of metabolic rates, the more sweat accumulates in the garments thus reducing the insulation on the one hand and causing cold sensations particularly during periods of low activities ('after exercise chill') on the other hand. This then increases (at least subjectively) the need for more insulation.

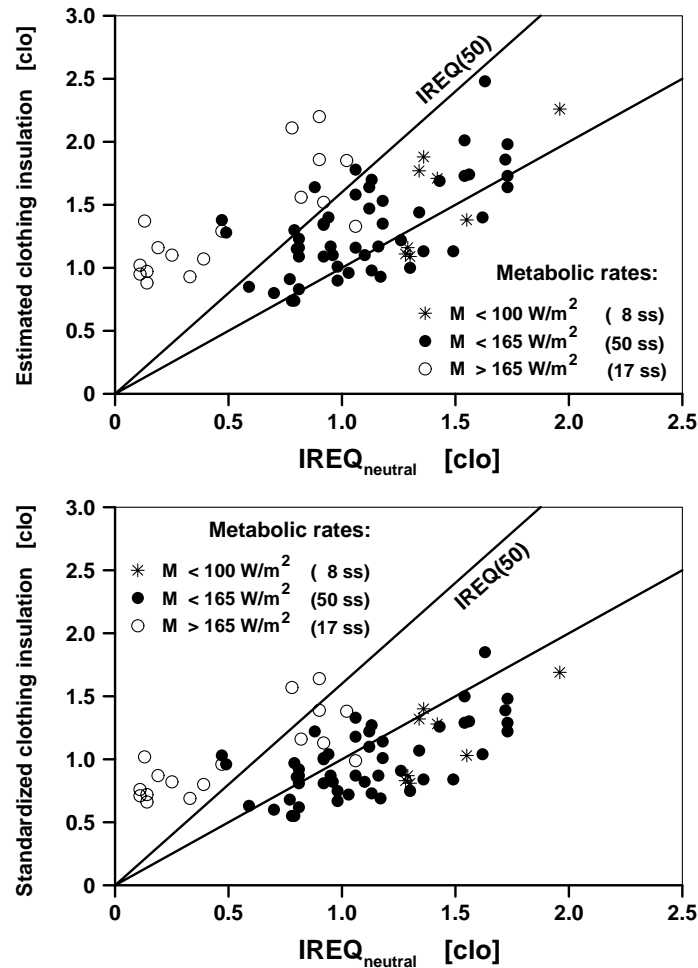


Figure 1. Estimated vs. calculated clothing insulation.

Working practices in the cold: measures for the alleviation of cold stress

K. C. Parsons

Department of Human Sciences, Loughborough University, Leics, UK.

Introduction

There are very many workers throughout the world who work in cold environments. The environments are usually determined by outside weather conditions or by the necessity to maintain indoor temperatures at appropriately low levels as a requirement of the process or product involved in the work. Cold environments will have affects on the health and safety, comfort and performance of workers. Cold can affect human behaviour, it can lead to a reduction in worker manual dexterity and strength, it can be a distraction, protective clothing will reduce mobility, sensory performance and so on. Such affects can lead to accidents, reduced productivity and worker dissatisfaction. It is important therefore to design cold workplaces to reduce detrimental affects on workers. It is also important to have effective methods for the evaluation of cold workplaces to allow work design, the establishment of appropriate working practices and recommendations for work improvement.

An effective measure for alleviating cold stress on workers, and consequent thermal strain, is not to expose the worker to the cold at all. Serious consideration should therefore be given to whether a job can be designed or reorganised to reduce cold exposure or eliminate it all together. If workers are exposed to cold then working practices are required to eliminate or reduce cold strain. Despite much research into human response to cold and the large numbers of people working in indoor and outdoor cool, chilled and freezing conditions, there is still room for improved guidance.

A cold environment can be defined as one that disposes the human body to a net loss of heat and hence challenges its thermoregulatory system to preserve heat and produce more if required. In those terms it can be affected by air temperature, radiant temperature, air movement and humidity of the environment as well as the clothing worn and the activity of the person. A systematic analysis of those parameters therefore demonstrates mechanisms for reducing cold stress. Appropriate clothing for the activity and environment, increased air temperature, reduced air velocity, increased radiation and combinations of these, all offer measures for the alleviation of cold stress.

In an integrated form this is the mechanism of the thermal index. That is a single number that can be related to the cold strain on a person or group of people. If criteria for acceptable cold strain (e.g. in terms of discomfort, physiological or functional (loss in performance) affects) are known then 'limit' values can be determined in terms of thermal indices. If valid (they really do relate to cold strain), well defined (there is no ambiguity in how to apply and calculate them in practice) and reliable (for the same conditions you get the same answer), thermal indices can provide a fundamental contribution to the design of effective working practices.

To provide effective working practices for cold environments a statement of objectives and a 'whole system' multi-disciplinary approach is required. Objectives for

working practices are likely to include the preservation of health and safety with an effective and productive workforce. Job satisfaction, well being and comfort are usually an integral part of those objectives. Much is known about the response of the human body to cold and the biophysics of heat transfer between a clothed worker and the cold environment. Knowledge however is incomplete. To provide working practices for an organisation a quality management system will be required that will co-ordinate all aspects of the work. The mechanisms for achieving this will depend upon organisational structure and culture and may involve medical personnel, safety managers and the workforce themselves. Knowledge required will include that of management, human behaviour, thermal physiology, medicine, the biophysics of the environment and clothing, standards and regulations and climatic ergonomics. This paper presents working practices, standards and guidance that are currently used. It also describes current thermal indices and preliminary research to investigate their use in practical application.

Working practices

The following presents a systematic review and some critical comment on issues relevant to the development of working practices in cold environments. Working practices could be regarded as a system of procedures that ensure the objectives of the work are achieved. The objectives would include the health and safety, well being and productivity of an individual and organisation. Working practices for cold environments would therefore be oriented towards ensuring that the effects of cold are sufficiently alleviated to ensure objectives are achieved. These are considered below.

Do the workers have to be exposed to the cold?

As cold can have significant effects on workers, a serious and primary consideration should be to whether it is necessary that the workers are exposed to cold. That is, can the objectives be met in some other way. An example would be the use of robotics in warehouse storage and retrieval. Another example is the design of the work to locate a product or process in the cold but maintain a higher temperature for the workers. In the food packing industry for example there is a move from large cooled rooms where workers work packing food on trays, to conveyer belt and cooled tray systems where workers work in 16 °C air temperatures but food is maintained below 4 °C. This, however, causes local cooling of the hands and asymmetric environments that have not been investigated in terms of human comfort and health. The general point is that if it is possible to remove the worker from the cold exposure then this should be given high priority. If it is necessary for the worker to be exposed to cold then consideration should be given to how exposure time can be kept to a minimum. Can some of the jobs be performed outside of the cold environment? Increasing the size of the workforce to allow shorter shifts, extended breaks and job rotation may also reduce exposure time. Work should be designed to avoid periods of inactivity such as waiting and resting in the cold. Work breaks may be useful but it is not clear that breaks are welcome as rewarming takes a considerable time and workers do not usually relish returning to the cold.

Selection of workers for cold work

Part of a system of working practices will include procedures for selection of workers. That is, as well as the normal procedures for selection there will be additional requirements related to cold work. Evidence for selecting particular personnel and populations for work in the cold is incomplete. General guidance suggests that younger workers (e.g. 25 to 45 years) are more tolerant than old workers and that those with medical complaints are more affected by cold. It is sometimes suggested that cold store operators are more healthy than the general population but evidence is inconclusive. Cold workers are a self selected population and it is misleading to imply that work in the cold promotes health. An additional consideration is that people should be able to respond appropriately to remove themselves from a cold environment if necessary. Restricted mobility and mental impairment will inhibit their ability to do this. It is also an advantage if workers selected are 'team players' as it is beneficial to use a buddy system (workers watch out for each other) and team working to enhance worker health and safety, morale and job satisfaction.

Screening

Workers selected for work in the cold should be screened by qualified medical personnel before exposure. Knowledge of how medical disorders are affected by cold is incomplete. Some specific disorders are consistently used in screening as indicators that will increase risk. The British Refrigerated Food Industry Confederation (RFIC) lists the following:

- heart or circulation problems
- diabetes
- thyroid problems
- blood disorders
- kidney or urine disorders
- any kind of arthritis or bone disease
- any infection including ear, nose and throat
- lung function problems or asthma
- chronic gastro-enteritis or acute diarrhoea or vomiting (must be notified the same day)
- neurological (nerve) malfunction
- psychological problems
- eyesight or hearing difficulty
- prescribed medication

Although sensible, the above list is a general list and provides little detail on interpretation. A more detailed list which is used in an organisation with cold warehouses down to -28 °C air temperature, is given in Table 1.

System of reporting

A system of reporting provides a method for monitoring health of workers. If they feel symptoms of dizziness, abnormal cold, pain in hands and feet, heavy legs or other abnormal responses then the workers should report it. They should be trained in the

systems for reporting and recording their symptoms. A system of monitoring and responding to reports will also be required.

Table 1. Example of actual screening criteria used by medical and health services in an organization with cold warehouses.

Work in very cold environments (-10 to -40 °C). Pre-employment fitness requirements.

- 1 Age - preferably 18 to 35. Either sex but NOT pregnant females.
- 2 Physique - preferably mesomorphic with adequate adipose tissue. Good physical fitness beneficial. Beware very tall - may not fit fork lift trucks.
- 3 No history of chronic respiratory disease, sinusitis or allergies. Asthma is a contra-indication. Normal pulmonary functions by P.E.F.R. or spirometry.
- 4 No history of cardiovascular disease. Normotensive - beware hypertensives on treatment. Myocardial infarction is a contra-indication. No circulatory disorders or vascular insufficiency, Raynaud's Disease, etc.
- 5 Anaemia is a contra-indication and beware haemoglobinaemias, e.g. sickle cell trait/disease in certain ethnic groups.
- 6 No chronic gastro-intestinal disease - class as food handlers.
- 7 No genito-urinary disease, including infections.
- 8 No neurological disorders and no history of mental disease. Emotionally stable and mentally alert in view of product-handling with pallet trucks and fork lift trucks.
- 9 No history of rheumatoid disease or osteo-arthritis.
- 10 Presence of endocrine disease a contra-indication. Changed requirement for insulin in diabetes. Euthyroid.
- 11 Exclude all chronic infections, including eye and ear infections.
- 12 Good personal hygiene is important, including dental hygiene.
- 13 Preferably no alcohol at least 12 hours prior to cold store work. Moderation in tobacco intake.
- 14 Eyesight and hearing must be adequate (define standard).
- 15 Spectacle wearers will have great difficulty in seeing on leaving cold environment because of fogging of glasses. Nothing really known about contact lens wearers - caution advised.
- 16 Take careful record of drug treatment - body thermoregulation can be altered by many drugs, e.g. barbiturates, phenothiazines, benzodiazapines, B-blockers, etc. People on these may not be able to work in the cold.
- 17 Where breathing apparatus is used, bearded men may be unable to wear masks correctly.

Advice

General advice can be provided to workers and a system will be required to ensure that the advice is followed. It is usually recommended that alcohol is not consumed eight to twelve hours before a shift. Coffee intake should be restricted and workers are often recommended to eat protein. Advice on behaviour and procedures is essential and particularly of the clothing worn.

Cold stress indices

A cold stress index integrates the affects of relevant factors into a single number the value of which can be related to cold strain. An index could therefore be used to

quantify the extent of the cold stress on the workers and provide limits for safe and comfortable working as well as guidance on how to design an environment and working practices that might alleviate cold strain. There are two indices that of very often used. The wind chill index (WCI, Siple and Passel (17)) and the IREQ index (Holmér (6)). The wind chill index is often regarded as a good indicator of local cooling of the hands, feet, face and exposed skin. The IREQ index is regarded as a whole-body cold stress index.

The Wind Chill Index

The WCI was determined by researchers in outside arctic conditions. It allows the effects of air temperature and wind to be combined to predict the affects on clothed people. It uses the following equation.

$$WCI = 1.16 \cdot (10\sqrt{v_{ar}} + 10.45 - v_{ar}) \cdot (33 - t_a) \quad \text{W/m}^2 \quad (1)$$

where

t_a = air temperature, °C

v_{ar} = relative air velocity between the person and the air, m/s

The value of 33 is representative of the mean skin temperature for comfort in °C. The equation takes the form of a convective heat transfer coefficient (related to v), and a 'driving' gradient for chilling as the difference between acceptable skin temperature and air temperature. It is clear therefore that the WCI will not take account of radiant or solar loads or any effects caused by chilling due to evaporation from a sweating clothed person (e.g. caused by high activity). A related index is the equivalent chilling temperature (t_{ch}). If the WCI is calculated for a cold environment with low air temperature and high wind for example, an air temperature which would give equivalent effect on a person (equivalent chilling) as if the air were calm instead of moving, can be calculated by rearranging equation (1) and assuming that $v_{ar}=1.8$ m/s (calm air). That is

$$t_{ch} = 33 - \frac{WCI}{25.5} \quad \text{°C} \quad (2)$$

This equation is probably of little use indoors where a value for v_{ar} of 1.8 m/s would not be regarded as calm and any correction may actually increase the equivalent temperature above that of the air temperature.

The IREQ index

The IREQ index is calculated from the human heat balance equation. It is the clothing insulation required to be worn to maintain comfort ($IREQ_{neutral}$) or in 'just acceptable' conditions ($IREQ_{min}$) where a person will become cold but not so extreme that it becomes unacceptable. The criteria are based upon heat loss from the body and physiological criteria in terms of skin temperatures. The IREQ method is to assess thermal stress in the cold. It is applicable to continuous, intermittent and occasional exposure, indoor and outdoor work and general whole body cooling. It allows selection of clothing for work (i.e. it provides the thermal insulation required which can be used to design and select clothing ensembles). It can also be used as a cold stress index. If IREQ cannot be met in an environment then maximum exposure times can be calculated as well as guidance on recovery times. The IREQ index has been criticised in

terms of its apparent academic and theoretical approach and that it may not be a good model for how people become cold and associated strain. For example extremities such as hands, nose, ears and feet are known to be of great importance yet IREQ is whole-body orientated. The use of the simpler wind chill index where experience has been gained over many years, is often proposed, especially for outdoor work. Additional issues with the IREQ approach are the difficulty in interpreting the clothing insulation required in terms of an appropriate ensemble, and the recognition that learning to behave and behavioural responses to the cold are of prime importance (i.e. you don't just accept cold you respond to it by becoming more active, changing posture etc.). Despite its limitations the IREQ index is a powerful analytical tool. It has been adopted with the WCI in ISO TR 11079 (8) which is described below. It is also becoming the basis for a number of national and regional standards throughout the world.

Oleary and Parsons (14) investigated the role of the IREQ index in the design of working practices for cold environments. In a series of climatic chamber and freezer room studies they demonstrated how the $IREQ_{min}$ index could be used as a starting point for the selection of clothing and design of working practices. They provided a systems approach which could be followed to design cold work. In a limited validation of the method they demonstrated how a worker in a supermarket freezer room could maintain comfort where previously he had not. Interestingly when workers were investigated for cold discomfort it was found that they claimed to be too hot. This demonstrates the lack of guidance on clothing selection and a tendency to recommend too much clothing to ensure protection. If the worker sweats into clothing however this will be counter productive. The $IREQ_{min}$ index therefore provides a valuable starting point for clothing design and selection that will be of great practical value.

Standards and Regulations

ISO TR 11079 (1993) Evaluation of cold environments - Determination of required clothing insulation.

ISO TR 11079 (8) is one of a series of international ergonomics standards concerned with the assessment of thermal environments. It integrates the IREQ index (with emphasis on whole-body affects) with the WCI index (with emphasis on local cooling) and thermal and physiological criteria to provide an assessment methodology. In its present form it is a Technical Report which emphasises that the method requires validation before becoming a full international standard. Such is the utility of the method however that it has already formed the basis for a number of national standards and it will be produced in the form of a draft international standard in late 1998. The series of international standards include those that support the use of ISO TR 11079. These include ISO 9920 (11) which provides clothing ensembles and associated thermal properties and hence would provide guidance to the selection of clothing. They also include ISO 8996(9) (estimation of metabolic heat production for an activity) and ISO 7726 (12) (specification of instruments for measurement of the environment) as well as ISO DIS 12894 (13) (medical screening) and ISO 9886 (10) (physiological monitoring). Descriptions of the standards are provided in Parsons (15). To aid in calculation a computer program listing is provided as an annex to ISO TR 11079.

American Conference of Governmental Industrial Hygienists(ACGIH)

The ACGIH (1) publish annually a booklet that provides Threshold Limit Values (TLV) for chemical substances and physical agents. Included in this is practical guidance for work in the cold. TLVs are provided in terms of the Wind Chill Index. A TLV defines conditions to which nearly all workers can be exposed, day after day, without adverse affects. Values of the TLV can therefore be included in working practices along with the substantial amount of other practical guidance provided. While probably the most influential and significant practical guidance document the ACGIH booklet contains recommendations based upon practical experience. This is an advantage, however the suggestions are not always validated in the scientific literature. It is also limited in its method of analysis. An analytical approach such as the IREQ has much to offer and links clearly to the selection of clothing. It could be argued that guidance has evolved from work in outdoor conditions including polar expeditions. The Wind Chill Index and associated equivalent chilling temperature may therefore require modification for work in cold indoor climates.

DIN 33 403 - 5 (1994). Ergonomics design of cold workplaces

After extensive surveys of German industry the German Standards Institute (DIN) produced a standard (DIN 33 403 part 5 (4)) based upon the IREQ index. The standard does not apply to outdoor work and defines cold environments as those from 15 °C to - 50 °C in five ranges. An assessment method is described and tables of minimum clothing insulation required are provided. General guidance on working practices is also provided as well as ergonomics measures for reducing cold strain.

BS 7915 (1998) Design of working practices for cold indoor environments

In recognition of the need for research and guidance on work in the cold, research was commissioned and conducted to survey current practices and requirements in British Industry (Graveling and Fleming (5)). When this was completed a British Standard was produced (BS 7915 (3)). The standard gives guidance on ways in which cold stress or discomfort in cold indoor environments can be evaluated and cold strain reduced. Cold environments are defined as those with an air temperature of less than 12 °C. The standard describes the human responses to the cold together with the influence on these of different working practices. Assessment methods are described as well as the Wind Chill Index and the IREQ index. Case studies are provided in an annex of the standard. They give practical guidance on analysis and practical interpretation of the assessment method for a range of applications.

An important development in standards work is the adoption of a work item to produce a European (and ISO) Standard concerned specifically with working practices for cold environments. It is likely that the German and British standards mentioned above (along with regulations and working practices in other countries outside of Europe) will have great influence on the structure and content of that standard.

Existing Guidance

While standards provide methods and guidance at a national and international level, more detailed and specific guidance is often provided at the level of an industry,

organisation or even a particular workplace. Such guidance should be based upon a systematic approach and involve what is known and recommended. Examples of such guidance from the UK and Europe are provided below.

HSE information sheet. Food sheet 3 (1994). Workroom temperatures in places where food is handled (7).

The UK Health and Safety Executive (HSE) provide guidance in terms of an information sheet. To achieve the two objectives of maintaining food at required temperatures while ensuring the health and safety of the workers a 'reasonable temperature of at least 16 °C (or 13 °C for active work) is required. This may be achieved by chilling food locally or minimising its exposure to ambient air. Additionally a warm workstation could be provided within a room where overall temperature is lower, suitable protective clothing could be provided, heated rest areas and facilities will be useful and systems could be instituted to minimise exposure to the cold. Employers need to consider alternate ways for controlling food temperatures.

RFIC (1995) Guidance on work in cold indoor environments (16).

An extensive and practical guide has been produced in pamphlet form by the UK Refrigerated Food Industry Confederation. This is a confederation that includes organisations involved in production, cold storage and distribution of frozen food and ice cream. The guidance is built upon a comprehensive survey of advice and methods. It is particularly relevant to aid in the risk assessment of workplaces that must be carried out under Health and Safety legislation. Guidance is provided on health, protective clothing, working hours in cold indoor environments and fork lift truck heated cabs in cold stores. While useful practical guidance is provided some further validation is required. For example, the suggestion that if a worker suffers physical discomfort due to cold then a 20 minute break in a 20 °C environment will allow recovery. It is possible that this is optimistic and in many cases it is likely that longer recovery times will be needed. For fork lift trucks it is recommended that they be treated as for 'normal' environments.

European Association of Refrigeration Enterprises report on working hours in cold conditions.

A European wide initiative by the European Association of Refrigeration Enterprises (AEEF - Bittles (2)) produced a comprehensive report on working practices across Europe. The study was essentially a survey with the aim to evaluate what trends or national practices/methods for work in the cold, had developed in Europe in recent years. A summary of medical findings indicated few major medical problems but note individual differences in workers. The wind chill index and IREQ index are referred to and it is noted that the current practice of local agreements is questionable because of individual differences. That is, a local agreement is made based on a fixed exposure time in the cold store and a fixed recovery time. The Kuhlmann report (October, 1988) is cited as important evidence. Although a full reference is not given a number of its conclusions are. Countries across Europe seem to operate similar working practices. Of interest is the practice across Europe for workers to decide individually on breaks according to activity level. The 10 minutes/hour break is usual. The AEEF report also describes a 1994 agreement between Danish employers and Trade Unions, DIN 33 403

part 5, a 1993 agreement between the National Cold Storage Association of Spain (ANEFE) and Spanish Trade Unions, UK guidelines (e.g. HSE) and the results of the survey of European countries including Denmark, France, Germany, Ireland, Spain, Sweden, Switzerland, Norway and the UK. Although no conclusion could be drawn there were consensus views. Trends for the future included fixed national agreements and the use of heated cabs. These however will bring associated and different ergonomics requirements.

Other issues

Contact with cold surfaces and individual physiological monitoring are two relevant issues that have not been considered. There is a lack of knowledge on the damage caused by skin on contact with cold surfaces. This will depend upon temperature, material type and other factors. Interestingly little mention is made of it in guidance or problems that have occurred probably because protective gloves are worn. Contact with the skin on bare metal, for example, should be avoided and data are required on skin reaction. Physiological monitoring will allow the design and evaluation of work in the cold by measuring actual reactions of workers. This is particularly important in extreme conditions. Heart rate, blood pressure, skin temperatures, internal body temperatures and sweat loss are all examples of measures that are useful indicators of human thermal strain. With present technology, individual monitoring is a feasible method for use in industry to establish working practices.

Conclusion. An integrated approach

It is clear from the above that much is known about work in the cold. In an integrated form this can provide a systematic methodology and approach to designing working practices for cold environments. This has yet to be done.

References.

1. ACGIH 1996 TLVs and BEIs. Threshold Limit Values for chemical substances and Physical Agents. ,ACGIH,Cincinnati,USA,1996. ISBN 1-882417-13-5.
2. Bittles W J 1994 Working hours in cold conditions. Technical and Administrative Committee, European Association of Refrigeration Enterprise (A.E.E.F), Brussels,1994.
3. BS 7915 1998 Design of working practices for cold indoor environments, BSI London.
4. DIN 33 403 1994 Climate at workplaces and their environments. Part 5. Ergonomic design of cold workplaces. DIN, Berlin
5. Graveling and Fleming 1996 Report to client. The development of a draft British standard on the thermal stress of working practices in cold indoor environments. Edinburgh, Institute of Occupational Medicine, 1996.95pp.
6. Holmér I 1994 Required clothing insulation (IREQ) as an analytical index of cold stress, ASHRAE Trans 90 Pt1, pp 116-128.
7. HSE 1994 Workroom temperatures in places where food is handled. HSE information sheet. Food sheet 3. HSE Books, Sudbury.

8. ISO TR 11079 1993 Evaluation of cold environments - Determination of required clothing insulation, ISO, Geneva.
9. ISO 8996 1990 Ergonomics - Determination of metabolic heat production, ISO, Geneva.
10. ISO 9886 1992 Evaluation of physiological strain by physiological measurement, ISO, Geneva
11. ISO 9920 1995 Ergonomics of the thermal environment - Estimation of the thermal insulation and evaporative resistance of a clothing ensemble, ISO, Geneva.
12. ISO 7726 1985 Ergonomics of the thermal environment - Instruments for measuring physical parameters, ISO, Geneva.
13. ISO DIS 12894 1998 Ergonomics of the thermal environment - Medical supervision of individuals exposed to extreme hot or cold environments, ISO, Geneva.
14. O'Leary C O and Parsons K C 1994 The role of the IREQ index in the design of working practices for cold environments, *Ann Occup. Hyg.* vol. 38 No 5, pp 705-719,1994.
15. Parsons K C 1993 *Human thermal environments*. Taylor & Francis, Hampshire, UK, 1993 ISBN 0-7484-0040-0
16. RFIC 1997 The Refrigerated food industry confederation. Pamphlet. Guidance on work in cold indoor environments. RFIC, London
17. Siple P A and Passel C F 1945 Measurement of dry atmospheric cooling in sub-freezing temperatures. *Proc. Amer. Phil. Soc.* 89, pp. 177-199

Effect of a wide hood on facial skin temperatures in cold and wind

*H. Rintamäki, T. Mäkinen, D. Gavhed**

Oulu Regional Institute of Occupational Health, Aapistie 1, FIN-90220 Oulu, Finland

*National Institute for Working Life, S-171 84 Solna, Sweden

Introduction

During a sudden cold exposure, especially when combined with wind, the lowest skin temperatures are usually measured from the face. There are a lot of cold receptors in the face skin and consequently the face is very cold sensitive (1). Face cooling affects heart rate, blood pressure, respiration and metabolism (2, 3).

A hood is traditionally used for cold protection of the head. However, the effects of different types of hoods on facial skin temperatures are not quantified. The aim of this study was to locate and quantify the effects of a wide hood on facial skin temperatures in cold and wind.

Material and methods

During the 30 min experiment the test subjects (6 healthy males, age 32 ± 9 (mean \pm SD) years, height 173 ± 7 cm, mass 70 ± 11 kg) were walking on a treadmill, face directed towards the wind, at a speed of $5.0 \text{ km}\cdot\text{h}^{-1}$. Ambient temperature was $-15 \text{ }^\circ\text{C}$ and air velocity $5.0 \text{ m}\cdot\text{s}^{-1}$.

The test subjects used a winter clothing (ca. 2.0 clo) and the head was protected by a woollen cap which covered also the upper part of auricles. When the hood was pulled on, the foremost part of the hood was extended ca. 5 cm in front of the forehead. The width of the hood opening was ca. 22 cm on the level of infraorbital region which allowed free space of about 4 cm in both sides of the face.

The experiment started without the hood and thereafter the 5 minute periods with hood off and hood on were repeated until the end of the experiment. Skin temperatures from 8 different sites of the head were recorded on 30 s intervals (YSI 400 series thermistors and Squirrel 1200 datalogger).

Results

In the beginning of the cold exposure the skin temperatures decreased rapidly. At the end of the second period (15 and 20 min after exposure to cold while hood off and on, respectively) the skin temperatures fluctuated in a pattern which continued until the end of the measurement. The lowest skin temperatures during the cold exposure without hood were in the range of 5 (auricle) - $12 \text{ }^\circ\text{C}$ (temporal region). The use of hood

increased skin temperatures in all measured sites, and the difference was greatest at the end of each 5 min period. Table 1 shows the average effect of hood.

Table 1. The difference between hood off (the end of the last hood off) and hood on (the end of the second last hood on). The values are mean \pm SE, n = 6.

Site	
Ear lobe	6.7 \pm 0.3***
Temporal region	5.3 \pm 1.3**
Cheek bone	5.2 \pm 1.1**
Buccal region	4.8 \pm 0.5***
Chin	4.7 \pm 1.8
Forehead	3.3 \pm 0.5**
Infraorbital area	3.2 \pm 0.7**
Tip of the nose	0.7 \pm 0.9

*** p<0.001, **p<0.01

Discussion

The results show that a loose-fitting hood with a wide opening and without any contact with the face efficiently prevents cooling especially in the lateral parts of the face. Only the temperature in the tip of the nose was not affected by the hood. Obviously larger differences in skin temperatures would have been seen if the measurement periods with hood off and on were longer than in the present study or if the hood had been less wide.

The effects of the hood do not clearly follow the isotherms of the face (4). Instead, the effects were most conspicuously seen in the parts of the face which were best covered by the hood. However, the effect of hood on the frontal parts of the face was neither negligible.

The results show a protective effect of the hood also in the uncovered parts of the face. Since a hood does not obstruct respiration and since there is no accumulation of moisture from the expired air, it is superior in comparison to other possibilities to protect the face such as a face mask or a scarf. Moreover, good adjustability of the hood favours its use.

Acknowledgement

Supported by grants from the Finnish Work Environment Fund and the Swedish Council for Work Life Research.

References

1. Crawshaw LI, Nadel ER, Stolwijk JAJ, Stamford BA. Effect of local cooling on sweating rate and cold sensation. *Pflügers Arch* 1975;354:19-27.
2. LeBlanc J, Blais B, Barabé B, Côte J. Effects of temperature and wind on facial temperature, heart rate, and sensation. *J Appl Physiol* 1976;40:127-131.
3. Riggs CE Jr, Johnson DJ, Kilgour RD, Konopka BJ. Metabolic effects of facial cooling in exercise. *Aviat Space & Environm Med* 1983;54:22-26.
4. Steegman AT Jr. Human facial temperatures in natural and laboratory cold. *Aviat Space Environm Med* 1979;50:227-232.

A re-examination of the cold stress threshold limit value (TLV)

H. Mahar

Physical Agents TVL Committee, American Conference of Governmental Industrial Hygienists (ACGIH)

Introduction

The American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs) for exposure to cold stress are intended to protect nearly all workers from the severest effects of exposure to cold conditions, including hypothermia and local tissue injury (e.g., frostbite, trenchfoot). According to ACGIH procedures, the Cold Stress TLV is undergoing a periodic technical review to ensure that the guidance provided is current and appropriate. The initial review of the current TLV suggests that the following areas need to receive additional consideration when re-issuing the TLV:

- exposures to cold stress under a variety of conditions (e.g., cold/dry versus cold/wet conditions);
- consideration of biological responses to cold stress other than hypothermia and acute, local tissue damage (e.g., endocrine effects; other chronic effects); and
- determination of significance of such responses (e.g., comfort/performance/productivity effects versus physiological decrement).

What follows is a brief summary of the approach the ACGIH Physical Agents Committee is taking in its review of the Cold Stress TLV.

Focus of current cold stress TLV

The current Cold Stress TLV focuses on exposure situations involving individuals in a cold, dry environment. The development of significant tissue damage in individuals exposed to even moderate cold in wet or damp conditions (e.g., immersion foot, trenchfoot) has been well documented (3), but is not addressed directly in the current TLV. Rapid heat loss in tissues from conduction or evaporation may cause severe localised vascular tissue injury as well, and should be considered in future updates. Since many cold-related injuries/fatalities involve cold/wet situations, revisions to the Cold Stress TLV will incorporate additional guidance in this area.

Exposure to even moderate cold conditions may result in subtle physiological effects which do not produce hypothermia or vascular injuries normally associated with exposure to severe cold (e.g., frostbite or trenchfoot/immersion foot). The role of seasonal or periodic, diurnal cold exposures (as encountered in an occupational setting) in modifying thyroid hormone kinetics is being clarified (4), but these endocrine changes appear to impact a variety of metabolic and cognitive functions as well as behaviour. These responses are well established in individuals experiencing seasonal climatic change in high-latitude zones of the world, but the endocrine changes are also

apparent in individuals exposed to cold stress in short (i.e., several hours), repetitive sequences comparable to those experienced in an occupational setting. The degree to which these apparently normal adaptive processes are considered adverse effects (and therefore, to be avoided) remains a matter of debate. There are also reports of statistical associations between exposure to cold and the frequency of reproductive disorders and testicular cancer (5), but the implication of cold stress in the aetiology of these diseases remains tenuous. Future editions of the Cold Stress TLV and its supporting documentation will consider these additional responses to cold stress, along with hypothermia and focal vascular tissue damage.

Biological basis of the TLV

The primary objective of the current TLV is to prevent the individual's deep core body temperature from falling below 36 °C (1). That deep core temperature cited is slightly above the temperature at which maximum shivering typically occurs and the point at which the body's metabolic rate increases to compensate for heat loss. Useful physical or mental work is limited when severe shivering occurs and the resulting reduction in mental alertness and rational decision making may have fatal consequences. When the deep core body temperature is depressed much below 35 °C, thermoregulatory control is lost in most people, along with the ability to recover unassisted. However, there is evidence to suggest that persons can tolerate body core temperatures approaching that value without ill effect, and that seasonal climatic changes at higher latitudes may produce up to a 1.5 °C reduction in individuals' "normal" baseline body temperature (3). Therefore, it may be inappropriate to apply this 36 °C core temperature benchmark too rigidly as an indicator of significant physiological impairment. It also may be inappropriate to consider any core temperature decrease that occurs within the normal thermoregulatory range to be significant, and therefore, to be avoided.

One cannot assume that if deep body core temperatures are maintained within normal ranges, cold injuries will not occur. Trenchfoot, or immersion foot, can occur with extended exposures to water or moisture at temperatures at or below ~10 °C. Less severe but similar forms of local tissue damage (i.e., chilblain, pernio) can occur in moist/wet conditions at environmental temperatures approaching 16 °C (2).

The current TLV is intended to prevent the adverse health impacts associated with acute, severe cold exposure. The current version of the Cold Stress TLV can be strengthened by consideration of: (a) significant physiological responses in addition to hypothermia and local vascular damage to extremities; (b) by the inclusion of guidance regarding exposure to moderate cold in damp or wet conditions; and (c) recognition of the distinction between adverse physiological effect from cold exposure and temporal discomfort or productivity decrements. In addition, any revisions to the Cold Stress TLV will incorporate recent advances in protective equipment ensembles, environmental or physiological monitoring techniques, and predictive models in identifying, assessing, and controlling cold injuries in the occupational setting.

References

1. American Conference of Governmental Industrial Hygienists. 1998 TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents, Biological Exposure Indices. Cincinnati, OH/USA, 1998.

2. Hamlet M P. Human cold injuries. In Pandolf KB, Sawka MN, and Gonzalez RR, eds. *Human Performance Physiology and Environmental Medicine at Terrestrial Extremes*: Cooper Publishing Group, Benchmark Press, Indianapolis, IN/USA. 1988: 435-466.
3. Reedy, KR. Personal communication. 1998.
4. Van Do N, LeMar H, and Reed HL. Thyroid hormone responses to environmental cold exposure and seasonal change: a proposed model. *Endocrinology and Metabolism* 1996;3:7-16.
5. Zhang, ZF, Vena JE, Zielezny M, Graham S, Haughey BP, Brasure J, and Marshall JR. Occupational exposure to extreme temperature and risk of testicular cancer. *Arch Envir Hlth* 1995;50(1):13-18.

Development of work environment in cold terrain conditions

H. Anttonen, J. Niskanen, A. Pekkarinen

Oulu Regional Institute of Occupational Health, Aapistie 1, FIN-90220 Oulu, Finland

Introduction

In terrain work, many professional groups like geologists, soldiers, frontier guards and lumberjacks have to repair their machines outdoors. When working outdoors the employees are exposed to cold weather, wind and rain, which may lower the body temperature especially of the hands.

The work tasks were observed as a system of four components: employee, working tool, object of the work, and physical environment. Special attention was given to the work postures, use of hand tools, and influence of the cold environment on the other parts of the system.

Table 1. Results of OWAS observations in the repair of different vehicles in terrain circumstances, %

OWAS code	Repair of vehicles N = 1021	OWAS code	Repair of vehicles N = 1021
BACK		FORCE USED	
straight	46	less than 100 N	92
bent	43	100 - 200 N	6
twisted or bent to the side	10	over 200 N	2
bent and twisted	1	HAND TOOL	
UPPER LIMBS		not in hand	53
below shoulder level	88	in hand	47
one above shoulder level	9		
both above shoulder level	3	LOWER LIMBS	
LOWER LIMBS		on one knee or kneeling	40
sitting	0	walking	7
standing on straight legs	31	lying down	8
standing with bent knees	13		

Material and methods

Two prototypes of tents supplied with heating and lighting equipment were planned, built and tested. One was a modern container supplied with an electric aggregate and special tools, the other a small tent transported on a snowmobile sled supplied with heating and lighting equipment.

Two different kinds of heaters were selected for the test. One was a warm air fan, developed for heating the cabins of lorries. It consists of a fan, a diesel fuel tank, an electrically controlled oil burner, battery and electric supply. The other heater was a radiation heater, which uses liquefied petroleum gas as fuel. Heat loss calculations were used to find the correct power for the heater, which cope with outside temperatures as low as -35 °C.

The work postures were classified according to the Finnish OWAS method (Salonen and Heinsalmi 1979) at the intervals of 5 sec after a randomly selected starting point. The results of the OWAS observations are shown in Table 1.

Table 2. Effect of different heating systems on the local temperatures

	Distance (m)	Temperature change (°C)
Warm air blower, 8 kW		
air temperature in the jet	1	35
- " -	2	15
hand tools	0.5	30-45
Radiation heater, 1 kW		
air in optimal place	1.2	4
person	1-2.5	3
hand tools	1.2	4.5

Discussion

The optimum temperature for service work depends on the thermal insulation of the clothing used and the work activity. Calculation with the IREQ index gave a temperature range of 0-+5 °C for repair work, when proper clothing was used. This temperature is too high for the tent, however because the snow on the floor starts to melt. Therefore the optimal temperature for the tent should be -5-0 °C with local heating provided for the hands. Because the outside temperature can vary greatly, the heating power should be adjustable. Proper adjustment methods were the half- power switch, opening the door of the tent, and an on/off thermistor switch connected to the heater.

The test showed that 8 kW was enough for the small tent and 24 kW for the larger tent down to a -35 °C outside temperature. The wind had a considerable effect on the heating efficiency. In calm weather the 5 kW heater outside raised the temperature by 16 °C and in a wind velocity of 8 m/s only by 9 °C.

The lowered skin temperature of the hands at the site of contact is the main reason for the cooling of hands. According to the measurements the skin temperature of the fingers at the contact site was 4-7 °C, which can decrease manual dexterity and cause pain when working outside at -14 °C. In the tent this temperature was 5 °C higher than when working outdoors. In addition if the handle of the tools used was made of plastic instead of metal, the temperature was 3 °C higher. The skin temperature of the fingers at the contact site was near the recommended level if the hand tools were warmed before use with the hot air jet. The warming of tools is therefore the most effective means of ensuring comfortable hand temperatures, the shelter offered by the tent is next most important, and then the material of the tools. Metal tools cause a risk of frostbite in cold weather.

The best work posture is achieved if the site to be repaired or serviced is near waist height and at arm's length. The sites to be repaired were commonly located very low, at knee height or even lower.

The work postures were improved if the part to be repaired could be detached and handled on a fixed or movable table. It is more pleasant to work on icy ground if low, possibly three-height seats, working carpets or knee cushions are available.

The best conditions were achieved in the terrain, when a tent connected to a modern container was in use. In the container there was a work table that allowed good work postures, the hand tools were warmed and conveniently available, and a suitable temperature and lighting were planned for the work.

Case study of cold work in a hospital ‘plating area’

K. C. Parsons

Department of Human Sciences, Loughborough University, Loughborough, Leics, LE11 3TU, United Kingdom

Background

A regional Health Manager, responsible for working conditions in hospitals, wished to establish that work design in a hospital ‘plating’ area was satisfactory. He approached the climatic ergonomist and in a preliminary meeting the ergonomist described his expertise and work and the manager described his requirements. After the meeting and completed actions, for the manager to produce a description of requirements and the ergonomist a proposal and costs, a project was agreed.

The food preparation, cooking and serving methods in the new hospital had moved away from the traditional ‘hot’ kitchen method to a chilled system which maintained food at around 2 °C until it was ready to be eaten when it was heated. This was for reasons of hygiene. Food arrived in refrigerated lorries, already cooked and chilled from the factory. It was unloaded through a sealed entrance into a chilled area in the hospital. ‘Kitchen’ staff manned workstations around a conveyer belt and served an item of chilled food from large containers (e.g. potatoes, rice, peas). Trays containing menu, fruit juice and plates are placed on the conveyer at one end and food served onto plates as the trays pass along to the other end of the conveyer where they are removed and stacked in trolleys. The closed trolleys are also heated ovens such that by appropriate timing and temperature a trolley is taken to a ward and the patient is given the requested meal at optimum temperature and condition, the food having been above 2 °C for a minimum period of time. The workers have therefore to work in the plating area at 2 °C air temperature for over one hour and there was a lack of guidance on correct working practices.

The Project

The scope of the project was agreed in writing as follows.

1. To carry out an objective assessment of the chilled environment .
2. To advise the Health Authority on thermal comfort, welfare, clothing and other areas thought relevant with respect to staff working in this environment.
3. To carry out a subjective assessment of staff.

Method

The ergonomist visited the hospital for one day and conducted the survey. The manager was present for a short period and introduced the catering manageresses for the hospital and the region. Preliminary (structured) interviews revealed that there was a clear interest in the assessment being undertaken. Over all shifts there were a total of 3 men and 38 women who work in the area. Activity in the plating room involves cleaning the area, delivering and removing trolleys and food, serving food and preparing trays. The activity for each workplace involved serving and placing or removing trays. Cleaning the area involved the use of a specialist machine but when the ergonomist was there he noticed that this was done by hand. When not in the plating area the staff prepare special meals and wash up. They put on extra clothes and go into the plating area for about one hour. When finished they take off the extra clothes and have a hot drink before continuing work. The selection of clothing had involved staff. It consisted of normal underwear, long john trousers, long john vest, T-shirt, blue trousers, white smock top, quilted jacket, quilted leggings, thin gloves, thin impermeable overgloves, neckerchief (optional), hair net, light trilby hat, shoes and own socks. When not in the plating area the overjacket was removed. The thermal underwear was worn at all times. An estimated clo value from ISO 9920 (1992) of 2.48 clo in the plating area with jacket and trousers, 2.3 clo with jacket and outside the plating area without quilted clothes, 2.0 clo.

Objective assessment.

All eight workplaces in the plating area were measured in terms of air temperature, radiant temperature, humidity and air velocity. Equipment was calibrated before and after the measurements. It included eight 150 mm diameter black globe thermometers, eight thermistor sensors linked to a data logger, a whirling hygrometer, a hot wire anemometer and a (child's) bubble kit. Measurements were made at ankle, chest and head height at each workplace. The room was empty for the period of about 110 minutes when the assessment was made. The engineer was asked to create the conditions experienced when at work. The empty room was acceptable but not ideal and the general lack of direct contact with the workers was an indication that it was a sensitive issue. A blue print plan of the rooms was provided by the manager. All work was light arm work with an estimated metabolic heat production of 70 W/m^2 .

The results showed that the air temperature had been successfully maintained in a cyclical pattern between 1 and 3 °C and was mixed by fans providing a turbulent and gusting air velocity of between 0.2 to 1.2 m/s over the workplaces. The globe temperatures and wet bulb temperatures were similar to the air temperatures and therefore humidity was close to 100 % and there were no radiant effects. A basic clothing insulation of 2.3 clo and metabolic heat production of 70 W/m^2 were assumed. The IREQ and Wind Chill indices were calculated according to ISO TR 11079 (1993). For the worst case of 1.6 °C air temperature and 1.2 m/s air velocity, the workers could work for 2.22 hours. If comfort was to be preserved then this exposure should be reduced to 1.33 hours and if the fans were turned off, to 1.7 hours. The wind chill index of 783 W/m^2 indicated that the environment was cold but that there would be no damage to extremities. It is also within ACGIH (1996) guidelines.

Subjective assessment

A standard single sheet questionnaire was administered under instruction, by the hospital manageress in a structured interview. The questions included thermal sensation, preference and satisfaction scales and a 'catchall' question for comments. It would be preferable for the ergonomist to have administered the questionnaire while staff were working but this was not practicable or allowed. Eighteen responses were obtained. While in the plating area 8 subjects were cold and 10 wished to be warmer with 7 no change and 1 cooler. Generally at work outside of the chilled area, 14 staff felt warm to hot and 6 indicated that they would like to be cooler. comments were made on local cooling of the hands, nose and ears, that it was too warm outside of the chilled area, putting on and taking off clothing was inconvenient and that fans caused discomfort and were noisy.

Summary of recommendations

A full report was provided including all data, analysis, conclusions tables of IREQ values for a range of conditions and guidelines for cold work. There were 7 recommendations.

1. $IREQ_{min}$ should be used as a starting point for designing and assessing future workplaces.
 2. Engineering control should allow the fans to be turned off during the work period.
 3. Wet skin and wet clothing should be avoided when cleaning.
 4. The use of easily donned and doffed additional layers of clothing (over normal clothing and no thermal underwear) to $IREQ_{min}$ levels should be used, with individual selection of available garments for extremities.
 5. A relatively light, tight fitting hat to cover hair net and ears is recommended. Appearance will be important.
 6. Staff should be encouraged to contribute to the design of their own system. Team work is important when working in the cold.
 7. If conversion from traditional to chilled work continues, a systematic approach to implementation should be developed. Methods exist and should be used. A system could include prototyping and evaluation in a climatic chamber away from the work.
- Feedback and clarification were provided in a telephone discussion of the report. The report was accepted, the ergonomist paid and no further contact made.

References

1. ACGIH (1996) TLVs and BEIs. Threshold Limit Values for chemical substances and physical agents. Biological Exposure Indices. ACGIH, ISBN: 1-882417-13-5, Cincinnati
2. ISO TR 11079 (1993) Evaluation of cold environments - Determination of required clothing insulation. ISO Geneva.
3. ISO 9920 (1992).Ergonomics of the thermal environment-Estimation of the thermal insulation and the evaporative resistance of a clothing ensemble. ISO, Geneva.

Microclimate variations in winter in industrial halls with metal processing by heat

H. Herman

Institute of Hygiene, Public Health, Health Services and Management, Bucharest, Romania

Introduction

In many industrial halls, where the metal is processed by heat, the external doors are permanently or long time open to assure the frequent displacement of the transport means with materials and parts (railway trucks, motor vehicles, manually). In winter the outside cold air penetrates into these halls through the respective doors. The influence of the cold air on the hall microclimate and on the workers and the possibility to avoid the unfavourable conditions were studied in a great forge workshop of a machine building plant, at an outside air temperature of $-3\text{ }^{\circ}\text{C}$. The studied forge hall had a great door at one of its extremities, which was open all the time. In the hall ran furnaces and forging and pressing machines. The doors of the industrial halls may be protected against the outside cold air by means of ante-room or marchioness mounted before the entry door, but these devices protect the hall only when the door is closed. Hence an air curtain was mounted at the external open door of the forge, as measure to stop the entrance of the outside cold air into the hall. The air curtain was realised by the air absorption from the forge hall and its distribution with great speed by the slits placed at the two lateral sides of the door. The air curtain separated as a wall the outside environment from the forge hall environment and the circulation and transport at the level of the open door carried out without obstacle.

Methods

The research methods included:

- Analysis of the work task and of the manner of its achievement (positions, movements and displacements of the workers).
- Assessment of some environmental factors in the forge hall without and with the air curtain:
 - the microclimate factors: measurement of the air temperature, relative humidity and air speed at the workplaces and in the middle of the hall in its lengthways (the transport way) at every 5 m; the intensity of the caloric radiation measurement at the workplaces;
 - determination of the carbon monoxide concentration in air.
- Statistical analysis of the morbidity with temporary work disability of the forge workers for a period of four years: two years before using the air curtain and after two years when the air curtain has run. There were analysed especially the diseases

favoured by cooling (acute diseases of the superior respiratory ways, angina, neuralgia, influenza, otitis, rheumatic state).

Results and Discussion

In the forge workshop the work was manual, manual-mechanised and mechanised to supervise the equipment running, to displace the metal between the furnace and the press, to act the press, to sustain the incandescent metal when forging. The posture of the workers was permanently standing with displacements in the work zone and on the circulation way. The physical effort is important (mean intensity), determined by the posture, the holding and carrying loads, the displacements, the large movements of the upper limbs. The furnaces and the incandescent metal, heated till 1200 °C, emit caloric radiation of 0.2-1.4 cal/cm²/min.

Results showed that the microclimate of the forge hall was intensely influenced in winter by the meteorological outside conditions because of the cold air penetrated through the open door without the air curtain. The cold air currents decreased the air temperature and increased the air speed in the forge hall. Air velocity increased proportionally to the temperature decrease. In these conditions at the workplaces (furnaces, forging and pressing machines) the temperature was between +6 and +17 °C and the speed was from 1 to 2.40 m/s. But the workers must go also in other places of the hall to transport parts and materials where the temperature was lower (between -3 and +9 °C) and the speed was greater (between 1.7 and 4.6 m/s). Therefore the workers were exposed to great variations of microclimate, to a temperature difference from 12 to 20 °C. At the workplaces a part of their body was exposed to heat radiation and other part of their body was exposed to cold air currents. While the displacements in the hall the workers passed suddenly from the warm to cold, heated by the thermal radiation emitted by the furnaces and the metallic incandescent parts and sometimes because of the muscular effort, scantily dressed and sweating. These conditions determine the heat loss of the body, favouring his cooling. Because of the great speed of the air currents, the air with lower temperature comes permanently in contact with the human body increasing his heat loss.

When the air curtain was mounted and ran at the open door, the microclimate improved in the forge hall. At the same outside climate, the air temperature was between 18 and 22.5 °C and the air speed decreased to between 0.17 and 1.2 m/s. Hence the unfavourable variations of the microclimate were eliminated. After stopping the air curtain running the air temperature decreased quickly. For example, after 2 minutes the temperature decreased from 19 to 15 °C and after 5 minutes, to 11 °C, confirming the protective quality of the air curtain against the cold air currents. In both conditions, without and with the air curtain, the relative humidity was about 50 % and the air concentration of the carbon monoxide was between 0.02 and 0.04 mg/m³ (much below the TLV). These results show that the natural ventilation of the forge hall was not reduced by the air curtain running at the open door.

The morbidity analysis showed that in winter, before the air curtain mounting, the frequency of the diseases favoured by cooling was 18.6 %. After the air curtain mounting and running this frequency decreased to 10.6 %, near the frequency registered in summer. For example, the frequency of the neuralgia was in winter 10.2 % without the air curtain and between 4.8 and 5.5 % after the air curtain running. It results that the professional cause of the diseases favoured by cold, respectively the sudden variations of the microclimate in the forge hall, was eliminated, improving the working conditions.

Conclusions

- The outside cold air penetrated into the industrial warm halls through the open doors in winter exposes the workers to great, sharp and sudden variations of the microclimate, which are a professional cause of the diseases favoured by cooling.
- The running of the air curtain mounted at the external open doors of the halls stops the entrance of the outside cold air into the halls in winter decreasing the frequency of the diseases favoured by cooling.

Limits for Cold Work

Summary of panel discussion

H. Rintamäki, K. Parsons¹

Oulu Regional Institute of Occupational Health, Oulu, Finland

¹Department of Work Sciences, University of Loughborough, UK

Background

The aim was to describe the current cold limits used internationally and in individual countries, to discuss their adequacy and to identify actions for the future. The panel discussion was particularly relevant to the international and European standards concerned with guidance on working practices and ergonomics in cold environments that were in the early stages of development.

Structure of the Discussion

The chairman noted that international standards and European standards, concerned with working in the cold, had been proposed and that a vote of member countries had agreed the proposals. The work will be carried out under the leadership of experts from Finland and through the co-operating working groups ISO TC 159 SC5 WG1 and CEN TC 122 WG11 'Ergonomics of the thermal environment'. It was agreed to structure the discussion under the headings:

1. Which cold limits are used now.
2. What are acceptable physiological and subjective states and performance levels.
3. Indices used: Wind Chill Index (WCI), IREQ (clothing insulation required), air temperature (t_a) and thermal models.
4. Implementation of standards and models.
5. Research needs.

Limits used now

The panel and audience briefly presented the position in their own countries as they understood it. In the United Kingdom a new British Standard was about to be published (BS 7915 1998) which has been based upon a request from industry and a field survey of current practices. This standard provides guidance and practical advice and presents the IREQ index for assessing work in cold environments. The standard is a guide and presents methods but not prescriptive limits.

In Sweden outdoor work in the cold is not controlled but trade union negotiations may produce limits for the lowest allowable temperature. the IREQ index has been developed as a Swedish initiative. Practices and limits for indoor work in the food processing industry are under discussion. A pragmatic approach is taken in Denmark

with no strict limits for outdoor work and a focus on practical solutions. There have been few problems reported and where they do occur practical advice is provided. In Finland there are not limits that are based upon legislation and trades unions are involved in agreements for work in the construction industry. There are guidelines for cold work in Japan. Time limits for work are provided based upon three temperature ranges (- 10 to - 25 °C, - 26 to - 40 °C and - 41 to - 55 °C) and taking account of levels of physical work. The higher the level of work the longer the allowed duration for a given temperature. Norway is waiting for the development of European standards, however, it was noted that although the situation is changing, industry has not yet identified that work in cold air can be a problem.

Of particular interest was the position of Russia where extensive work had been carried out. Legislation prescribed limits and procedures for different regions and industries. The limits were dependent upon clothing and activity and gave guidance on required clothing. Extensive research has been carried out in Germany in a survey of German industry. DIN standard (33 403 - 5) has been produced providing practical guidance based upon the IREQ index. A definition of cold work was in terms of those who work daily at air temperatures below 15 °C. In France some research had been carried out into the IREQ index but current practices are based upon the WCI index. The Netherlands are aware of current ISO proposals and an interesting development is a revised version of the WCI index, based upon heat transfer calculations. Australia presently follows developments in the world literature and New Zealand has no specific regulations and generally awaits guidance from Europe. A conclusion to the discussion referred again to the initiative within European standardisation to produce working practices for cold work. This is at an early stage and will be led by experts from Finland.

Limits in terms of physiological and subjective states and performance levels.

Physiological limits for cold could be established and based upon the measurement methods given in ISO 9886 concerned with physiological measurements. What limits are appropriate however is not clear and also whether it is possible to have limits based upon subjective or even performance criteria. The following points summarise the discussion of delegates and experts from a range of countries.

It was suggested that new limit values were required. The concept of risk was important but we need a definition. Is it risk of discomfort or risk to health? Maybe we need categories. Hypothermia in work could be a physiological limit but we need a practical definition. Limits for hand temperature were suggested to be 16 °C. Cold water exposure requires different criteria and consideration than cold air exposure. It was suggested that any deviation from the normal condition can provide a physiological criterion however it is noted that not all deviations will provide a limit of unacceptability. It was reported that internal body temperatures often fell below 36 °C in children when swimming.

If comfort provides the criteria for limits then individual differences must be taken into account. A critical factor is the affect cold will have on behaviour. The effects of cold on communication, work organisation, work group capacity and decision making are all important. Subjective experiences should be taken seriously into consideration. Cold can affect muscular diseases and lead to muscular accidents. Numb hands may contribute to severe accidents but this is often not reported. Safety for the job is

required not only safety for the body. It was suggested that an acceptable limit would be when loss in manual dexterity becomes unacceptable.

It was concluded that some knowledge exists but more knowledge was needed. It was not known for example, how much cooling can be accepted either continuously or in repeated exposure. More delicate criteria were needed for areas where affects occur but not at extreme levels of cold.

Cold indices.

A brief discussion of cold indices found that the Wind Chill Index was used as was the IREQ index and air temperature alone. The discussion moved to an acknowledgement that a lot of work had been done and that we should ensure that we are not ignoring this. The IREQ was an idea of Burton and Edholm (1955) for example that had been developed into its recent form. It was particularly important not to ignore the work on manual performance in the cold. It was noted that there was little work on cold and wet environments and no appropriate index.

Implementation of Standards

This discussion was truncated through shortage of time. It was noted that even if good scientific data exist then it must be presented in a way that is of practical use. That is, usability issues must be considered. We need to specify who is going to use the criteria and their user requirements.

Research Needs

The following research needs were identified:

1. review of the literature on hand performance in the cold.
2. manual handling and accidents
3. mental and cognitive performance and what is the critical temperature.
4. an investigation into performance when brain temperature goes below 37 °C, in particular memory affects.
5. individual differences, including age, in responses to cold.
6. limits affecting accidents
7. collation of data concerned with cold induced injury (e.g. from the US mining industry).
8. affects of long term exposure to cold.
9. cold and the use of tools.
10. PPE for use in the cold and ergonomics requirements.
11. clothing ensemble performance specification.
12. a t_{ch} and WCI for indoor work.
13. limits based upon ear and nose temperatures.
14. integration of knowledge with practical requirements.

Performance criteria for cold protective clothing

T. Risikko, H. Anttonen, E. Hiltunen

Oulu Regional Institute of Occupational Health, FIN-90220 Oulu, Finland

Introduction

Cold has a direct impact on the human body, it causes changes in the regulation of thermal status, physiological and psychological responses. Working in the cold is more strenuous than working in warm conditions. In many outdoor work tasks the physical load varies greatly from one work phase to another. As protection is needed against cold, wetness and mechanical hazards, the clothing must not be too light or permeable. This causes sweating during the heaviest work phases. The condensed sweat in the clothing causes cooling of the skin and sensation of cold during the light work phases. The cold-protective clothing ensembles on the market are not sufficiently adjustable for the varying weather conditions and tasks involving different levels of heat production. The European draft standard prENV 342 for cold-protective clothing determines the limit values and classification for protective and functional properties of clothing and fabrics (6). Garments with different thermal insulation values are selected according to the IREQ-index (4). However, the effect of the wind is accounted for rather superficially. This study concerns the protective and functional objectives of cold-protective clothing. The objectives are determined separately for different work tasks and ambient conditions. Special attention is paid to the need for regulation in windy, cold conditions, when the heat production of the worker varies greatly.

Aim

This study determines the objectives for the quantitative protective and functional properties that a good outdoor work garment should reach. The objectives are given as limit values according to various work tasks (different levels of heat production), weather conditions (temperature, wind, rain), and duration of exposure. The objectives are derived from the heat balance, local and mean skin temperatures, and physical performance of the worker. The objectives are outlined for the following properties:

- Thermal insulation ($\text{m}^2\text{K}/\text{W}$, clo) (6)
- Air permeability ($\text{l}/\text{m}^2 \text{ s}$) (3)
- Ventilation of the clothing microclimate (l/min) (5)
- Water vapour permeability ($\text{m}^2\text{Pa}/\text{W}$) (1)
- Resistance to water penetration (Pa) (2)

Materials and methods

The study is based on several research projects in the areas of cold protection and clothing physiology. The quantitative protective and functional properties of clothing and fabrics are determined by using the methods stated in the above list.

Results

Table 1. The objectives for the protective and functional properties that a good outdoor work garment should reach in various tasks and different weather conditions.

Parameter	Limit	Basis	Method
Thermal insulation ($T < -20\text{ }^{\circ}\text{C}$)			
• long-term cold exposure	$\geq 3\text{ clo}$	IREQ	prENV 342
• short-term cold exposure	$\geq 2.5\text{ clo}$	IREQ	prENV 343
• gloves	$2.5\text{...}3.0\text{ clo}$	frostbites	EN 511
Air permeability			
• in wind, rest (100 W/m^2)	$< 20\text{ l/m}^2\text{ s}$	preventing of cooling	EN
• heavy work ($> 300\text{ W/m}^2$)	$20\text{...}150\text{ l/m}^2\text{ s}$	evaporation	EN
Ventilation			
• heavy work ($> 300\text{ W/m}^2$)	$\geq 300\text{ l/min}$		
Water vapour permeability			
• cold weather clothing	$\leq 13\text{ m}^2\text{Pa/W}$	evaporation	EN 31092
• cold / foul weather clothing	$< 20\text{ m}^2\text{Pa/W}$	evaporation	EN 31092
Resistance to water penetration			
• light rain	$\geq 2200\text{ Pa}$	protection against moisture	EN 20811
• heavy rain	$\geq 13000\text{ Pa}$	protection against moisture	EN 20811

Discussion

The objectives determined in this study are to be used as guidelines in the development of cold protective clothing, especially for outdoor work in the Nordic countries. The optimum combination of protective and functional factors is achieved by emphasising the factor most needed in each specific design case. The additional protective, functional, ergonomic and aesthetic objectives derived from each individual design case should also be taken into account.

References

1. ISO 11092. Textiles. Determination of physiological properties - Measurements of thermal and water vapour resistance under steady-state conditions. ISO 1991.
2. ISO 811 Textile fabrics - Determination of resistance to water penetration - Hydrostatic pressure test. ISO 1981.
3. ISO 9237 Textiles. Determination of permeability of fabrics to air.
4. ISO TR 11079: Evaluation of cold environment - Determination of required clothing insulation IREQ. Geneva: International Organisation for Standardisation, 1990
5. Lotens WA, Havenith G. Ventilation of Rainwear Determined by a Trace Gas Method. In: Mekjavic IB, Banister EW, Morrison JB (eds.): Environmental Ergonomics: Sustaining Human Performance in Harsh Environments. London, Taylor & Francis 1988: 162-176.
6. prENV 342. Protective clothing. Ensembles for protection against cold. CEN 1997.
7. prENV 343. Protective clothing against foul weather. CEN 1997.

The effect of cold, wind and movements on clothing insulation

H. Anttonen, E. Hiltunen, I. Holmér, G. Ohlsson**

Oulu Regional Institute of Occupational Health, Aapistie 1, FIN-90220 Oulu, Finland

*National Institute for Working Life, S-17184 Solna, Sweden

Introduction

The thermal properties are important for all types of protective clothing. The three factors that influence the thermal balance are activity, clothing and environment, especially temperature and wind. The mechanisms of the effect of wind on clothing are related to radiation, conduction, air permeability, evaporation and condensation, contact layers, the effect of compression, effect of wetting and freezing, the effect of contact layers, air gaps and convection. The purpose of the study was to estimate the effect of cold, wind and movement on the total thermal insulation of clothing, body cooling and the usage of IREQ-index.

Material and methods

The basic clothing was three layer winter clothing which was varied by one impermeable outer clothing and two intermediate layers with higher air permeability. The measurements were done in wind tunnel ($T_a = -5 - +15$ °C, $v = 0.4 - 18$ m/s) with manikin (walking speed of 0, 0.3 and 0.8 m/s).

Thermal insulation was calculated either as a local or an average thermal insulation using data of temperatures and heat flux by the equation 1 and 2.

$$I_i = T_{sk} - T_i / HF_i \quad (1)$$

$$I_{cl} = T_{sk} - T_a / f_i * HF_i \quad (2)$$

Results

The thermal insulation of the basic clothing decreased from 0.35 to 0.11 m²K/W when wind speed increased from 1 to 18 m/s (Figure 1). With clothing with microporous membrane laminated outer garment change of thermal insulation was from 0.38 to 0.20 m²K/W. The basic clothing with woollen or cotton intermediate clothing did not differ from each other more than from 1 to 3 percent.

Increase of wind from 0.4 m/s to 8 m/s decreased total thermal insulation by about 75 % with air permeable outerwear and 50 % with impermeable outerwear. Walking decreased total thermal insulation of the basic clothing about 10 % and from 20 to 24 % with higher air permeable intermediate layer.

When the outer garment of basic clothing was changed from air permeable to impermeable, the thermal insulation increased 8 % at wind velocity 1 m/s and 82 % at wind velocity 18 m/s.

Discussion

In this case of standing position the air permeability of the outer garment and the adjacent of layer effected mainly on thermal insulation.

Walking broke the immobile adjacent air layer on clothing and caused decrease in thermal insulation and decreased total thermal insulation at low wind velocities from 10 to 15 % and only 5 % when wind velocity was 18 m/s.

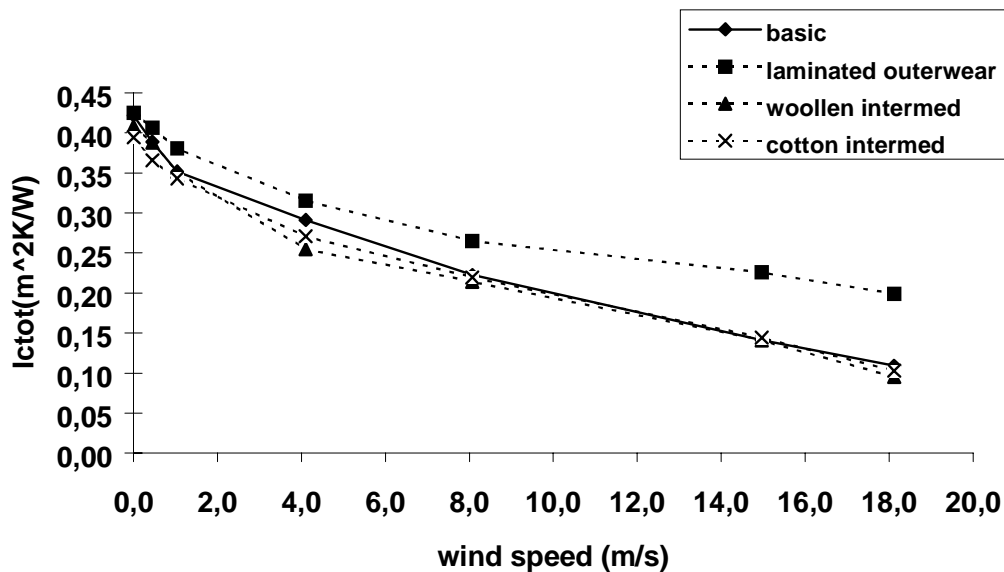


Figure 1. Thermal insulations of garments studied by standing manikin.

According to the IREQ index the increase of wind from 0.4 to 18 m/s required the increase of thermal insulation to be from 5 to 7 % in the standing position and from 20 to 25 % in moderate work, which are considerably lower than measured.

There is also a considerable difference in behaviour of wind between permeable and impermeable outerwear which the IREQ -index does not take into account. In this study the optimal ambient temperature in moderate work is 12 °C higher with impermeable outerwear than with air permeable one in wind.

Acknowledgement

Supported by grants from the Finnish Work Environment Fund and the Swedish Council for Work Life Research.

References

1. ISO TR 11079: Evaluation of cold environment - Determination of required clothing insulation IREQ. Geneva: International Organisation for Standardisation, 1990

Thermal properties of three sets of garments measured with a heated sweating mannequin

*K. Kuklane, I. Holmér, H. Meinander**

National Institute for Working Life, Department of Occupational Medicine,
S - 171 84 Solna, Sweden

* VTT Chemical Technology, Tampere, Finland

Introduction

The choice of proper insulation for cold protection is important. However, “proper insulation” depends on activity and at lots of jobs the activity varies along the working day. The choice of low insulation for heavy work makes people feel cold during low activity levels and the choice of high insulation for light work makes them feel hot and sweating during high activity levels. The sweating increases the heat losses through evaporation and reduces the insulation due to wetting of insulation layers. Moist clothing often causes strong discomfort sensation.

In this experiment the effect of sweating and ambient temperature on insulation, evaporation and condensation was studied in 5 clothing ensembles.

Methods

Five sets of garments were studied at 3 air temperatures (-10 ,0 and +10 °C). GK, GKU and VRU were more or less impermeable protective clothing, while PMV and IREQ were commonly used cold weather working clothes in construction industry.

The measurements were made with a sweating thermal mannequin Coppelius (1). The tests were carried out both without and with sweating. The PMV and IREQ were measured with a sweat rate adjusted to 100 g/m²h. For these sets of clothing the dry test was carried out at +10 °C and wet test at -10 °C. Both dry and wet test was carried out for GK, GKU and VRU at +10 and 0 °C (VRU even at -10 °C). For these garments the water supply during sweating tests was 200 g/m²h. The length of the wet test was 3 hours and of dry test 1.5 hours.

Results and discussion

The calculation of the insulation values on the basis of the measurements on sweating manikin is based on the heat balance equation. However, previous calculations have not taken into account the heat gain from condensation. In the cold, water vapour from the skin will condense in clothing layers on its way to the surface and ambient air. With condensation heat is liberated and taken up by adjacent air and layers. If it occurs at the skin then almost all heat is gained. The insulation was calculated by following formula:

$$I_{tot,corr} = \frac{T_s - T_a}{H - H_e + 0.4 \cdot H_{cond}}$$

where $I_{tot,corr}$ - total insulation corrected for evaporation and condensation, T_s - model surface temperature, T_a - ambient air temperature, H - total heat supply, H_e - evaporative heat loss, H_{cond} - heat gain/loss from condensation. The choice of condensation factor had bigger influence on impermeable clothing, especially VRU and minimal effect on PMV and IREQ. This is because much more condensation occurred in the more impermeable garments

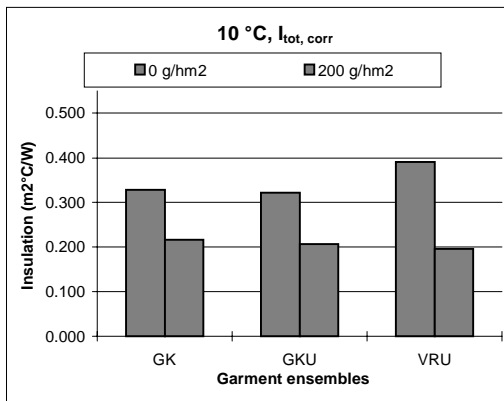


Figure 1. Corrected total insulation ($I_{tot,corr}$) for dry and sweating test at +10 °C .

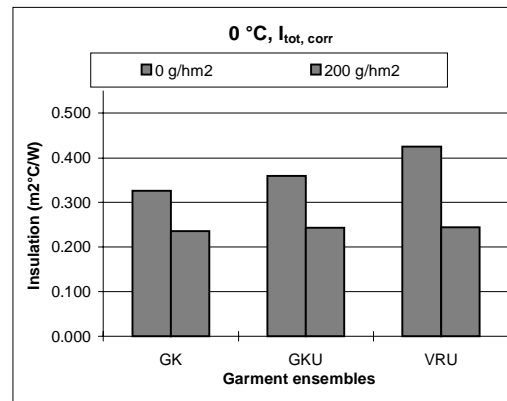


Figure 2. Corrected total insulation ($I_{tot,corr}$) for dry and sweating test at 0 °C .

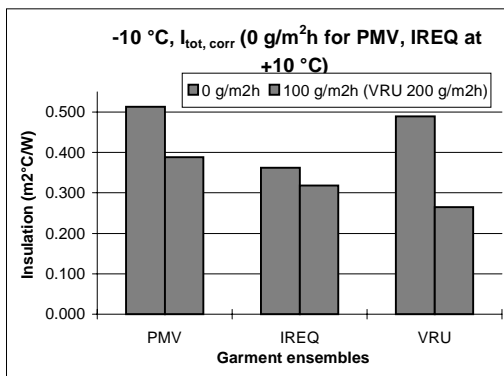


Figure 3. Corrected total insulation ($I_{tot,corr}$).

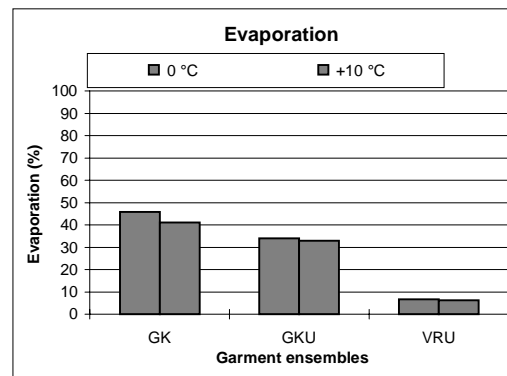


Figure 4. Percentage of evaporation from supplied water at two environmental temperatures.

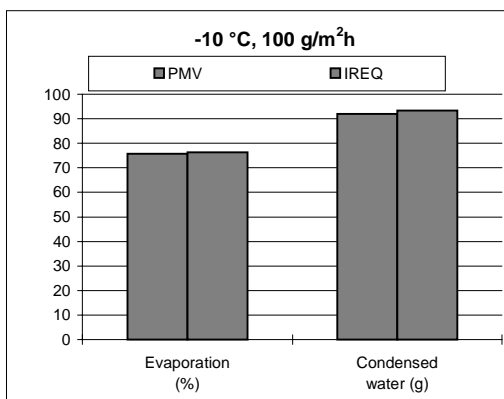


Figure 5. Percentage of evaporation from supplied water and amount of condensed water in clothing.

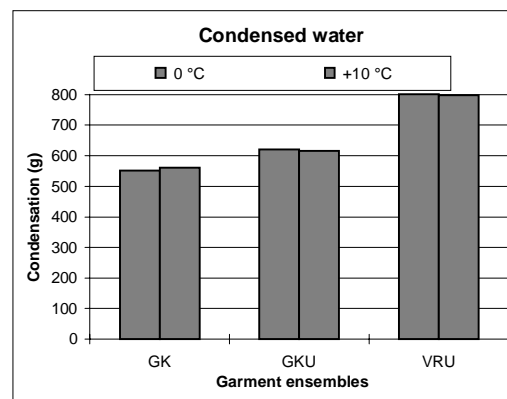


Figure 6. Amount of condensed water in clothing at two environmental temperatures.

Figures 1, 2 and 3 show the differences in $I_{tot,corr}$ values for the dry and sweating measurements at various environmental temperatures. The difference shows the

reduction of insulation due to wetting of insulation layers. For GK and GKU the difference was 28-36 %, while the difference for VRU was 42-50 %. The reduction of insulation was 24 % for PMV and only 12 % for IREQ. The latter had a thinner outer layer compared to PMV.

Figure 4 shows the evaporation percentage from the supplied water and Figure 6 shows the condensation in clothing for garments GK, GKU and VRU. The same parameters for IREQ and PMV are shown in Figure 5. Evaporation was highest for the permeable clothing (IREQ and PMV), followed by the protective garment with the best water vapour permeability (GK) and it was the lowest for VRU. Condensation shows the opposite results.

It can be easily seen that while the $I_{\text{tot,corr}}$ for dry condition is in the same range, $I_{\text{tot,corr}}$ for sweating and the percentage of evaporation are much higher in PMV and IREQ than in more impermeable protective garments. The results show a clear relation between the water that was condensed in the garment and insulation level. Higher water contents in clothing reduce the insulation and contribute to cooling of the body.

References

1. Meinander, H., Experience with a sweating thermal manikin - Ready for standard use? In: Nilsson, H., Holmér, I., eds. Proceedings of a European seminar on Thermal Manikin Testing. Solna: Arbetslivsinstitutet, Department of Ergonomics, 1997, pp. 38-42.

Moisture accumulation in sleeping bags

G. Havenith, R. Heus

TNO Human Factors Research Institute, Soesterberg, The Netherlands

Introduction

In the use of sleeping bags in low temperatures, the accumulation of moisture in the bags over prolonged periods of use has been a major problem. This accumulated moisture causes a reduction in heat resistance due to the higher conductance of moisture compared to air and due to a constant evaporation/condensation cycle which takes place from the warmer (inner) to the cooler (outer) parts of the bag.

The source of the moisture are the users of the bag themselves, who may expire warm moist air into the bag, and who lose moisture through their skin, as well as any moist clothing or equipment they take into the bag. The water may then enter the bag by wicking from the clothing or by evaporation and condensation. At or close to the user's skin, the temperature will be high, which means moisture evaporates easily. As the environment is cool, with a low moisture content, a water vapour gradient is present from the skin to the environment, and thus moisture will move in that direction. As the temperature decreases following this path from skin to environment, also the dewpoint for water vapour and thus the maximal water vapour concentration in the air decreases along this path. In the cold, the gradient in dewpoint will be steep enough for water vapour concentration to reach its saturation level, and condensation of water vapour will take place within the sleeping bag.

This moisture accumulation takes place in all types of sleeping bags, but the extent of the phenomenon is, apart from the environmental temperature, highly dependent on the vapour permeability of the sleeping bag materials. Especially when sleeping bags are used with water impermeable, rain protective covers, the problem will increase dramatically, as the vapour resistance of such covers is usually much higher than of normal fabrics.

To minimise the problem, many manufacturers developed rain covers from waterproof, but vapour permeable materials, to allow for optimal evaporation. Recent studies on the behaviour of such materials at low temperature (Osczevski, DREO, 1993) however have shown that the vapour resistance of some of these materials increases dramatically when temperatures fall below zero degrees Celsius. The functionality of these materials in such conditions can therefore be questioned.

As further the price of such semipermeable covers is relatively high, some researchers suggest (Vanggaard, personal communication) that in the cold one should use a cheap impermeable cover. This will collect frost on the inner surface during the sleep period. This cover should then be removed after the sleep period, the frost shaken out and in that way the moisture removed.

In order to study these problems for their relevance for the Netherlands Army sleeping bag, an experiment was devised to answer the following questions: Is the use of semi-permeable versus impermeable rain covers for sleeping bags effective in

removing excess moisture in moderate cold? Will a daily “shake” of an impermeable cover prevent moisture accumulation?

Methods

Sleeping bags:

For the experiments, sleeping bags with identical insulation were used, differing only in the type of outer cover. Six conditions were used:

- no cover (reference condition)
 - fixed impermeable cover (worst case)
 - fixed, full semipermeable¹ cover
 - separate cover with semipermeable top¹, shake out frost daily
 - fixed, full semipermeable² cover
 - impermeable cover, shake out frost after each use
- (1) = PTFE membrane, (2) = PU coating

Procedures:

The bags were used in a climatic chamber, set at a temperature of $-7\text{ }^{\circ}\text{C}$, wind of $0.2\text{ m}\cdot\text{s}^{-1}$, relative humidity 40-50 %. The bags were used for six consecutive days, with 6 hours “sleep” per day. The bags were packed in impermeable plastic bags between use periods, to simulate field conditions, where no airing of the bags between uses is possible. Six subjects used the bags, with a daily rotation over bags. Before entering the bag, the subjects put on underwear and combat clothing. The latter was treated daily, to contain a moisture amount of 150 grams when entering the bag. Before and after each trial period, weights of the bags, clothing and subjects were obtained in order to determine the moisture balance.

Results

The results for the best and the worst case (no cover and impermeable cover respectively) are presented in Figure 1.

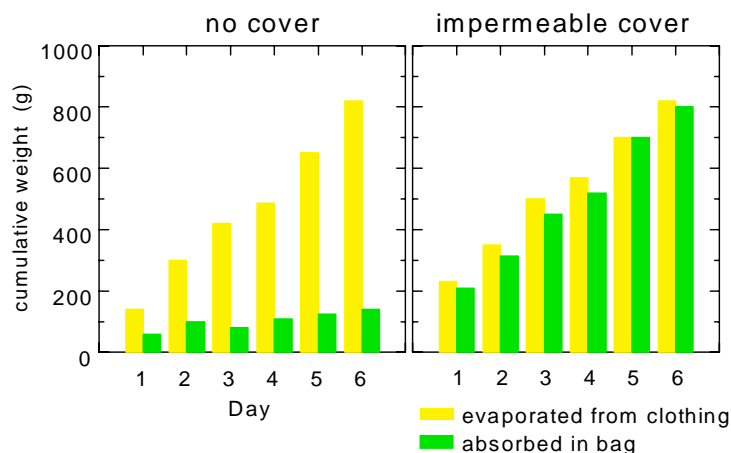


Figure 1. Cumulative weight change of the clothing and of the sleeping bag.

From this figure, following the time course of the moisture accumulation and evaporation over the six days, it is clear that the amount of moisture evaporating from the clothing is roughly identical for both cases. The amount staying within the sleeping bag is very different though. While in the no cover condition the accumulation is minimal, it is almost equal to the amount evaporated from the clothing in the impermeable cover condition, consistent with the type of material. In Figure 2, the results for the other sleeping bag covers are presented.

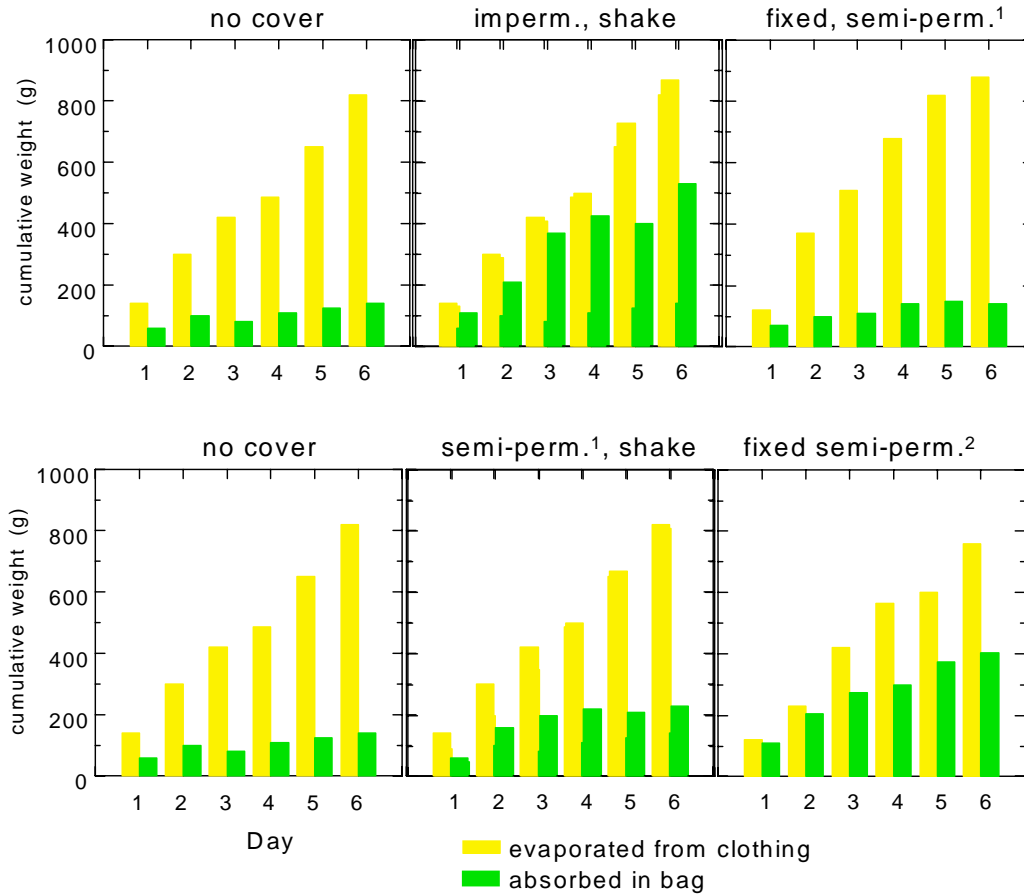


Figure 2. Cumulative weight change over six days of use of sleeping bags and of clothing worn, for different sleeping bag covers. 1=PTFE membrane cover with hydrophilic layer; 2=polyurethane coating.

Shaking the frost out of the impermeable cover after each use did not have an effect on the moisture accumulation in the bag for the first couple of days. After 4 days, however, the total accumulated moisture amount seems to stabilise, and further accumulation takes place at a slower pace. Of the two fixed, semi-permeable covers, the one made from PTFE material shows only minimal moisture accumulation, which does not seem different from that without a cover. The other semi-permeable cover, with a polyurethane based coating, reduces moisture accumulation compared to the impermeable cover, but does not perform as well as the PTFE based cover.

The semi-permeable cover, with the bottom half of the cover impermeable, and with a daily removal of frost from the inner surface, performs quite well too, and comes close to the full impermeable cover.

These results are brought together in Figure 3, which presents the total amounts of moisture accumulated in the bags after 6 days, and compares it to the total amount of moisture evaporated from the clothing.

Discussion

The results show that using an impermeable, non-detachable cover around a sleeping bag will lead to excessive moisture accumulation over a period of days. Having a detachable cover, from which accumulated condensation and frost can be removed after each use, can reduce this problem. It was observed however, that using a semi-permeable membrane is much more beneficial in the tested climatic conditions (-7 °C). Of the three tested semi-permeable covers, the worst performing still reduced moisture accumulation by half. The best material did show a similar performance to the condition without a cover.

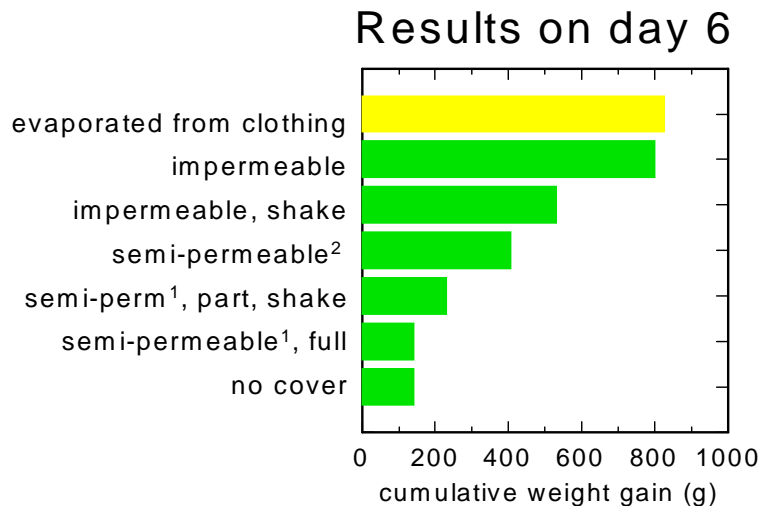


Figure 3. Total amount of moisture evaporated from the clothing over the six days of sleeping bag use, compared to the total amount of moisture accumulated in the bags over the same period.

As the semi-permeable materials were selected based on availability, one should not conclude that the difference between them is related to their material type. Already in neutral conditions, these materials were quite different in vapour permeability, with the same ranking as observed here.

References

1. Osczevski, R. J. (1993) Diffusion of water vapour through cold Gore-Tex™, Report 1202, DREO, Canada

Physiological study of some protective clothes for cold work

H. Herman

Institute of Hygiene, Public Health, Health Services and Management, Bucharest.
Romania

Introduction

In work at cold (in rooms or outside) the clothing is the most important way to protect the organism against this environmental factor. From physiological point of view the clothes must be adapted to the values of the microclimate and to the activity of the workers for assuring the comfort during their wearing. Therefore we have studied from physiological point of view some protective clothes of various materials and cuts for cold work:

- vests (coats without sleeves) padded with cotton and with synthetic (of polyacrylonitril) wadding for indoor temperatures of above 0 °C (as the non-heated rooms in winter);
- coats with hood of impermeable materials and lining padded with cotton and with synthetic (of polyacrylonitril) wadding and of artificial fur for work at air temperature of -10 °C in outdoor installations of the chemical industry. Results of the study are showed in this paper.

Methods

The vests and coats were studied in laboratory conditions, in a cold room, on 10 voluntary healthful males (22-25 years of age), at light (3 kcal/min) and mean (5 kcal/min) effort made by cycloergometer. For each effort the subjects have executed three effort periods of 15 minutes with break of 7 minutes between those in standing position. The air temperature was +2-4 °C for the vests and -10 °C for the coats. In the both cases the relative air humidity was 60 % and the air velocity was 0.1 m/s. All subjects were dressed with the same clothing under the studied clothes: underwear, drawers and shirt of cotton, high sweater of wool. At vests, they wore stuff trousers and the work overalls on the trousers and sweater. At coats, the subjects wore wadded trousers with cotton or synthetic wadding and stuff jacket. Other dress worn at vests and coats was: wool muffler, gloves and stockings, high stuff cap, high leather shoe. The vest and coat with nature fur were reference clothes.

Before the effort in standing rest and at the end of every effort period, the following indicators of the organism were assessed: oral temperature; skin temperature on the forehead and sternum; relative humidity in the underclothing space (URH) between the extremities of the two scapulae; heart rate; thermal sensation according to the following notation: well, cool, cold, very cold, warm, very warm and the opinions of subjects about the comfort during the wear of the protective clothes.

The coats were also investigated in the chemical industry, at supervision and checking of outside installations (effort intensity of 2.5-4 kcal/min), in periods of 20-60 minutes during the workday, at the air temperature of about -11 °C, relative humidity of 45-95 % and wind speed of 0.25-7 m/s. Between the work periods the operators sat in the control room. The same organism's indicators were investigated before and during the work.

During the laboratory study, the necessary changes of the protective clothes were made, and even the clothes which did not correspond to the comfort of wearing were avoided.

Results and Discussion

The indicators to establish the thermoprotective quality and the wearing comfort of the studied clothes are: oral temperature of 36.4-37 °C, sternum skin temperature of minimum 32.5 °C, thermal sensation, liberty of body movements, weight of clothes, URH.

At light effort the vest with nature fur assured a good protection against the cold. At the vest of cotton wadding in one stratum (weight of 1050 g), the protection was lower: skin sternum temperature of 31 °C, sensation of "cold" at the shoulder and sternum, because of the wadding absence at the seam level. Introduction of wadding in these regions and in the upper half of vest back and front sides (weight of 1200 g) has increased the protection against the cold in some body regions (sternum skin temperature of 35 °C), but the thermal sensation was contradictory, of "cold"- "warm", because the vest was rigid and it was not well adapted to the all body regions favouring free spaces through which the cold air penetrated under the vest. The subjects showed that the weight of the vest is great, it is rigid and does not heat uniformly. The vest of synthetic wadding in one stratum (weight of 630 g) had a low quality for heating: skin temperature of 28 °C on the forehead and of 31 °C on the sternum, oral temperature of 36.2 °C, thermal sensation of "cool". But by introducing still one and two strata of synthetic wadding the heating quality of the vest had increased: skin temperature of 31 °C on the forehead and of 32.5-34.5 °C on the sternum, oral temperature of 36.4-36.8 °C, thermal sensation of "well"- "warm". The URH did not increase and the subjects showed that the vest is light (weight of 750 or 850 g) favouring the movements and assures a uniform heating because it is well adapted to the body. The URH was at all vests 40-45 %.

At the mean effort the studied vests have assured a good thermoprotection: skin temperature of 32-32.4 °C on the forehead and of 35.8-36 °C on the sternum, oral temperature of 36.8-36.9 °C, URH of 72-75 %. The most comfortable wearing was at the vest of synthetic wadding.

Regarding the coats, at the light effort the coats with lining of synthetic wadding and of nature fur showed the best thermoinsulating quality: skin temperature of 29 °C of the forehead and of 33.5-34.5 °C on the sternum, oral temperature of 36.8 °C, URH of 68-75 %, thermal sensation of "warm". The thermoprotection of the coats with lining of cotton wadding or of artificial fur was lower: skin temperature of 27-28 °C on the forehead and of 30.4-31.5 °C on the sternum, oral temperature of 36.2-36.4 °C, thermal sensation of "cold" or "cool".

At the mean effort, all coats have assured a high protection against the air temperature of -10 °C of the cold room. In this case the heat production of the organism is important. The sternum skin temperature (35-38.5 °C) and the URH (78-100 %)

increased much; the thermal sensation was “very warm” and the subjects were sweating. However the coat with lining of synthetic wadding has assured the best comfort: skin temperature of 30.4 °C on the forehead and of 35.5°C on the sternum, oral temperature of 37 °C, URH of 82 %. The indicators of the coat with nature fur were higher (for example, the URH was 100 %).

In the industry, at the air temperature above 0 °C, all coats assured the thermoinsulation of the workers. The coat with lining and trousers with synthetic wadding assured a good protection against the cold at the low temperature (of -11 °C) and great air speed (till 7 m/s). The weight of these clothes is lower than that of the clothes with nature fur and with cotton wadding. The movements of the body, especially of the upper limbs, are made easily, without impediment. At the third upper part of the coats (faces and sleeves) the stratum of the wadding should have a greater thickness. The impermeable outer and the hood of the coats have contributed to their thermoprotective quality.

Conclusions

The synthetic polyacrylonitril wadding, obtained in the industry of chemical threads, should be a good material for protection against the cold during the work, as padding the clothes (vest, coat, trousers, hood) in a certain thickness. The protective clothes for the cold work must be adapted to the values of the microclimate and the work characteristics (effort intensity, body positions and movements, time of work in cold environment). The other clothing of the workers (under the protective clothes, as addition to these clothes) must have also thermoprotective qualities.

A new winter clothing system for construction workers

R. Heus, L. Kistemaker, G. Havenith

TNO Human Factors Research Institute, Soesterberg, the Netherlands

Introduction

In order to improve construction worker's protection against adverse climatic circumstances a new clothing system was developed. This all-weather-concept should protect workers throughout the year in a temperate zone. This implies protection against (mild) cold, rain, snow and windy conditions, but also comfort during heavy work in more moderate temperatures. The question was whether the new clothing will be more comfortable than the clothing usually worn by construction workers. To study this the following questions were formulated:

- 1 Does the new clothing system provide better cold protection at low work rates or rest, yet allow better heat dissipation when performing heavy work?
- 2 Does the new, full waterproof outer clothing layer provide sufficient breathability, compared to the old system of which only the jacket was waterproof?

Two studies were carried out to answer these questions.

Materials and methods

Clothing

The new clothing system consists of a jacket and trousers, both with a watertight layer and a liner, a sweatshirt and thermal underwear. The reference clothing consists of a jacket with watertight coating and a liner, trousers without waterproof coating (both cotton/polyester), a jersey, a T-shirt and pants (cotton). In the first experiment subjects wore mittens and boots with both clothing configurations. The second experiment was carried out with only the outer layers of the clothing configurations over the same cotton/polyester undergarments.

Experiments

In the first experiment insulation of the clothing and moisture accumulation was studied in a cold (-5 °C) climate. During the first part of the experiment (30 min) subjects were resting in the wind ($1\text{m}\cdot\text{s}^{-1}$) to study the insulation of the clothing. After the rest period subjects started working (45 min) at a heavy work load (120 W) on a bicycle ergometer without wind ($<0.2\text{ m}\cdot\text{s}^{-1}$) to study rewarming of the subjects and heat dissipation through the clothing.

In the second experiment in a cool (+7 °C) climate light work (50 W) was carried out by the subjects. Before this experiment the standard underclothing was wetted with 150

ml water. In both experiments temperatures (T_{skin} and T_{core}) and weight losses (D_{mass}) were measured. The subjects were also asked for their comfort votes.

Subjects

Both experiments were done with the same eight healthy male subjects (19-23 years) who signed an informed consent to participate in these experiments.

Design and analysis

All subjects wore both clothing systems in a balanced order. Temperatures were registered every 15 seconds, comfort votes were scored every 10 minutes and D_{mass} was determined by weighing subjects and clothing before and after the experiments.

Data of every 10th minute and the weight loss data were submitted to an analysis of variance for repeated measures with factors clothing and subject. Results were accepted as significant when $p \leq 0.05$.

Results

During the cooling period (rest) of the first experiment subjects felt less cold with the new clothing (“a little cool” vs. “cool”) though body temperatures were equal. During heavy exercise no difference in thermal comfort (“warm”) was found, though T_{skin} was significantly lower with the new clothing (Fig. 1). Also less moisture was absorbed during heavy exercise in the new clothing (20.0 g vs. 32.3 g).

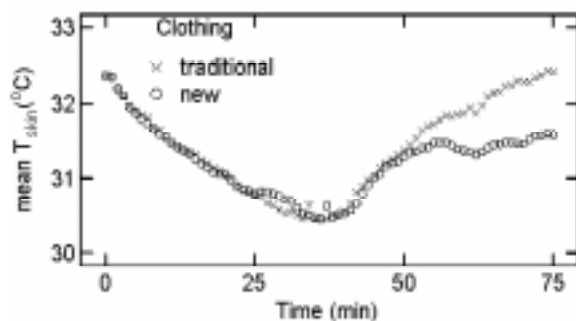


Figure 1. Mean T_{skin} averaged over all subjects during the first cold experiment for both clothing systems

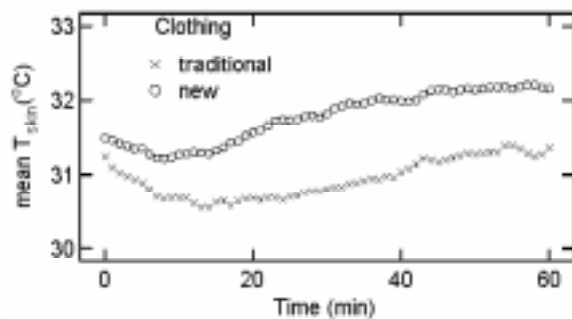


Figure 2. Mean T_{skin} averaged over all subjects during the second cool experiment for both clothing systems

In the second experiment subjects felt slightly more wet with the new clothing (“slightly humid” vs. “neutral” to “slightly humid”). During the first 10 minutes a smaller decrease of T_{skin} (Fig. 2) was measured in the new clothing and during the complete period T_{skin} remained higher. In the new clothing people produced significantly more sweat (221.4 g vs. 108.2 g). The new trousers absorbed more moisture than the traditional (6.8 g vs. 2.9 g). Total removal of moisture from the clothing with the new outer layers was 52 g and did not differ significantly from the clothes (88 g) with traditional outer layers. The wetted underclothing with the new clothing dried less than with the traditional clothing (-111.3 g vs. -128.3 g).

Discussion and conclusions

Results of the cooling period of the first experiment showed that the static insulation of both ensembles was probably comparable (equal body temperatures), but that the new system subjectively felt warmer. During the exercise period the subjects heated up less in the new system (lower dynamic insulation and/or higher breathability), but felt equally warm. Thus, when the new system was worn as complete configuration, results suggest a better performance both at rest and during work than of the old system.

Despite the better performance of the new clothing system in the first experiment, subjects felt marginally more wet with the new clothing in the second experiment, supported by the slower drying of the underclothing. This can be attributed to a higher total vapour resistance of the outer layers of the new clothes (both jacket and trousers waterproof) compared to the traditional ones (only jacket waterproof). This explanation is supported by the smaller decrease in T_{skin} at the start of the test (less “after-chill”) in the new clothing with wet underclothing. Thus, the lower insulation of the new clothing system observed during exercise in the cold, apparently is combined with a higher vapour resistance of the outer, waterproof layer.

Conclusions about the new clothing system from above experiments were that it is more comfortable in the cold, that total heat dissipation during exercise is better, but that due to the improved waterproofness, the vapour resistance of the new clothing is higher.

Physiological and hygienic requirements to thermal protective properties indices of headgear

R. Afanasieva, O. Burmistrova

Research Institute of Labour Medicine of Russian Academy of Medical Sciences,
Moscow, Russia

One principle method for protection of humans against cold is the use of clothing with a thermal resistance corresponding to climatic conditions, stay time in the working area, and physical activity [1]. All parts of the body surface must be protected according to the level of heat loss from their surfaces, skin temperatures, thermal sensitivity and also their degree of influence on cooling of the body as a whole [1; 2]. Data of head heat exchange and its thermal insulation requirements in cold environments are few. There are data according to which head surface heat losses part can reach 20 % in air and 50 % in water [2]. Head warming significantly influences the heat loss of the body on the whole [1]. One of the reasons for high heat losses from the head region in the cold is poor vasoconstriction [3].

The present article is devoted to physiological and hygienic requirements for properties of thermal protective headwear (R_{sum}) which is the physical characteristics the layer of materials.

Some research series were carried out. The first was carried out in the microclimate chamber under t_a ranging from -10 to $+28$ °C; $RH= 51\pm 5$ %; $V_a \leq 0,1$ m/s. Fifteen volunteers performed different kinds of physical work dressed in clothing with an insulation of 1,0 clo. The following was measured: rectal temperature (t_r), skin temperature (t_s) and “dry” heat flow (q_f) in 15 parts of body: *forehead, crown, back of the head, temple, neck, chest, back, stomach, waist, shoulder, hand, thigh (upper and lower part), shin, foot*; heart rate, metabolism, heat sensation are determined. In a second series 100 experiments were carried out at a t_a of -6 ± 1 °C and $V_a = 0,1; 1,0; 5,0$ and $8,0$ m/s. The aim was to study of relations between head skin temperature (t_h), heat flow from head surface (q_h), R_{sum} of the material (δ , mm), air penetration (AP , $dm^3/m^2 \cdot s$) and air velocity (V_a). R_{sum} of headwear is calculated by the following formula:

$$R_{sum.h} = (t_h - t_a) / q_{fh}, \text{ } ^\circ\text{C}\cdot\text{m}^2/\text{W} \quad (1)$$

In a cold environment (independent of air temperature and physical activity) most fall in skin temperature (t_s) was observed in the region of the crown, the forehead and the back of the head, for the last one - in the temple region. The highest values of heat flow were registered in the region of temple and forehead. The least lowering heat flow was observed in the temple region obviously a result from head surface blood-vessel topography.

For the determination of allowable values of skin temperature and heat flow in the head region we were considered the allowable thermal state indices of the body on the

whole and the corresponding distribution. In this case the part of head surface heat flow under physical activity is equal to 11,5 – 12,1 % (11,79 ±1,0 %). Upper (t_{h1}) and lower (t_{h2}) limits of human head skin temperature whose thermal state corresponding to allowable levels are determined by equations:

$$t_{h1} = 37,294 - 0,0369 \cdot Q_m \quad (r = -0,9991; p < 0,001) \quad (2)$$

$$t_{h2} = 37,047 - 0,0457 \cdot Q_m \quad (r = -0,9988; p < 0,001) \quad (3)$$

Requirements for highest head surface heat losses (lower and upper limits) follow the above-mentioned range with reference to the whole body surface heat loss. The values are interpreted in terms of stay times in cold environment s(table 1).

From skin temperature (equation 2 and 3) and heat flow (table 1) a proper value of R_{sum} for headwear can be determined as function of ambient temperature and physical activity.

The relation between R_{sum} and air velocity (V_a , m/s), air penetration (AP, dm³/m²·s) and thickness of material layers (δ , mm) are expressed by equation:

$$R_{sum} = (0,11 \cdot \delta + 0,145) / (0,082 \sqrt{V_a + 1,24 \cdot V_a^2} \cdot AP \cdot 10^{-4} + 0,979) \quad (4)$$

Table 1. Heat flow from the head and its relation to stay time ($Q_m=113 \text{ W/m}^2$)

τ , hours	Head surface heat flow, W/m ²	
	Lower limit	Upper limit
1	160,3	196,3
2	154,5	176,5
3	152,6	170,6
4	151,6	166,7
8	150,2	161,7

References

1. Afanasieva R. Hygienic principles of clothing projection for cold protection. Legkaya industria, Moscow, 1977.
2. Burton A. , Edholm O. Human under cold conditions. Foreign Literature, Moscow, 1957.
3. Froese G, Burton A. Heat losses from human head. J Appl Physiol 1957;10:235-241.

Effect of temperature and gloves on frostbite of hands

H. Anttonen, E. Hiltunen

Oulu Regional Institute of Occupational Health, Aapistie 1, FIN-90220 Oulu, Finland

Introduction

One of the most vulnerable parts of the human body to frostbite are hands. In this study a theoretical model was developed to predict environmental temperatures resulting in hand frostbites as a function of protective clothing, handwear and activity levels.

The model is based on thermoregulation of blood flow to hands. However, the aim of the model was to achieve results with a practical model rather than to include sophisticated thermoregulatory mechanisms.

Material and methods

In the model the finger temperature (1), the blood flow that controls the finger temperature and hand temperature were expressed by equations 1-3.

$$T_{fing} = \frac{T_a - T_{rect}}{e^{(E \cdot LDG)}} + T_{rect} \quad (1)$$

$$LDG = A \cdot 2^{B \cdot (T_{rect} - 36.5) + C \cdot (T_{skin} - 33) + D \cdot (T_{hand} - 29)} \quad (2)$$

$$T_{hand} = \frac{I \cdot K}{A_{hand}} + T_a \quad (3)$$

where, T_{fing} - finger temperature ($^{\circ}\text{C}$), T_a - ambient temperature ($^{\circ}\text{C}$), T_{rect} - rectal temperature ($^{\circ}\text{C}$), $E=0.069$ (constant), LDG - bloodflow to the finger ($\text{ml}/100 \cdot \text{ml} \cdot \text{min}$), K - constant depending on metabolic rate (W/m^2), I - thermal insulation of gloves ($\text{m}^2\text{K}/\text{W}$), A_{hand} - the area of hand (m^2), A, \dots, D - constants.

According to the equations the temperature of finger can be calculated when ambient temperature, working level, the insulation of clothing of middle body and gloves are known. Sweating and moisture in clothing are taken into account by the decreased thermal insulation.

Results

The hand frostbites of the conscripts during field manoeuvres were used to test the model ($N=207$). In the field manoeuvres 90 % of the frostbites occurred at temperatures below -15°C and only 20 % at temperature extremes below -30°C . In most cases frostbite injuries occurred at low activity levels ($80 \dots 140 \text{ W}/\text{m}^2$).

Results of model are presented in Figures 1-2. Figure 1 shows the modelled frostbite temperatures and Figure 2 the effect of change of metabolic rate on frostbite temperatures.

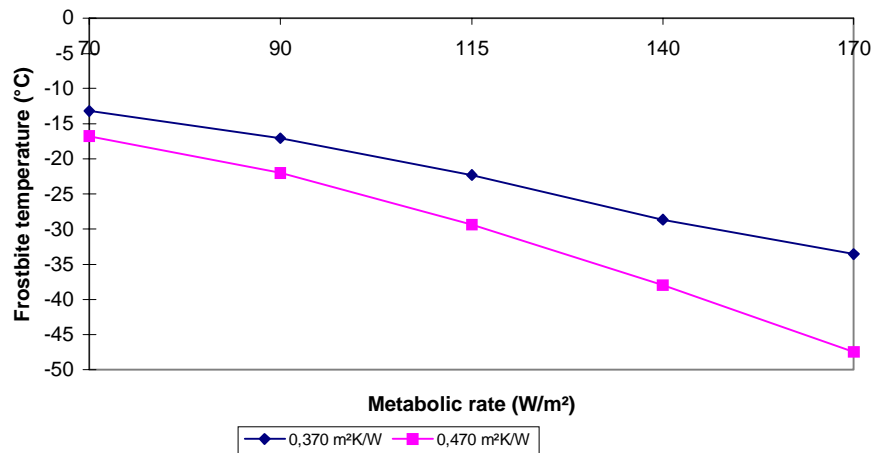


Figure 1. Hand model curves with two clothing (0.370 and 0.470 m^2K/W).

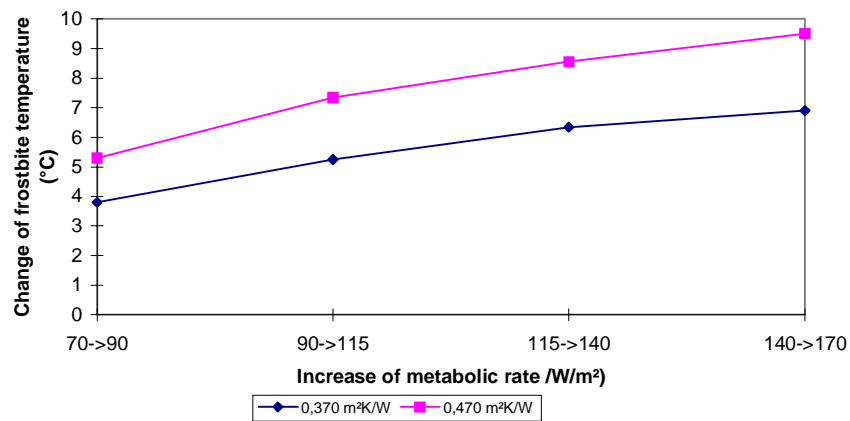


Figure 2.Effect of metabolic rate (W/m^2) on frostbite temperatures ($^{\circ}C$).

Conclusions

- According to the model a risk of frostbite depends on ambient temperature, rectal temperature and activity level.
- Moisture inside gloves had only minor effect on frostbite temperatures.
- Increasing of total thermal insulation of clothing with 0.100 m^2K/W lowered frostbite temperatures from 5 to 9 $^{\circ}C$.
- The model shows that with a 20 % increase in the activity, the ambient temperature resulting a risk of frostbite decreases with 6-7 $^{\circ}C$.

References

1. Schwarzlose H.: Zur Beanspruchung des Menschen durch Hand-Arm-Vibration bei verschiedenen Umgebungstemperaturen unter besonderer Berücksichtigung der Tätigkeit von Steinmetzen, Fortschritt-Berichte der VDI Zeitschriften, Reihe 11 Nr 55, VDI-verlag GmbH Düsseldorf 1983.

Reduction of footwear insulation due to walking and sweating: a preliminary study

K. Kuklane¹, I. Holmér

Department of Occupational Medicine, National Institute for Working Life,
S - 171 84 Solna, Sweden

Introduction

During the work in the cold the extremities are affected to a great extent and the performance drops or the exposure time has to be shortened. A good insulation of feet is thus important. EN 344 (1) estimates the thermal protection of footwear at one point on the innersole of the boot that is filled with 4 kg of 5 mm steel balls by the means of recording a temperature change. The rate of temperature drop is used for classification of footwear. A standard of USSR (2) is more advanced. It measures the temperature change in last shaped rubber balloons that are filled with water. Empirical formulas are used to calculate the insulation. A third method uses a thermal foot model. From temperature gradient between model's surface temperature and environmental temperature, and the heat loss, it is possible to calculate the insulation of footwear.

The measurements with a walking thermal mannequin(3) have shown considerable effect from air velocity and motion. Dynamic tests have been carried out on foot model, too (4). The motion reduces the insulation about 10-25 %. The effects of wetting of the insulation can be even higher. The tests of immersion (5) and sweat simulation (6) have been carried out with thermal foot models and in both cases the reduction of insulation could reach up to 40 %. It can be suspected that combined effect of wetting and motion is even higher.

The first dynamic tests with sweat simulation have been carried out. This paper shows some results and discusses the problems that occurred.

Methods

Three boots were used in the test: BN, VS and WS. BN was a rubber boot, and VS and WS were the warm winter boots. For comparison the insulation values were measured in 4 conditions: dry standing (SD), wet standing (SW), dry walking(WD) and wet walking (WW). The standing measurements are the results from a previous study (6).

Foot model and measuring principles are described in more detail in (4) and (6). Walking speed (step rate) was adjusted to 4 km/h. Water was supplied to three "sweat glands" with a peristaltic pump at the rate of 10 g/h (ca 3.3 g/h per "gland"). For better water distribution a thin sock was used. Each test lasted for 90 minutes and the insulation was calculation the basis of last 10 minute data. The calculation of the total insulation used the data from toe, sole, heel, mid-foot and ankle zones.

¹ Doctoral student at Department of Human Work Sciences, Luleå University of Technology, Luleå, Sweden

Results and discussion

Figure 1 shows the total insulation of the boots. The total insulation reduced due to walking less than 10 % for warm winter boots and 32 % for rubber boot. This agrees with a previous study (4). (4) noted also the biggest reduction in a rubber boot. The reduction of the total insulation due to wetting and walking was 37- 46 %. The reduction of the insulation due to sweating during standing has been discussed by (6).

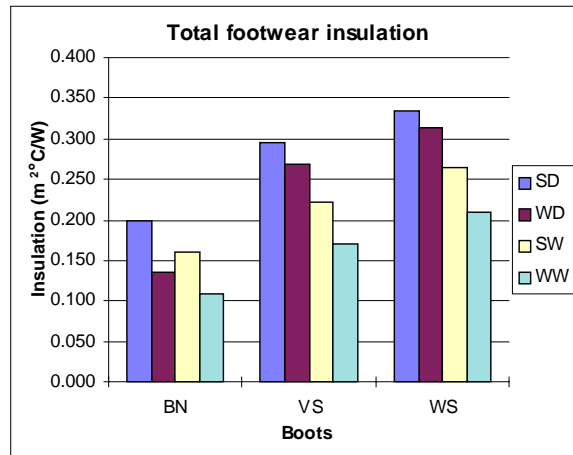


Figure 1. Total insulation of footwear. Toe, sole, heel, mid-foot and ankle zones are included. Conditions: SD - standing dry; WD - walking dry; SW - standing wet; WW - walking wet.

The insulation of the toes reduced up to 55 % due to sweating and walking compared to the standing and dry (Figure 2). It should be noted that one “sweat gland” was located on top of the toes. Walking in dry condition reduced insulation of toes up to 10 % in warm boots and 26 % in rubber boot. These values are also in the range of those that were reported by (4).

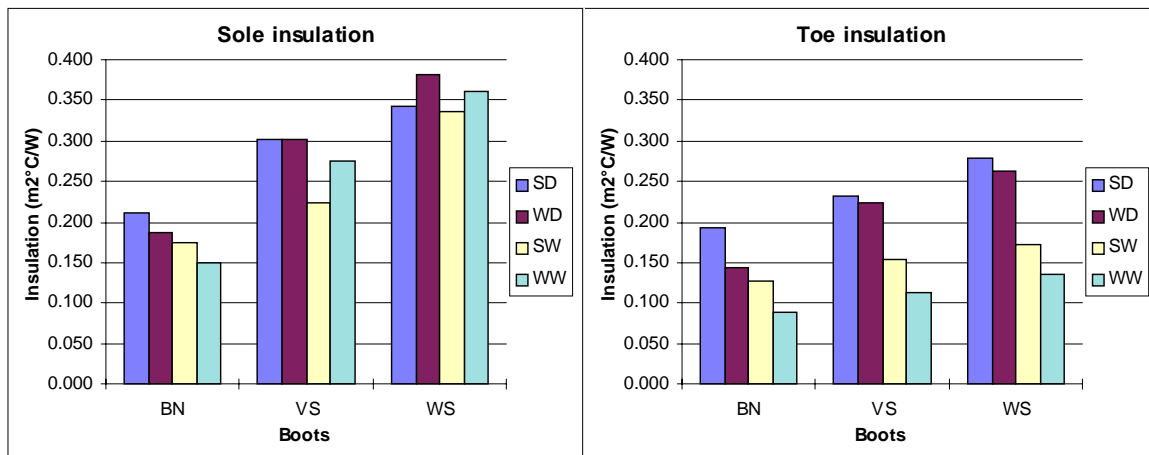


Figure 3. Sole insulation of footwear. Conditions: SD - standing dry; WD - walking dry; SW - standing wet; WW - walking wet.

Figure 2. Toe insulation of footwear. Conditions: SD - standing dry; WD - walking dry; SW - standing wet; WW - walking wet.

The sole insulation changed differently (Figure 3). During walking condition the sole insulation of boot WS even gained compared to dry standing condition. For boot VS the picture is similar, although less pronounced. Even for BN this effect is noticeable. The effect could depend on following reasons:

- less heat loss by conduction
- heat production from friction between the foot model and the sole
- heat production from friction between the sole and the walking surface

This first experience with a sweating and walking foot model indicated the need for enforcement and improvement of model and wiring system. Also, a better design for walking simulation (surface motion) is needed - due to the strong friction between boot and walking surface a considerable amount of sole material was slipped away. This made impossible to check the amount evaporated water.

Conclusions

- The results from walking tests agree with the results from the previous studies.
- The insulation of the footwear is reduced up to 10 % by walking, in thin rubber boots up to 32 %.
- Sweating and walking together reduce the insulation up to 45 %, in toes up to 55 %.
- The insulation of the sole is affected by walking. The heat losses are diminished by less conductive heat loss and heat generation due to friction, and the calculated insulation can be higher during walking than during standing.

Acknowledgement

Footwear was supplied by Arbesko AB and Sweden Boots AB.

References

1. EN344. Requirements and test methods for safety, protective and occupational footwear for professional use. Brussels: European Committee for Standardisation, 1992
2. GOST12.4.104-81. Safety standards system. Leather protective footwear. Method for the determination of summary thermal resistance. Standardisation Committee of the USSR, 1981
3. Nilsson H, Holmér I. Development and clothing measurements methods with the thermal manikin TORE. In: Nielsen R, Borg C, eds. Fifth Scandinavian Symposium on Protective Clothing. Elsinore, Denmark: Danish Work Environment Fund, 1997:30-35
4. Bergquist K, Holmér I. A method for dynamic measurement of the resistance to dry heat exchange by footwear. *Applied Ergonomics*, Vol. 28, No. 5/6, pp.383-388, 1997
5. Endrusick TL, Santee WR, DiRaimo DA, Blanchard LA, Gonzalez RR. Physiological responses while wearing protective footwear in a cold-wet environment. In: McBriarty J, Henry N, eds. Fourth International Symposium on the Performance of Protective Clothing. Montreal, Canada: ASTM STP 1133, Philadelphia, 1992:544-556
6. Kuklane K, Holmér I. Effect of sweating on insulation of footwear. *International Journal of Occupational Safety and Ergonomics*, Vol. 4, No. 2, pp. 123-136, 1997

Development of a new cold protective clothing with phase change material

B. Pause

OUTLAST TECHNOLOGIES, INC., Boulder, Colorado, USA

Cold protective clothing such as overalls, caps and gloves are designed to protect those working in extremely low temperatures against substantial body heat loss. These garments are generally made of two fabric layers with a thick batting in between. The thermal insulation of the garment is provided mainly by the batting and is directly related to the amount of air trapped within it.

Different activities are carried out in cold-storage areas including the operation of forklifts and lifting and transporting packages. Each operation requires a different amount of physical exertion and therefore generates a different metabolic heat rate. For example, while operating a forklift, the metabolic heat rate generated by the body is relatively low as a result of the driver being seated and comparatively inactive throughout the activity. In this particular case, the driver requires a garment possessing a high thermal insulation value in order to avoid a substantial drop in skin temperature within a relatively short period of time. Wearing the same highly-insulated garment while manually transporting heavy packages, which generates a relatively high metabolic heat rate, would prevent the emission of body heat into the environment which is necessary in order to prevent excess sweating. The more sweat penetrating into the fabrics of the garment, the further the insulating capabilities of the garment are reduced. In neither of the above cases does the thermal insulation of the garment provide adequate protection over an extended period of time. Due to its static nature, the thermal insulation of the garment is also not capable of adapting itself to the prevailing wearing conditions. Thus, after approximately 60 minutes of activity in such a garment, it is necessary to interrupt the activity for at least 30 minutes to allow the body to warm up.

The idea for improving existing cold-protective clothing is based on replacing the traditional static thermal insulation in a garment with dynamic thermal insulation, i.e. insulation capable of adapting itself to the prevailing wearing conditions. The expected results for such a new clothing include improved wearing comfort as well as extended wearing intervals, which transform into longer working intervals without warm-up breaks. Another objective in the application of dynamic thermal insulation to a garment was to decrease its overall thickness in order to enhance the range of motion experienced by the wearer. In order to achieve these goals Phase Change Material (PCM) was applied to garment components.

PCM possesses the ability to physically change from a solid to a liquid and vice-versa within a certain temperature range. During the phase change from a solid to a liquid (as the material is heated), the PCM absorbs a large amount of latent heat. This heat is then stored within the PCM and released during the cooling process as a reverse phase change (from the liquid to a solid) occurs. Applied to cold-protective garment the PCM absorbs surplus body heat produced during extreme physical exertion. In absorbing

heat, the PCM prevents an increase in skin temperature and therefore prevents large amounts of sweat from being produced. The absorbed heat is stored within the PCM and is released when the skin temperature begins to drop. In this case the PCM acts as a thermal barrier which enhances the thermal insulation capability of a garment. By either heat absorption or emission, the PCM creates a thermoregulating system which responds to any temperature change in the microclimate of the wearer and ensures that the thermal insulation adapts itself to the prevailing wearing conditions.

For the application of PCM in new cold protective clothing, two different types of PCM are used which differ in their respective phase change temperature range. The phase change of one PCM occurs within the 'comfort temperature range' while the phase change temperature of the other is slightly lower. The PCM is first encapsulated into Microcapsules, each with a diameter between 1 μm and 10 μm . The Microcapsules are then either coated onto the surface of a fabric or manufactured directly into Acrylic fibres. In applying PCM–Microcapsules to cold protective clothing, the liner fabric is coated with PCM whose phase change temperature is within the 'comfort temperature range'. During wearing this PCM responds directly to any temperature change in the microclimate of the wearer by either absorbing or emitting heat. The thick batting lining traditional cold-protective garments was replaced by a much thinner batting made up of Acrylic fibres containing PCM. The PCM within these Acrylic fibres has a lower phase change temperature range as compared to the PCM coated onto the liner, creating a second thermal barrier by responding in situations involving heat loss during extended periods of exposure to low temperatures.

The thermal insulation capacity as well as the thermoregulating effect resulting from the application of PCM to cold-protective clothing is determined using a new measuring and evaluation system. This system contains 3 different steps:

1. Determination of the Dynamic Thermal Insulation Effect by the PCM,
2. Determination of the Thermoregulating Effect,
3. Wearing Tests of the Garments.

In the first step heat emission by the PCM is translated into insulation terms. This new measurement is called 'dynamic thermal resistance' and given in units typically used for thermal resistance measurements. A new measuring technique allows for the separation of the thermal insulation effect of the PCM from that of the substrate. The total thermal resistance of a textile containing PCM is then the sum of the basic thermal resistance of the substrate and the dynamic thermal resistance of the PCM. The total thermal resistance of a textile without PCM is equal to its basic thermal resistance. Therefore, a direct comparison of textiles with and without PCM is made possible.

After the calculation of these values, the garment containing PCM is tested in a climatic chamber at various temperatures to determine the thermoregulating effect provided by the PCM. In this test the garment samples are attached to a simulated skin apparatus, the temperature of which is measured over time at various ambient temperatures and metabolic heat rates. Based on these tests, time intervals are estimated within which the skin temperature can be stabilised within a desired temperature range. Finally, wearing tests with the new garments were carried out in a cold-storage area to elicit feedback on the performance of cold-protective garment from workers themselves.

All of the tests conducted have shown that the new cold protective clothing containing PCM can be worn substantial longer than its traditional counterparts and that PCM-based clothing is more comfortable to wear due to the thermoregulating effect it provides. Furthermore, the new clothing with PCM is substantially thinner than the traditional cold-protective garments, which, in the case of gloves, leads to a substantial improvement in gripping ability.

Prediction of cold responses

P. Tikuisis

Defence and Civil Institute of Environmental Medicine, North York, Ontario, Canada

Introduction

Predicting the response to cold is pursued primarily through mathematical modelling. Models vary widely according to their origin and application, and are constructed to represent data, objects, or processes for the purpose of replication, simulation, or prediction. Also, models have and continue to become considerably more complex and detailed as computing power increases. The possibility of solving non-analytical problems through numerical procedures has greatly expanded investigations of heat transfer problems. However, before moving ahead to where this technology might lead, we begin with a classification of models and a selective review. Examples will be limited exclusively to those that relate to human response to cold, although this will not be an exhaustive list. Reference 18 includes a number of models specifically applied to cold exposure; certain of these will be cited throughout the text by their original authors. Following the review will be a discussion of how emerging soft computing technologies might be applied in modelling cold exposure.

Figure 1 illustrates the classification of models based on conventional and non-conventional approaches. Under conventional are placed ‘representational’ and ‘relational’ models which will be familiar to most readers. Non-conventional approaches are heuristic or experimental in nature.

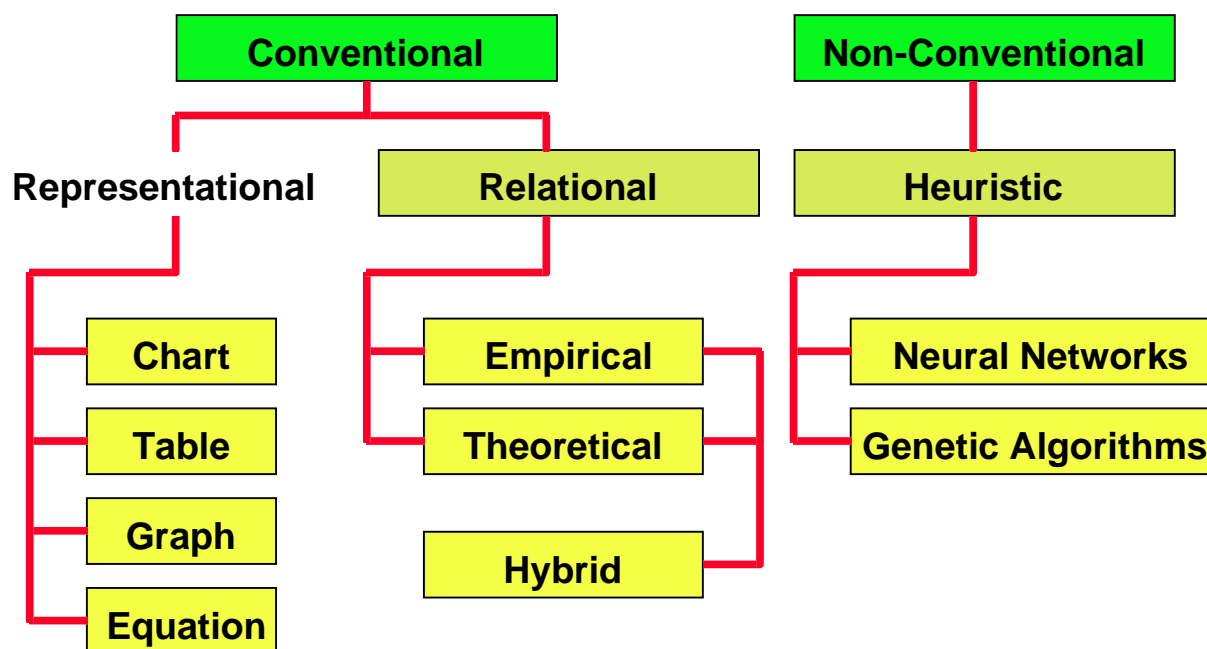


Figure 1. Classification of models.

Representational Models

Representational models, sometimes referred to as descriptive, imply a reduction of an observation without inference. These often take a visual form such as a chart, table, or graph. A good example of this is the wind chill index of Siple and Passel (13) where the air temperatures under calm conditions represent the equivalent cooling power of higher air temperatures with increased wind. More frequently, the representational model is a regression equation of a measured (or dependent) variable *against* a controlling (independent) variable, i.e., *y vs. x*. One example is the body cooling rate (*CR*; °C•min⁻¹) determined by Hayward et al. (5) for unprotected immersion in water expressed as:

$$CR = 0.0785 - 0.0034 \cdot T_{water}$$

Another is the cooling rate of skin temperature in cold air derived by Iampietro (8). More recently, Chen et al. (3) regressed a multi-exponential model to describe the decrease in finger skin temperature upon contact with cold surfaces. Thermal and pain sensations of hands in contact with cold surfaces have also been regressed, in this case linearly against ambient and skin temperatures (5). Several other examples exist and all have the common feature of summarising data in a mathematically concise manner without any inference of the mechanism underlying the response.

Relational Models

Relational models attempt to link cause and effect which goes beyond a simple regression since the variable of interest is often a complex function of several independent variables, i.e., $y = fnc(x_1, x_2, etc.)$. Such models, sometimes referred to as rational, are usually developed to explain or simulate physical and/or physiological processes. They are also deterministic in the sense that a given input will lead to a predictable and repeatable output. There are essentially two types of relational models: theoretical and empirical. The former are founded on basic principles while the latter require *a priori* knowledge of cause and effect to relate the dependent to the independent variables.

Theoretical Models

Perhaps two of the best-known theoretical models in thermal physiology are the Arrhenius thermodynamic expression of temperature effects on metabolism and the Pennes bioheat equation. The Arrhenius expression (11) is used to define the Q_{10} value which predicts the increase in metabolism (or rate of oxygen consumption) for a 10 °C increase in tissue temperature, i.e.,

$$m = m_o \cdot Q_{10}^{(T-T_o)/10}$$

where m is the metabolic rate and ' o ' denotes the reference value. Mathematically, Q_{10} is expressed as:

$$Q_{10} = \exp\left\{\frac{\mu}{R} \cdot \frac{10}{T(T+10)}\right\}$$

where μ is the activation constant, R is the universal gas constant, and T is the absolute temperature. For example, if $\mu = 12,286 \text{ mole}\cdot\text{cal}^{-1}$, then the often-cited value of Q_{10} is 2 in the temperature interval between 20 and 30 °C.

The bioheat equation, originally derived by Pennes (10), defines the tissue temperature distribution for given tissue and blood properties, and is usually expressed in cylindrical coordinates as:

$$\rho c \frac{\partial T}{\partial t} = \frac{k}{r} \cdot \frac{d}{dr} \cdot \left(r \frac{dT}{dr} \right) + \rho_b c_b w_b \cdot (T_a - T_v) + q_m$$

where ρ is density, c is heat capacity, k is heat conductivity, r is radius, w is blood perfusion, q is heat production, t is time, T is temperature, and the subscripts b , a , and v represent blood, arterial, and venous, respectively. The bioheat equation combines the transfer of heat conduction through tissue, the convective exchange of heat between tissue and blood, and metabolic heat production. It is fundamental to the development of thermoregulatory models where the state of heat storage in the tissue or body segment must be determined. A major criticism of Pennes' derivation of the bioheat equation is that it does not match his own data very well. Wissler (25) has recently re-examined the derivation and discovered that Pennes did not normalise his data properly, but upon correction found the equation to be quite accurate.

Empirical Models

Empirical models go beyond a simple relationship between the dependent and independent variables. Relationships are made using rational arguments or hypotheses. The prediction of heat production from shivering is a good example where this approach has often been used; below are various formulae:

$$MR = P_1 - P_2 \cdot T_{sk} - P_3 \cdot T_c \quad (16)$$

$$MR = sa \cdot (P_1 - P_2 \cdot T_{sk} - P_3 \cdot T_c - P_4 \cdot \dot{T}_{sk}) \quad (21)$$

$$MR = wt \cdot P_1 \cdot (P_2 \cdot T_{sk}) \cdot (P_3 \cdot T_c) \quad (7)$$

$$\Delta MR = P_1 \cdot (P_2 - T_{sk}) \cdot (P_3 - T_c) - P_4 - P_5 \cdot (\dot{T}_c + 0.01) \quad (24)$$

$$\Delta MR = P_1 \cdot (P_2 - T_{sk}) \cdot (P_3 - T_c) + P_4 \cdot (P_2 - T_{sk}) \quad (9)$$

$$\Delta MR = P_1 \cdot (P_2 - T_{sk}) \cdot (P_3 - T_c) + P_4 \cdot (P_2 - T_{sk})^2 \quad (15)$$

$$\Delta MR = \left\{ P_1 \cdot (P_2 - T_{sk}) \cdot (P_3 - T_c) + P_4 \cdot (P_2 - T_{sk})^2 \right\} / bf \quad (17)$$

where MR is the metabolic rate, Δ represents values above resting, P_j 's are parameter (fitted) values, T is temperature where the subscripts sk and c refer to the skin and core, and sa , wt , and bf are body surface area, weight, and fatness, respectively. Although the parameter values are mathematically regressed in the same manner as representative models, the relationships between metabolic response and body temperatures are based on some *a priori* knowledge of the system. Given the number of independent variables (body characteristics, body temperatures and their rates of change), there are many possible combinations to construct a cause and effect relationship. For example, Wissler (24) found that the rate of change of core temperature is a significant

determinate of shivering metabolism whereas Tikuisis et al. (17) found that body fatness attenuates the response. Each formula has been derived with a specific data set, hence the user must exercise caution when selecting the formula for their particular application.

Hybrid Models

Many sophisticated models combine theoretical and empirical approaches out of necessity. While the theoretical approach provides a foundation and understanding of the mechanism(s) under study and is therefore desirable, the physiology of human thermal response is too complex for theoretical derivation alone. Theoretical components, such as the bioheat equation, are integrated with other empirically-derived components such as the heat production from shivering. One recent example of this integrative approach is the prediction of finger blood flow during cold-induced vasodilatation where a theoretical solution of heat transfer in the finger was combined with assumptions about the shape of blood flow onset and decay (12).

Perhaps the most cited hybrid models are those that predict whole-body thermoregulation beginning with the pioneering work of Wissler (23) and Stolwijk and Hardy (14), and continuing with the more recent work of Werner and Buse (22). Most versions approximate the human as a collection of cylindrical segments for mathematical simplicity. Each cylinder is comprised of concentric annular compartments representing various tissues/structures (e.g., skin, fat, muscle, and bone). More realistic models such as the 3-D representation developed by Werner and Buse not only account for asymmetries in the body but also allow for asymmetries in exposure. Common to all these models, however, is the attempt to predict the physiological responses to thermal stress while adhering to the physical laws of heat transfer.

The complexity of human response to cold coupled with the scarcity of data far from thermal neutrality have constrained the calibration of these models to a relatively narrow thermoregulatory zone. Consequently, the prediction of survival time (ST) for cold exposure involves considerable, and often untested, extrapolation. The approach taken by the author (19, 20) was to concentrate on the competition between heat loss and heat production in a simple cylindrical representation of the body, and to calibrate the model specifically for ST based on well-documented case reports. In this derivation, the cylinder is separated into a core region that produces heat and a multi-shell region that insulates the body. Heat production is driven by decreases in core and skin temperatures, and heat loss is attenuated by the body's fat thickness and clothing insulation. The resultant model inputs are simplified to anthropometric characteristics, ambient conditions, and clothing; outputs are cooling times to deep body temperatures of 34 °C (functional limitation) and 28 °C (ST). The following figure compares the model prediction of ST for underprotected (shirt + sweater) neck-level immersion in calm water between males and females. Despite having a lower body fatness, the generally higher predicted STs for males (at similar percentiles of the population) is attributed to a combination of a higher resting metabolic rate (per unit body surface area), a smaller surface area to volume ratio, and higher muscle content.

In Figure 2, each set of three lines for both genders represent in ascending order of ST the worst, average, and best cases. The worst case is based on a combination of body weight (kg) at the 5th percentile of the population (2) and height (m) at the 95th percentile (i.e., very lean and very tall). The best case is the opposite and the average is based on the 50th percentile for both weight and height. Body fat (%) is based on gender, age, weight, and height. Specific values for 30 yr olds used for the figure are:

	males			females		
	wt	ht	bf	wt	ht	bf
worst case	59.0	1.90	12.2	46.0	1.75	17.7
average “	74.7	1.75	18.1	57.4	1.62	22.8
best “	99.5	1.61	29.0	78.0	1.46	34.6

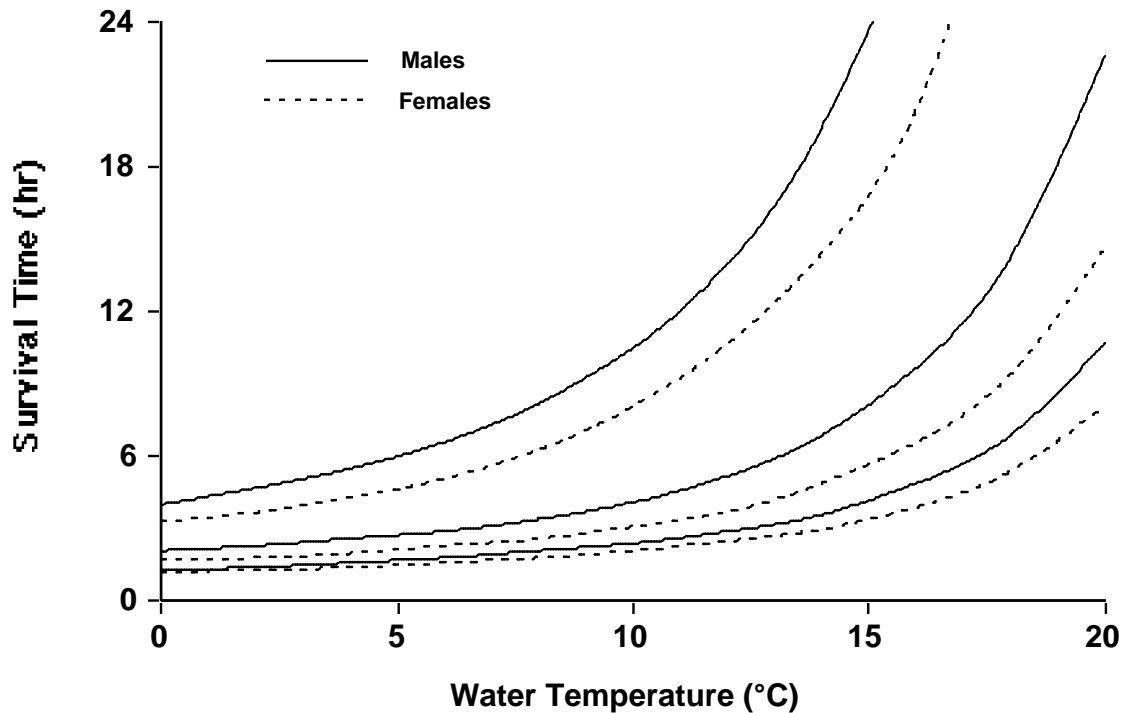


Figure 2. Survival time in water.

Heuristic Models

Heuristic models are mathematical constructs inspired by biology that involve parallel processing of information. The two classes of heuristic models introduced here are neural networks and genetic algorithms. Both are probabilistic in nature since their outputs are unpredictable and vary with each iteration.

Neural Networks

Neural networks involve an architecture of nodes (engineering equivalent of neurons) through which numerical information is processed and weighted. Inputs are entered at the first level of nodes; their outputs become the inputs at the second level, etc., until a final output emerges. Each node within a level connects with all nodes in adjacent levels. Calibration or ‘training’ of the network is accomplished by providing several examples of inputs with known outputs. Little, if any, physiological information is actually required to define the connection between nodes. Given this versatility, neural networks are usually applied in control theory, making it a potential candidate for thermoregulatory modelling (e.g., where first level nodes are temperature and heat flow receptors, and outputs are vasomotor and metabolic responses). Indeed, neural networks

have been applied in thermal physiology, although not specifically for cold exposure. Examples are models of sweat regulation (1) and temperature distribution during hyperthermia (4).

Genetic Algorithms

Genetic algorithms are applied to problems that are analytically unsolvable or numerically impractical. Patterned after the architecture of chromosomes, a candidate solution of the problem is coded onto a one dimensional array where each element represents a numerical value or operation. A second solution is proposed and the two are then combined through a random application of mating, crossovers, and mutations. The resultant solution or 'offspring' forms the next 'parent' in the search for the best solution. The best solution might be expressed as an extremum (i.e., max or minimisation) or simply as a distribution of values (e.g., temperature) that is most consistent with the measured quantities (e.g., heat flow). An example might be the determination of a tissue temperature profile subject to variations in the efficiency of heat exchange between tissue and blood, and between counter-current blood vessels, but constrained under the physical laws of heat conduction and conservation.

Closing Remarks

Mathematical models have and will continue to be developed for the replication, simulation, or prediction of numerical values. Their acceptance and use are contingent on how well their results match observations and expectations. Prediction models, in particular, should rarely be considered complete. Many continue to evolve through improvements in resolution and in our increasing knowledge of human response to cold.

References

1. Campbell AB, Nair SS, Miles JB. Modelling the sweat regulation mechanism. Warrendale, PA, USA: SAE International Tech Paper Series 1994: No. 941259.
2. Campbell survey on well-being. Ottawa, Canada: Canadian Fitness and Lifestyle Research Institute, 1988.
3. Chen F, Nilsson H, Holmér I. Finger cooling by contact with cold aluminium surfaces- effects of pressure, mass and whole body thermal balance. *Eur J Appl Physiol*
4. Chen YY, Chen CH, Lin WL. Neural networks modelling of temperature field distribution in hyperthermia. *Proceedings of the Asian Fuzzy Systems Symposium*. IEEE Soft Computing in Intelligent Systems and Information Processing p 573-578, Piscataway, NJ, USA 1996.
5. Havenith G, Van de Linde FJG, Heus R. Pain, thermal sensation and cooling rates of hands while touching cold materials. *Eur J Appl Physiol* 1992;65(1):43-51.
6. Hayward JS, Eckerson JD, Collis ML. Thermal balance and survival time prediction of man in cold water. *Can J Physiol Pharmacol* 1975;53(1):21-32.
7. Hayward JS, Eckerson JD, Collis ML. Thermoregulatory heat production in man: prediction equation based on skin and core temperatures. *J Appl Physiol* 1977;42(3):377-384.

8. Iampietro PF. Prediction of skin temperature of men in the cold. *J Appl Physiol* 1961;16(3):405-408.
9. Nadel ER, Horvath SM, Dawson CA, Tucker A. Sensitivity to central and peripheral thermal stimulation in man. *J Appl Physiol* 1970;29(5):603-609.
10. Pennes HH. Analysis of tissue and arterial blood temperatures in the resting human forearm. *J Appl Physiol* 1948;1(2):93-122.
11. Schmidt-Nielsen K. *Animal physiology: Adaptation and Environment*. Cambridge University Press, London, UK, 1975.
12. Shitzer A, Stroschein LA, Gonzalez RR, Pandolf KB. Lumped-parameter tissue temperature-blood perfusion model of a cold-stressed fingertip. *J Appl Physiol* 1996;80(5):1829-1834.
13. Siple A, Passel CF. Measurements of dry atmospheric cooling in subfreezing temperatures. *Proc Amer Phil Soc* 1945;89:177-199.
14. Stolwijk JAJ, Hardy JD. Temperature regulation in man - a theoretical study. *Pflugers Arch* 1966;291:129-162.
15. Stolwijk JAJ, Hardy JD. Control of body temperature. In: Lee DHK, ed. *Handbook of Physiology: Reactions to Environmental Agents*. Bethesda, MD: American Physiological Society, 1977: 45-68.
16. Strong LH, Gee GK, Goldman RF. Metabolic and vasomotor insulative responses occurring on immersion in cold water. *J Appl Physiol* 1985;58(3):964-977.
17. Tikuisis P, Gonzalez RR, Oster RA, Pandolf KB. Role of body fat in the prediction of the metabolic response for immersion in cold water. *Undersea Biomed Res* 1988;15(2):123-134.
18. Tikuisis P, ed. *Handbook on predicting responses to cold exposure*. NATO AC/243 (Panel 8) TR/20, 1995.
19. Tikuisis P. Predicting survival time for cold exposure. *Int J Biometeorol* 1995;39:94-102.
20. Tikuisis P. Prediction of survival time at sea based on observed body cooling rates. *Aviat Space Environ Med* 1997;68(5):441-448.
21. Timbal J Loncle M, Boutelier C. Mathematical model of man's tolerance to cold using morphological factors. *Aviat Space Environ Med* 1976;47(9):958-964.
22. Werner J, Buse M. Temperature profiles with respect to inhomogeneity and geometry of the human body. 1988;65(3):1110-1118.
23. Wissler EH. A mathematical model of the human thermal system. *Bull Math Biophys* 1964;26:147-166.
24. Wissler EH. Mathematical simulation of human thermal behaviour using whole-body models. In: Shitzer A, Eberhart RC, eds. *Heat Transfer in Medicine and Biology*, v 1, New York: Plenum Press, 1985: 347-355.
25. Wissler EH. Pennes revisited. *J Appl Physiol* 1998 (in press).

The models of cooling effect of wind in cold conditions

H. Anttonen, E. Hiltunen, A. Oikarinen

Oulu Regional Institute of Occupational Health, Aapistie 1, FIN-90220 Oulu, Finland

Introduction

The cold wind has both physical and physiological effects on human being in cold conditions and it has been studied already for many decades. Those effects have been modelled for simulation purposes and for predicting the frostbite and cooling of the human being (1). Those models can be divided into cooling indices of bare skin or clothed body and physical or physiological models (2). In this work the effect of wind on insulation, on face and body cooling were studied with manikin and test subjects. The tests were done in the wind tunnel of a cold laboratory. The results were compared with existing indices and calculation models.

Materials and methods

The basic clothing was a three layer winter clothing which was varied by one impermeable outer clothing and two intermediate layers with higher air permeability. The measurements were done in the wind tunnel in a cold climate laboratory where the ambient temperature varied from +15 to -5 °C, and the wind from 0,4 to 18 m/s. The thermal insulation was measured with a walking manikin with a walking speed of 0, 0,3 and 0,8 m/s according INSTA 353 - 355. The used cooling or frostbite models were made by Siple & Passel, Anttonen, Kerslake, Steadman, Rodrigues, Hey, Missenard, Winslow, Gagge, Mitchell, Gordon, Stolwijk, Fanger, Seppänen and Werner. Most of the models above were related to cooling of the head. For the clothed man we used the models of Steadman, Humphryes, Wyon, Beal and Ennemoser.

More complicated physical models used for clothed man were called Farnworth's model, Cloman and Clodyn (clothing dynamics) and physiological models called Gordon, THDYN, Thermosim and IREQ.

Results

The examples of the results are shown in Figures 1 and 2.

Based on two-layer model we have derived the equation of the cooling of the naked skin

$$T_{sk} = \frac{16.1 \cdot T_a + (4.5 + 16 \cdot v_a^{0.5}) \cdot 37}{20.6 + 16 \cdot v_a^{0.5}}$$

which gives a better correlation of experimental results than the cited models.

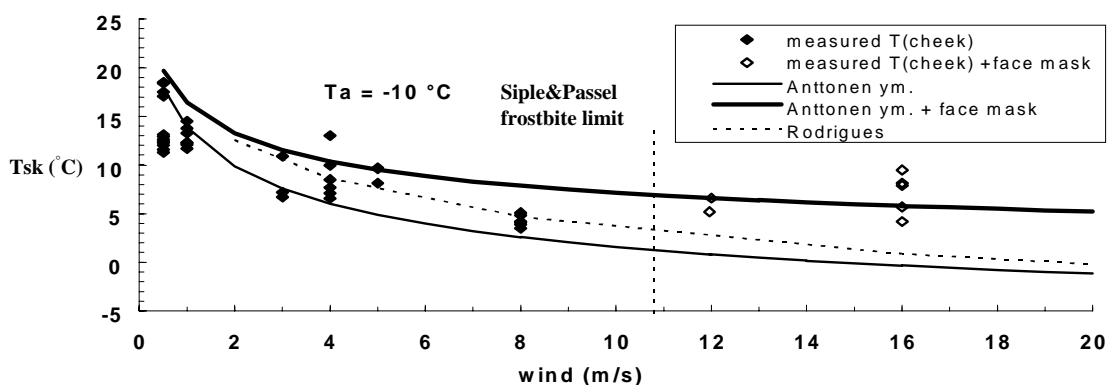


Figure 1. The measured minimum cheek temperatures compared to the used models.

In the physiological model the analysis resulted in that the effect of air permeability of clothing, activity and wind velocity should be included in the calculations and also the correction to the equations used was needed.

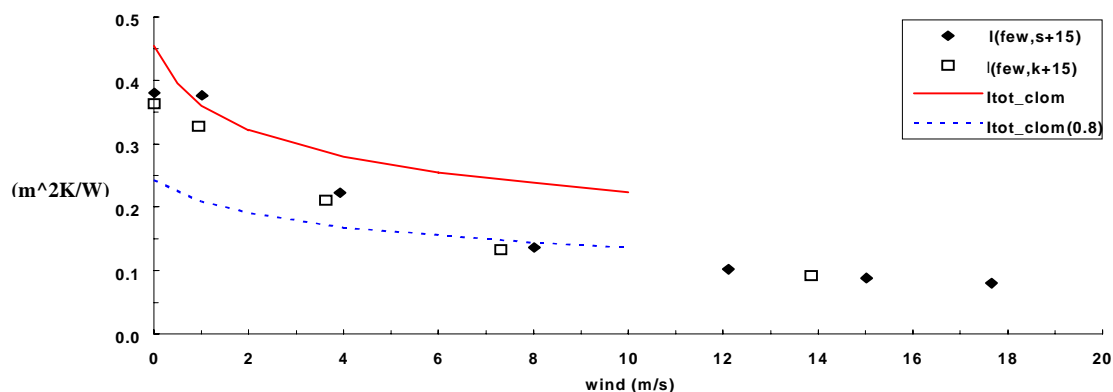


Figure 2. Cloman model and clothing with low air permeability.

Discussion

The main defect of the used models was the lack of air permeability (0.900 l/m²s) information of clothing, which usually decreases the insulation value. The effect of movements and ventilation in clothing was also added into the equations. However the change of insulation in manikin tests was less than predicted by the models. Also the improved windchill-index for bare skin was introduced making an estimation of minimum skin temperature in the given condition. The indices were developed by using real low skin temperatures, new convection coefficient and taking care of protective properties of the clothing system.

Acknowledgement

Supported by grants from the Finnish Work Environment Fund.

References

1. Gordon RG. *The response of a human temperature regulatory system model in the cold*. Doctoral thesis, University of California, Santa Barbara, 1974.
2. Lotens WA. *Heat transfer from humans wearing clothing*. Doctoral thesis, TNO, Institute of Perception, Soesterberg, 1992.

Solar radiation and cold tolerance

K. Blazejczyk

Institute of Geography and Spatial Organisation, 00-818 Warszawa, Twarda 51/55, Poland

Introduction

Solar radiation is a factor playing important role in human life and work outdoors. Nothing but presence of Sun light influences work ability and efficiency. It also effect resultant value of man-environment heat exchange since human skin can absorb solar beams (direct, diffuse, reflected). In hot climates it can produce the hazard of body overheating. However in cool and cold climates it can reduce the amount of heat loss from the body. The aim of the paper is to present preliminary results of investigations dealing with absorption of solar radiation by man outdoors and its impact on physiological reactions of subjects.

Material and methods

Two series of field measurements (July 1996, August 1997) were made. 5 volunteers, female subjects within the age category of 19-30 years, high of 153-165 cm and weight of 45-54 kg took part in the experiments reported. Skin temperature and dry heat exchange on the body surface (on forehead, palm, arm, chest, back, thigh and calf) were measured. Simultaneously meteorological and solar radiation parameters were controlled. The subject worn sport cotton clothing with insulation of 1 clo and albedo of outer surface of 30 %. They were exposed for 130 minutes. In the first series subjects stood in upright, relaxed posture facing to the sun; after 60 minutes they took 10 minutes rest sitting. In the second one - subjects walked with the speed of 3 km per hour; after every 30 minutes of walk they rested standing.

Results

Solar radiation, especially its direct flux, influenced both, dry heat exchange (DHE) and skin temperature (T_{sk}) at subject. At standing persons radiative balance of man (Q) was in the sunny conditions of about $60-90 \text{ W}\cdot\text{m}^{-2}$. However, during cloudy conditions Q values reached of about $10-20 \text{ W}\cdot\text{m}^{-2}$ only. At the same time the skin temperature was $28-29 \text{ }^\circ\text{C}$ and $25-26 \text{ }^\circ\text{C}$, respectively. At the same time (18:50 till 19:30) global solar radiation intensity was about $200-300 \text{ W}\cdot\text{m}^{-2}$ in the sunny day and $80-120 \text{ W}\cdot\text{m}^{-2}$ in the absence of direct radiation (Figure 1).

Also at walking subjects DHE during sunny day was about $30-40 \text{ W}\cdot\text{m}^{-2}$ higher then during the cloudy one. T_{sk} at sunny day was lower then at cloudy one. During cloudy day differences of T_{sk} between standing and walking persons were smaller then at sunny

conditions. It was caused by high heating of the body surface by direct solar beams and its small cooling by sweat secretion and evaporation at standing subjects (Figure 2).

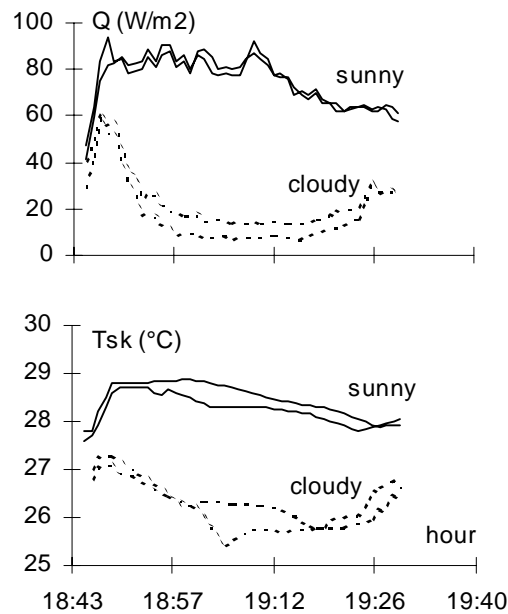


Figure 1. Radiative balance (Q) and skin temperature (T_{sk}) at standing subjects during sunny (1 July 1996) and cloudy (6 July 1996) conditions, vicinity of Warsaw, central Poland.

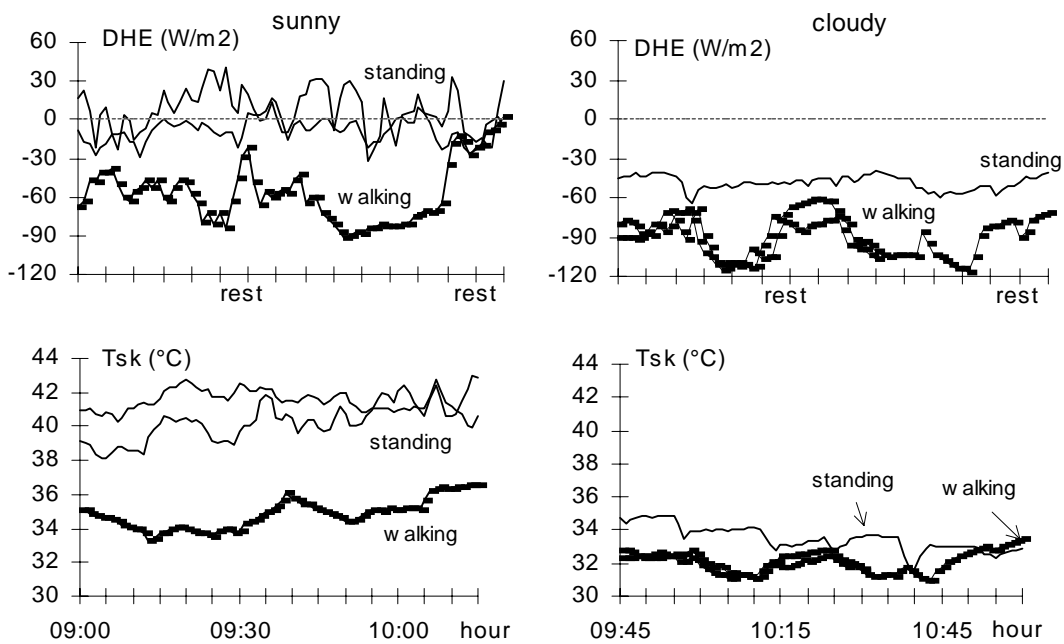


Figure 2. Dry heat exchange (DHE) and skin temperature (T_{sk}) at standing and walking subjects during sunny (left panel - 17 August 1997) and cloudy (right panel - 16 August 1997) days, Tatry Mts., south Poland; global solar radiation was 600-800 and 50-250 $W \cdot m^{-2}$, respectively

There were observed simple relationships between intensity of solar radiation and thermal sensations at subjects. During rapid appearance of direct solar beams thermal sensations can be changed of 2 classes up (e.g. from neutral to hot) as well as T_{sk} can increase significantly of about 2-3 °C after 8-10 minutes of intensive insulation. On the other hand when clouds cover rapidly Sun's disc thermal sensations can change of 2-3

classes down (e.g. from neutral to cool or cold) and skin temperature may be lower of 2 and even 4 °C.

Discussion

A lot of authors tried to find equations which can assess amount of solar radiation absorbed by man; their review contains the paper of Blazejczyk et al. 1993. The realistic values of absorbed solar radiation can be achieved when using equation -based on ellipsoid model of man - proposed by Blazejczyk et al. (1992). However the best estimation can be made with the use of equations derived from the latest, unpublished results of investigations performed by author with the use of a mannequin as a model of man. The equation have the following form (for $h > 5^\circ$):

$$R = 1.4 [K_{dir} (18.816/h - 0.235) + (K_{dir} + K_{ref}) (0.0013 + 0.033 \ln h)] (1 - 0.01 ac) Irc$$

Conclusions

Physioclimateological investigations performed outdoors emphasis importance of solar radiation in reduction of cold stress in man both, at subjective sensations and objective level of physiological parameters (DHE, T_{sk}).

References

1. Blazejczyk K, Holmér I, Nilsson H. A modified equation for the calculation of solar heat load in man. In: Lotens WA, Havenith G, eds. The Fifth International Conference on Environmental Ergonomics, 1992: 82-83.
2. Blazejczyk K, Nilsson H, Holmér I. Solar heat load on man. Int J Biometeor 1993: 125-132.

Clothing insulation at high wind speed

*H. Nilsson, I. Holmér, G. Ohlsson, H. Anttonen**

Division of Occupational Medicine, Climate Group, National Institute for Working Life, S-171 84 Solna, Sweden

* Oulu Regional Institute of Occupational Health, Aapistie 1, FIN-902 20 Oulu, Finland

Introduction

It is known in prior work (1) that insulation values measured with subjects can be reduced with up to 50 % from the value measured on a standing thermal manikin. A general correction equation has been developed. This equation makes it possible to calculate the insulation reduction for most types of normal working clothes. The equation is valid for total insulation values from 0.73 to 4.61 clo. Walking speed from standing to 1.2 m/s and wind speed from 0.2 to 1.0 m/s

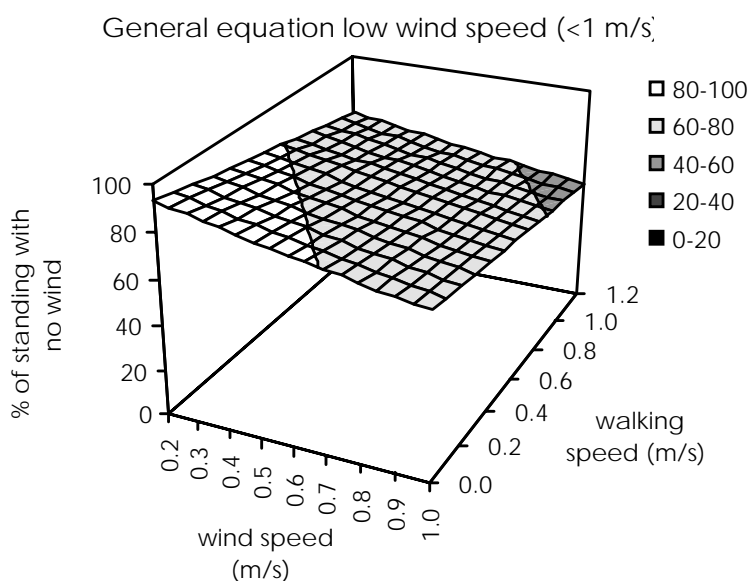


Figure 1. The combined effect of wind and walking speed for TORE while walking at 0 to 1.2 m/s with wind speed from 0.2 to 1.0 m/s. For clothing combinations with 0 to 3 layers and a total insulation of 0.73- 4.61 clo.

The aim of this paper is to look at the equation validity range at higher wind speeds. The experiments have been carried out with 4 different clothing combinations and 7 different wind speed levels up to 20 m/s at three walking speeds.

Materials and methods

The thermal manikin used is one in the TORE-series that has been described earlier (2, 3). The power transmission, in the walking apparatus, has been made with pneumatic

cylinders, which gives a simple and durable construction with a minimum of mechanical components.

To investigate the relevance of the testing method, and create a relationship between the influences of wind and motion on the insulation, a number of experiments were made in a climatic chamber. The tests comprised 4 different types of working clothes

TORE was positioned in the controlled environment of the climatic chamber until steady state was reached. Then the insulation was calculated from the measured heat loss. In this study the walking speed was set to 0, 0.3 and 0.8 m/s. The measurements were made in the climatic chamber where the wind speed was set to 0.2, 0.4, 1.0, 4.0, 8.0, 16 and 20 m/s. The repeatability for the used method for determination of insulation values was high; the difference between double determinations was less than 5 % of the mean value of the two measurements based on 84 independent measurements.

Results

The results show that the clothing insulation is strongly influenced by wind and body movements. It is also shown that the effect of wind on the clothing insulation increases slower at these extreme velocities. The combined effect of body movements and wind increases the heat loss from the human body substantially. The results are given as percentage of the total insulation (I_t) measured with a standing manikin during wind still (0.2 m/s) conditions.

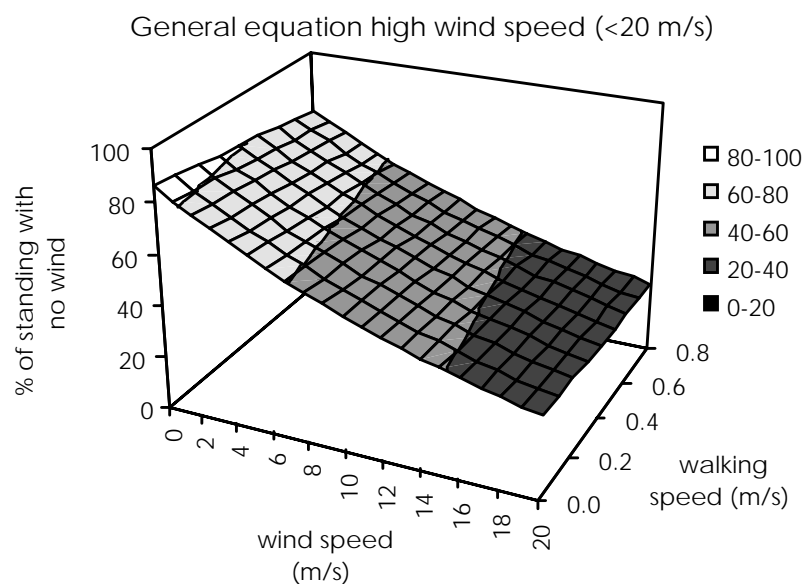


Figure 2. The combined effect of wind and walking speed for TORE while walking at 0 to 0.8 m/s with wind speed from 0.2 to 20 m/s. For clothing combinations with 3 layers and a total insulation of 2.64- 3.16 clo.

The influence of air permeability on the insulation has also been examined with stepwise multiple regression. The permeability has some influence at wind speeds above 10 m/s and will be further investigated in future studies. Equations for insulation reduction ($I_{t,r} / I_t$) as a function of wind speed (v , m/s) and walking speed (w , m/s) is calculated. The validity interval for the equations is 0.2 - 20 m/s wind speed and 0 - 0.8 m/s walking speed. If they are used outside this interval the reduction will be over

estimated. The relative change is large when changed from standing to light walk or when the wind goes from zero to low wind. Additional wind and movement make the reduction more stabile.

With just a minor increase in the error the old and new equations can be put together in the following relationships, containing data from 300 measurements:

$$I_{t,r}/I_t = 0.858 \cdot e^{(-0.050 \cdot v - 0.161 \cdot w)} \quad (R = 0.934) \quad (\text{High speed})$$

$$I_{t,r}/I_t = 0.858 \cdot e^{(-0.049 \cdot v - 0.196 \cdot w)} \quad (R = 0.908) \quad (\text{All})$$

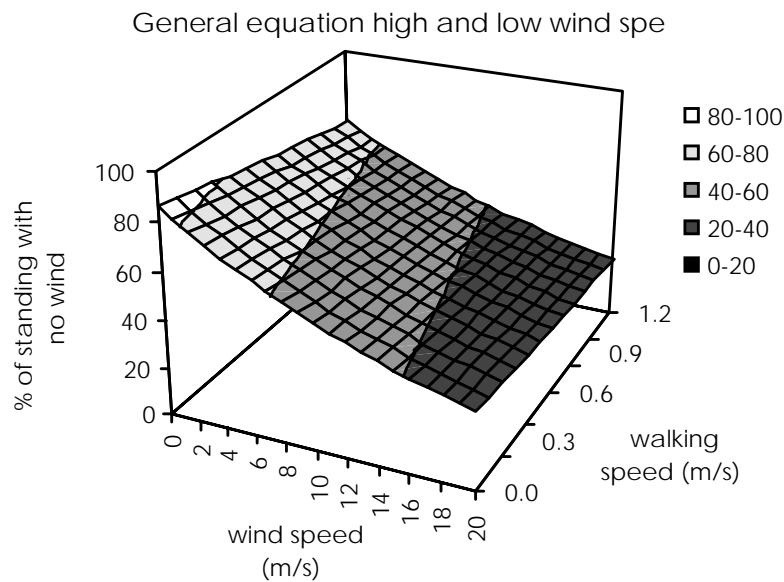


Figure 3. The combined effect of wind and walking speed for TORE while walking at 0 to 1.2 m/s with wind speed from 0.2 to 20 m/s. For clothing combinations with 0 to 3 layers with a total insulation of 0.73- 4.61 clo.

Discussion and conclusions

The clothing insulation is strongly affected by wind and body movements. The combined effect of body movements and wind increases the heat loss from the human body. A reduction of the clothing insulation measured with a static thermal manikin is consequently needed. The insulation is reduced exponentially with increased step frequency (walking speed) and increased wind speed.

A general reduction equation has been developed. The equation makes it possible to calculate the reduction of different activity for most work clothing, if the static clothing insulation is known from measurements or tables. To validate these relationships more measurements on subjects exposed to wind and motion in working life are needed.

With TORE standing with clothes in 20 m/s wind speed, the total insulation was reduced with 70 % to about 30 %, compared to the wind still conditions, furthermore reduced with around 5 % with TORE walking against the high wind as well. Other factors like number of layers and permeability as well as clothing insulation have been shown to only give small improvements of the accuracy. Further investigations will be made to include permeability at high wind speeds.

Originally the proposed standard (prENV 342:1997) suggested two principles to calculate the total insulation (4). If the manikin is covered with exactly the same insulation over all sections the results from the two formulas is the same. If the heat loss

from one or more sections are substantially lower, compared to the other zones, the "Local" formula will give a higher value. This could easily happen when some garments, of many reasons, have very different insulation on different body parts, for example if the garment is compressed by high wind speed. The insulation calculated with the "Local" equation would then be substantially higher compared to the "Total", that would give the same value as if the insulation was evenly distributed.

One way for a not so serious manufacturer to get a higher insulation value would be to distribute the insulation so that the ensemble has a very high insulation on the back and very low at the front. Consequently very low heat loss from the back would increase the total insulation with the "Local" equation but not with the "Total" method. This way of calculation combined with high wind speeds can easily lead to dangerous situations in the working life

This work has been supported by the Swedish Council for Work Life Research (former Swedish Work Environment Fund) project no: 94-0428.

Acknowledgement

Supported by grants from the Swedish Council for Work Life Research and the Finnish Work Environment Fund.

References

1. Nilsson H and Holmér I. Development of Clothing Measurement Methods with the Thermal Manikin TORE. 5th Scandinavian Symposium on Protective Clothing (NOKOBETEF V). Helsingør, Denmark, (1997) 30-35.
2. Hänel S-E. A joint Nordic project to develop an improved thermal manikin for modelling and measuring human heat exchange. In: Aspect médicaux et biophysiques des vêtements de protection. Lyon: Centre de Recherche du Service de Santé des Armées, 1983: 280-282.
3. Nilsson H O, Gavhed D C E, Holmér I. Effect of step rate on clothing insulation. – Measurement with a moveable thermal manikin. In: Lotens W, Havenith G, ed. Environmental Ergonomics V. Maastricht, Netherlands, 1992.
4. Nilsson, H., 1997, Analysis of two methods of calculating the total insulation. Proceedings of a European seminar on Thermal Manikin Testing, Solna, Arbetslivsinstitutet, Department of Ergonomics, 17-22.

Combined effects of dietary salt intake and acute whole body cold exposure on blood pressure

O. Arjamaa¹, L. Turunen¹, T. Mäkinen³, J. Laitinen³, J. Leppäluoto^{1,2}, O. Vuolteenaho², H. Rintamäki³

¹Institute of Arctic Medicine and ²Department of Physiology, University of Oulu
³Cold Work Action Program, Finnish Institute of Occupational Health, Oulu, Finland

Introduction

A large number of studies have been published on the effects of dietary salt intake on the resting blood pressure and the general concept is that high salt intake is associated with increased blood pressure with elevated risk to develop essential hypertension although contradicting reports have also been published (for review, see Muntzel and Drüeke 1992). Some subjects are salt resistant and therefore not hypertension prone which may have been a confounding factor in some epidemiological studies (Weinberger 1996).

It is well known that cold exposure increases blood pressure. This fact has led to numerous studies in which the aim has been to identify those who are hyper-reactive to cold and hence may later develop hypertension. The method widely used in these studies has been the cold pressor test in which upper arms are exposed to a cold stimulus. Less is known about the effects of dietary salt intake on the cold-induced increase in blood pressure.

We wished to test a hypothesis that increased dietary salt intake will potentate the blood pressure response to an acute whole body cold exposure. Experiments were carried out during the months of January and February in Oulu, Finland (65° Northern latitude) where atmospheric temperatures may range from -30 °C in winter to +30 °C in summer. A whole body cold exposure after a salt load was produced in a cold chamber in which the temperature and the wind speed were regulated and subjects wore a standard Finnish military clothing.

Methods

Twelve healthy, non-smoking males volunteered for the study and spoken consent was obtained from each subject before the study. The subjects were instructed to eat their normal diet which included free access to table salt. Then the subjects consumed an additional dose of NaCl (7 g/day) for 14 days. The cold exposure was performed before and after the extra salt load. First the subjects were allowed to stabilise for 30 min at 18 °C in a sitting position. Then they moved into a climatic chamber (-15 °C, wind speed 3.5 m/s) in which they remained in a sitting position for 15 min. After the cold

exposure, the subjects stayed an additional 30 min under the same conditions as before the exposure. Blood pressure and peripheral temperatures were recorded during the experiment and a blood sample was drawn before and after the experiment.

Results

When 7 g extra salt was added in the daily diet, the water intake and the urinary output increased as expected. The subjects did not gain any extra weight during the salt load and subjective feelings about the health status remained unchanged. In the cold chamber, with or without extra salt load, all subjects experienced severe cold sensations as judged from the interview records. The mean peripheral temperature decreased to 26 °C but the rectal temperature did not change. All the subjects were normotensive and the blood pressure was 125/80 mmHg. During the salt load, we saw unexpectedly a significant decrease both in the systolic and diastolic blood pressure under normal conditions recorded before the cold exposure. The subjects appeared to be counter-regulators, persons that respond by at least 5 mmHg fall in the mean arterial pressure (MAP) during a high-salt diet (Overlack et al. 1993). During the cold exposure, in both control and high salt group the blood pressure was increased. The level to which blood pressures rose was the same in both groups and this finding was more clearly seen in the MAP. The largest change was found in the diastolic pressure of the high salt group in which the increase was significantly higher than in the control group during the cold exposure. Plasma ANP, renin activity, and aldosterone were at the same level 40 min after the exposure as before the exposure.

Conclusions

Taken together, these findings show that a heavy salt load, an additional 7 g/day for two weeks to the normal dietary salt intake of 9.7 g/day in Finnish healthy male subjects, caused a counter-regulation phenomenon in which the mean arterial blood pressure decreased. The decrease was more obvious in the case of the diastolic blood pressure. During a rigorous and acute cold exposure, the increase in the diastolic pressure was significantly higher after the salt load compared to the situation when the same subjects were on their normal diet confirming partly our main hypothesis. These findings may have implications regarding work and life in the arctic or subarctic climate.

References

1. Muntzel, M. and Drüeke, T. 1992. A comprehensive review of the salt and blood pressure relationship. *Am. J. Hypertension* 5:1-92.
2. Overlack, A., Ruppert, M., Kolloch, R., Göbel, B., Kraft, K., Diehl, J., Schmitt, W., and Stumpe, K.O. 1993. Divergent hemodynamic and hormonal responses to varying salt intake in normotensive subjects. *Hypertension* 22: 331-338.
3. Weinberger, M.H. 1996. Salt sensitivity of blood pressure in humans. *Hypertension* 27: 481-490.

Hazards of cold immersion

W. R. Keatinge

Department of Physiology, Queen Mary and Westfield College, University of London., Mile End Road, LONDON, E1 4NS, U.K.

Immersion represents the most effective means of removing the external insulation that is normally provided by clothing and by the air trapped in it, or stationary outside it. Immersion in cold water therefore provides a severe thermal stress, in which the individual becomes dependent largely on the internal insulation of the body to control heat loss. An intense period of research on cold water survival during the quarter century that followed the Second World War (see 1 for review) concentrated on these internal factors that make the cooling rates of different people dramatically different in given conditions of cold immersion. It was also a period in which much work was done to provide thermal protection by life rafts and immersion suits for survivors after they abandon ship.

The studies made during that time showed that by far the most important factor in determining a person's ability to maintain body temperature in cold water without external protection was the thickness of the individual's subcutaneous fat. Once immersion in water at around 15 °C has led to vasoconstriction in the skin and subcutaneous fat, the internal insulation of the body is determined largely by the thickness of that fat. Consequently fat people could stabilise body temperature for long periods in such water, while thin people cooled rapidly and could become dangerously hypothermic within an hour. Swimming, with its combined arm and leg exercise, greatly reduced internal insulation, mainly by increasing blood flow to muscles of the limbs which generally have only a thin covering of subcutaneous fat. Such activity consequently almost always increased heat loss more than heat production when people were in water too cold to enable them to maintain heat balance when still. The surface area to mass ratio of the body is high in children, and is generally higher in women than men, because a relatively small object has a larger surface to mass ratio than a larger object of the same shape. Since surface area is a major determinant of heat loss, and body mass is the source of heat production and heat storage, children of given fat thickness consequently cool faster in cold water than adults (2), and women often cool faster than men of similar fat thickness (3). In practice, a greater fat thickness in women is generally more important than their tendency to small size, and they generally cool more slowly than men. Children, on the contrary, generally have less fat as well as being smaller than adults and are at great risk from hypothermia after accidents to boats and shipping.

It became clear during this time (4) that there were special problems in very cold water, near 0 °C, and later (5, 6) that there were paradoxically also problems in relatively warm water, around 28 °C. One of the problems of very cold water was that sudden immersion induced intense cardiovascular and respiratory reflexes. The reflex rise in cardiac work and arterial pressure produced by the cardiovascular reflexes often induces ventricular ectopic beats in the heat; these occasionally progress to ventricular fibrillation with sudden death (7). This may be assisted by the reflex bradycardia that is

caused by facial immersion (8). Death simply from these causes is a very rare event, although ventricular fibrillation may be a cause of sudden death of people being rescued from cold water, who are already hypothermic. More commonly the reflex respiratory disturbance after sudden immersion in cold, with inspiratory gasping and increased ventilation, can be so intense that breathing cannot be controlled voluntarily, and the victim is liable to drown suddenly if the face becomes briefly immersed. It also causes waste of energy, forcing the victim to swim high in the water to keep the face continuously clear of the water. Combined with the fact that water at 0 °C is twice as viscous as water at 25 °C, making movement of limbs through the water more laborious, this greatly increases the work of swimming. Paradoxically, this is hazardous mainly to thin people, who are generally younger and physically fitter than older and fatter people (9). The reason is that fat provides buoyancy, and can enable people to keep their head above water with less effort of swimming. While the fatter people can then float, the young and fit without much fat are particularly at risk of rapid exhaustion and sudden drowning when they attempt to swim in very cold water. This is particularly so if they are wearing clothing with much viscous drag.

The main practical solution to this problem of sudden collapse while swimming in very cold water is for people at risk of cold immersion to wear buoyancy aids at all times. However, the reflexes may still cause inhalation of water, particularly in situations such as escape from sinking aircraft when brief dives may be needed. Substantial work has been done on ways of reducing these hazards. Consumption of alcohol does not greatly reduce the reflexes (10) but adaptation by repeated brief immersion does so, particularly in non-exercising immersions (11). Recent cold water training can therefore be expected to be of some benefit for people who suffer such immersions.

One of the most interesting problems of extreme cold immersion is presented by cold vasodilatation, a delayed return of blood flow to extremities after they are locally cooled below about 12 °C. This can occur during general immersion in water at 5 °C, and can cause even fat people to cool progressively. Under these conditions, when the dilatation develops in the face of intense vasoconstriction nerve activity, it is due largely to cold paralysis of the blood vessels of the extremities (12). It is of major practical importance, as fat people would otherwise be able to swim and dive without thermal protection in water near 0 °C, as seals can do. In general, the solution is to provide enough external insulation to keep skin temperature above 12 °C. Ordinary thick clothing will often achieve this for shipwreck survivors. However, it has become clear that a few individuals with adequate subcutaneous fat can stabilise body temperature without protection in water around 5 °C, for several hours (13, 14). The factors that permit this are not yet fully understood. The ability of some people to restrict local cold vasodilatation when they are generally cold is not due to shutting down of the large arteries that supply the cold extremities; these arteries remain open and still supply blood at high pressure in these conditions (15). There is recent evidence that prior cold adaptation can enable a generally cold individual to maintain better vasoconstriction during intense cooling of an extremity (16). This finding therefore raises the possibility that people of suitable body build could be trained and adapted to work safely for substantial periods without external heating, and with only moderate external insulation, in water down to 0 °C.

The special thermal problems presented by immersion in relatively warm water, around 28 °C, are due to failure of such immersion to activate heat conservation and production reflexes fully. In these conditions, people may cool to core temperatures a little below 35 °C with little response or discomfort. This marginal hypothermia

presents little direct threat to life, but does greatly impair memory registration and the speed of reasoning, which can in turn be a major hazard to people carrying out underwater activities. Improved stimulation of the cold receptors in the skin, by fluctuation of skin temperature, and by cooling of the extremities (17) can restore a normal response and normal body temperature. The heat production of exercise can also help raise body temperature (6) in these conditions, but the main practical solution for working situations has been to supply enough heating to give full subjective thermal comfort, which generally ensures that core temperature remains within normal limits.

References

1. Keatinge, W.R. Book: Survival in Cold Water. The physiology and treatment of immersion hypothermia and of drowning. Blackwell Scientific Publications: Oxford; 1969.
2. Sloan R.E.G. and Keatinge, W.R Cooling rates of young people swimming in cold water. 1973; *J. Appl. Physiol.* **35**: 371-375.
3. McArdle, W.D., Magel, JR., Spina, R.J., Gergley, T.J. and Toner, MM. Thermal adjustment to cold-water exposure in exercising men and women. *J. Appl. Physiol.* 1984; **56**:1572-7.
4. Cannon, P. and Keatinge, W.R. The metabolic rate and heat loss of fat and thin men in heat balance in cold and warm water. *J. Physiol.* 1960; **154**: 329-344.
5. Keatinge, W. R., Hayward, M.G. and McIver, N.K.I. Hypothermia during saturation diving in the North Sea. *Brit. Med. J.* 1980; **1**; 291.
6. Hayward, M.G. and Keatinge, W.R. Roles of subcutaneous fat and thermoregulatory reflexes in determining ability to stabilise body temperature in water. *J. Physiol.* 1981; **320**: 229-251.
7. Keatinge, W.R. and Hayward, M.G. Sudden death in cold water and ventricular arrhythmia. *Journal of Forensic Sciences* 1981; **26**: 459-461.
8. Smith, J.C., Stephens, D.P., Winchester, P.K. and Williamson, J.W. Facial cooling-induced bradycardia: attenuating effect of central command at exercise onset. *Med. Sci. Sports. Exerc.* 1997; **29(3)**: 320-5.
9. Keatinge, W.R., Prys-Roberts, C., Cooper, K.E., Honour, A.J. and Haight, J.S.J. Sudden failure of swimming in cold water. *Brit. Med. J.* 1969; **1**: 480-483.
10. Franks, C.M., Golden, F.S., Hampton, I.F. and Tipton, M.J. The effect of blood alcohol on the initial responses to cold water immersion in humans. *Eur. J. Appl. Physiol.* 1997; **75(3)**: 279-81.
11. Golden, F.S. and Tipton, M.J. Human adaptation to repeated cold immersions. *J. Physiol.* 1988; **396**: 349-63.
12. Keatinge, W.R. The return of blood flow to fingers in ice-water after suppression by adrenaline or noradrenaline. *J. Physiol.* 1961; **159**:101-110.
13. Keatinge, W.R., Coleshaw, S.R.K., Millard, C.E. and Axelsson, J. Exceptional case of survival in cold water. *Brit. Med. J.* 1986; **292**:171-172.
14. Keatinge, W.R. and Nyboer, J. Body temperature during a 125-minute swim in Bering Straits in water at 7.2-7.4 °C. *J. Physiol.* 1989; **412**: 42P.
15. Whelan, L.J., Donaldson, G.C., Counce, M.T., Mridha, K., Scarborough, M., Keatinge, W.R. Constriction of forearm arteries during cold exposure. *J. Physiol.* 1994; **479**: 38-39P.

16. Protheroe, RE., Rhodes, B., Yagci, A.G., Donaldson, G.C., Keatinge, W.R. The effects of local and general cold adaptation on cold-induced vasodilatation in cold conditions in humans. *J. Physiol.* 1996; **491**: 56P.
17. Keatinge, W.R., Mason, A.C., Millard, C.E. and Newstead, C.G. Effects of fluctuating skin temperature on thermoregulatory responses in man. *Journal of Physiology* 1986; **378**: 241-252.

A preliminary comparison of the efficacy of two immersion protection ensembles in Antarctic water

S. J. Legg

Environmental Ergonomics Laboratory, Department of Management Systems,
Massey University, Palmerston North, New Zealand

Introduction

Antarctica New Zealand has identified a strategic need for small boat operations to support its scientific operations in the sea in Antarctica (3). In the event of capsizing and for the purposes of safety, immersion protection for the working scientist is essential. The present preliminary study was conducted with the aim of comparing the efficacy of two dry immersion protection ensembles, either or both of which could be used to support Antarctica New Zealand's future small boat programme.

Methods

The first ensemble comprised an insulated (5 mm thick neoprene) dry overgarment worn over work clothing (thermal underwear, work suit, jacket, gloves, socks and boots). The overgarment was originally designed as a Quick-Don Immersion Suit (QDIS) (Seaquel Ltd) for emergency use by Royal New Zealand Airforce (RNZAF) transport and maritime aircrew in the event of ditching in the sea. The overgarment is bulky and restrictive to wear but can be donned within 30 seconds, has integral rubber gloves with neoprene overmitts and boots and a high immersed insulation (1.4 CLO) (1). The second ensemble comprised an uninsulated (goretex) dry undergarment with integral booties but no gloves, with rubber seals at the neck and wrists, worn over woollen underwear, polarfleece trousers and woollen shirt, under an outer layer of protective Antarctic work clothing (thinsulate sallopettes, heavy down parka, polarfleece neckwarmer, polypropylene and woollen gloves and Sorrel boots). The undergarment was originally designed as a Constant-Wear Immersion Suit (CWIS) (MacPac Ltd) for use by RNZAF helicopter and strike aircrew. It permits considerable freedom of movement, takes longer to don, can be worn continuously and has a lower immersed insulation (0.7 CLO) (1).

Four male volunteers wearing the QDIS ensemble and three wearing the CWIS ensemble were immersed and lay horizontally in calm Antarctic water at -2°C . Subjects also wore a Mk 15A life jacket and kept their hands out of the water. Ambient air temperature, wind speed and solar radiation ranged between -11 to -1°C , 0-16 knots and 0-2.8 MJ-m⁻². Age, stature, body weight and % body fat (2) were measured. Every 15 minutes core temperature was measured with a thermistor inserted 10 cm into the rectum (T_{re}) and toe and finger skin temperatures (T_{toe} , T_{finger}) were measured with thermistors attached to the right little toe and finger. Subjects rated their thermal

sensation on a scale of 0 (unbearably cold) though 4 (neutral) to 8 (unbearably hot). They also indicated any specific body region that was causing particularly severe thermal discomfort.

For safety reasons, immersions were terminated if T_{re} fell below 36.0 °C or T_{finger} or T_{toe} fell below 7.0 °C for more than three minutes, or at an immersion time of 6 hours or at the discretion of the experimenters or if requested by the subject.

Results

Subject	QDIS ensemble				CWIS ensemble		
	JL	EM	MM	SL	BH	PR	SL
Age (years)	28.1	25.9	35.7	39.9	31.9	39.4	39.9
Stature (cm)	173	178	169	176	176	175	176
Weight (kg)	71.0	81.8	65.0	74.5	67.3	68.6	74.5
Body fat (%)	11.8	20.8	16.0	18.3	12.9	17.5	18.3
Final T_{re} (°C)	35.8	36.2	35.9	36.0	36.15	36.5	36.25
Final T_{finger} (°C)	11.3	13.0	12.15	10.75	10.85	12.1	12.25
Final T_{toe} (°C)	11.9	10.35	20.65	10.5	13.45	9.05	17.75
Final thermal strain	1.0	2.0	2.0	1.0	1.0	0.4	0.5
Region of particular thermal discomfort	nil	nil	nil	nil	Heels	Heels	Heels
Reason for immersion termination	$T_{re} < 36$	6 hours	$T_{re} < 36$	$T_{re} < 36$	Cold feet	Cold feet	Cold feet
Immersion duration (hours)	1.75	6.0	0.75	4.25	2.25	2.5	3.25

Discussion and conclusions

If the time taken for T_{re} to fall to 34 °C is accepted as an indication of survival time, it is clear that both ensembles provide a high level of protection from hypothermia. A realistic estimate of survival time for most healthy males in still water in either ensemble would be at least 1-3 hours. However thermal strain, particularly of the feet and heels was greater for the CWIS ensemble. Also, if the hands had been immersed when using the CWIS ensemble the fingers would have rapidly cooled to near water temperature, increasing cooling rates. If suitably insulated (and partially detachable) overboots and gloves were added to the CWIS ensemble for emergency use when in the water, it would probably be the ensemble of choice because it can be worn continuously and affords greater freedom of movement to the wearer when working.

References

1. Cord Group Report R92-017. Immersed CLO of the RNZAF Quick Don and Constant Wear Immersion Suits, Nova Scotia, Canada, 1992.

2. Durnin JVGA and Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Brit J Nutr* 1974;32:77-97.
3. Howard-Williams C and Knox G. in *Antarctic Sciences beyond 2000: a strategic science directions workshop* (eds. Fitzgerald and Higham), Antarctica NZ 1997.

Peripheral cold injury

M. Hamlet

USARIEM, NATICK, Massachusetts 01760, USA

Non-freezing cold injuries

The severity is determined by the degree of cold, the duration of exposure, and the wetness of the tissue. Modifiers of this injury are fatigue, individual variability, nutrition and clothing. The pathogenesis involves cold-producing vasoconstriction, ischemia and decreased cell metabolism. Wetness increases conductive heat loss and changes membrane permeability with changes in cell function.

Although this was thought to have been the disease of the past and that modern armies would not be subject to this injury, the British and the Argentine experience in the Falkland Islands clearly defined this as a possibility, as both suffered extensive trenchfoot injuries. Although cold urticaria, cold-induced paresthesia, Raynaud's, and cold-induced asthma have a relation to cold exposure, they are not usually considered to be cold injuries. Cold urticaria patients are subject to anaphylaxis and loss of function associated with plunging into cold water and are difficult to wean from cardiac by-pass. Cold-induced paresthesia are usually result of repeated mild cold injuries and are more of a nuisance than a serious medical threat. Raynaud's is an abnormal peripheral constriction associated with emotional stress, vibration, or cold. It is often a symptom of more serious life-threatening autoimmune disease but can exist as an idiopathic syndrome. Cold-induced asthma is bronchial constriction associated with breathing cold, dry air. Coronary artery constrictions may also occur from breathing cold air. This may elicit an episode of angina in compromised patients. The true non-freezing cold injuries, however, are chilblain, immersion foot and trenchfoot.

Chilblain

Chilblain results from a non-freezing cold exposure to the hands and feet, which usually produces swelling, arrhythmia, and some discomfort. Lesions generally occur between the joints, rather than over them. The chronic form of chilblain is termed pernio with superficial neurotic plaques about a half millimeter thick. It is caused by repeated exposures to above freezing temperatures, usually associated in high humidity. This injury is produced by repeated vasospasm and localized histamine release in the tissues which accounts for the subsequent compromise of blood flow. It appears swollen, red and quite tender and warm to touch. Itching is usually a common symptom. There is swelling, vasodilatation, purple or red color and occasionally blisters will form with superficial ulcers. As it progresses, the itching is replaced by pain and tenderness. Chilblain is usually a self-limiting disease which has few long-term sequelae although the pain from the pernio injury can last a life-time, especially in children.

Immersion Foot

Immersion foot is long term cold water immersion, even in tropical water, which increases conductive heat loss. Immersion merely keeps the extremities cold and the vessels constricted. There are three stages: (1) Pre-hyperemic - may last hours or days. The tissue is cold, numb and swollen; (2) The hyperemic phase - up to three months long. There is tingling pain, swelling, blisters, which rupture producing ulcers, and gangrene. (3) Post-hyperemic phase - can last from weeks to years. It usually produces post-injury sequelae such as cold-induced Raynaud's, paresthesia, and severe pain upon cold exposure.

The general symptoms include numbness, tingling, itching, modest pain, leg cramps, the feeling of rubbing cotton on the feet. Life-raft injuries are immersion injuries, where individuals are exposed to long-term exposure in life-rafts.

Trenchfoot

Trenchfoot results from an exposure to a cold, wet environment, usually zero to 10 degrees C. Contributing factors are dependency of limbs, constrictive footwear, fear, fatigue and enemy action which restricts mobility. This is a circulatory and neuralgic injury. Nerve and fat cells are particularly susceptible as is muscle.

Most of the damage is the result of ischemia and anoxia from vasoconstriction. As vessel walls become damaged, fluid leak out causing cellular plugs which make vasospastic ischemia permanent. The direct effect of cold on cell metabolism, membrane integrity and fluid dynamics plays a unspecified role in this injury.

The sequelae consists of hypohidrosis, pain, warm, dry, scaly skin and cold sensitivity. There are leg spasms, severe cold sensitivity, deep plantar aching, atrophy of tissue, particularly of muscle and fat. There is persistent pain which does not respond to pain medication. Osteoporosis may occur. Flexion contracture of the hands and feet along with claw deformities are common.

Most research effort in trenchfoot injury and treatment occurred after World War II and another flurry during the Korean War. Good histopathologic evaluation of the injury has been done on man and animal models. There is little interest in this injury in the civilian community and because Armies consider that prevention is more important than treatment, there has not been a sustained research effort. Prevention involves specific insulating footwear and enhanced training procedures for foot care which are more easily accomplished. If one were searching for new therapeutic modalities, free radical scavengers and non-steroidal anti-inflammatory drugs might be helpful. We have learned a great deal about re-perfusion injuries which might be useful in the early management of trenchfoot. New diagnostic procedures such as infrared thermography and Technicum scanning combined with older methods of nerve conduction and electromyography may define the severity of injury more precisely early in its course.

Treatment of trenchfoot has been palliative at best. Acute management utilizing anti-inflammatory, non-steroidal medications along with Dextran intravenous therapy seems appropriate. Sympathetic blockade may be helpful but may increase edema and internal tissue pressures which lead to more ischemia. Free radical scavengers such as Allopurinol may improve cell survival. There is not a sharp line demarcation for tissue sloughing as there is in frostbite and moist liquefaction gangrene is common. Systemic infections with extremely high CPKs and DIC and fever are indications for surgical intervention. Sequential amputations may be necessary over a period of weeks because of the difference in tissue susceptibility and depth of injury in different parts of the limb. This is a much different course than freezing injuries which demarcate at a sharp 2

millimeter line, produce dry mummifying gangrene, seldom develop systemic infections, and do not require early surgical effort. The acute injuries are difficult to get out of the hospital. Pain, paresthesia, edema, poor healing, poor graft retention, and other sequelae combine to keep them bed ridden. Once out, they become a chronic medical burden because of symptoms, especially associated with cold, damp exposure, long-term standing, or ill-fitting shoes. Deep aching and pain on pressure are the most common complaints, although chronic ulceration also occurs. Argentine injuries have shown the same pattern of sequelae as injuries incurred in World War I. British injuries, although not as severe as the Argentine's required early release from military for many soldiers and marines. This injury will continue to be a sporadic problem in the civilian world, but Armies in certain battle scenarios will no doubt have to relearn the lessons of wars past about keeping the feet dry and changing socks.

Frostbite

Frostbite injuries can result from working in the cold. They can be relatively minor injuries with only mild pain and swelling which lasts a day or two. More serious injuries may produce blisters and deep tissue damage, which results in lost work time and long healing times. Infections and amputation may occur.

Long-term sequelae include crushing contractures, cold sensitivity, bone changes, arthritis, loss of muscle mass and increased sensitivity. Cold injury sequelae generally have significant Workmen's Compensation issues associated with them. Long recovery times and an inability to do a specific job may require changing jobs with retraining requirements.

It would behoove supervisors to spend the time and effort to train employees in prevention of cold injuries. It may also be wise for employers to buy proper gloves and boots to prevent these injuries. .a small expense, when considering the long-term cost of serious cold sequelae.

Raynaud's disease

Raynaud's Disease (or "White Finger Disease") is an abnormal maintenance of vasoconstriction of the fingers or toes associated with emotional stress, vibration, or cold. It is highly associated with 35- to 45-year-old females, but can affect anyone at almost any age. The actual cause is unknown, but there appears to be some genetic factors involved. Idiopathic Raynaud's has an onset of 35-40 years, but a good clinical history will often define the first overt signs when initiating menses at 12 or 13 years. Symptoms remain minor until a decreased hormonal balance increases the severity.

Raynaud's symptoms appear to be associated with auto-immune diseases, such as Lupus, Sclero Derma, and Rheumatoid Arthritis. Occupational Raynaud's (or White Finger Disease) is associated with workers with vibrating tools, such as jackhammers, chainsaws, and vibrating handlebars of snowmobiles.

The etiology may relate to repeated histamine release, causing smooth muscle fibrosis in small vessels. There is a progressive loss of vessel wall elasticity and inability to dilate. Early in the symptomatology, the vessels will contract and dilate. But as the fibrosis progresses, they lose this ability. Along with vascular constriction goes color changes, tingling, paraesthesias, numbness and loss of dexterity. In the work setting, this can be a significant problem. Symptoms can be so severe that the worker is unable

to perform the job, or will be at high risk to injury from loss of sensation in the hands or feet.

In countries where logging is a major industry, workmen's compensation claims for occupational Raynaud's is large financial issue. Raynaud's can be a permanent job-related disability. The chain saw manufacturers have made significant in-roads into developing vibration isolation systems in their saws for this very reason.

Treatment of Raynaud's is outside the scope of this paper, but one re-training procedure is worth describing. It is a Pavlovian conditioning procedure designed to trick the sympathetic system and vessel into dilating when the skin sensation says to constrict. The procedure is simple but requires time in a cold area, such as a walk-in refrigerator, a cold storage, or a cold garage. Two insulated containers, a thermometer, and mittens or booties are needed for equipment.

The procedure involves filling the insulated containers with hot tap water (about 40 °C), placing one in a normal temperature room and one in a cold area. Dress lightly as one would indoors. The individual immerses his/her hands or feet into hot water for two to five minutes, to obtain dilation. The hands (or feet) are then removed from the hot water, covered with a towel or mittens, and then the patient goes to the cold area. The hands are then immersed into the hot water for ten minutes, while the torso gets cold. Then the hands are removed from the hot water, insulated with the towel or mittens, and the individual goes back into the warmer area to again immerse the hands (or feet) in hot water for two to five minutes. This is one cycle.

This procedure is repeated after one half hour, three to six times per day, every other day. Some individuals will train more quickly than others, but some require fifty cycles. Training will last a number of years before the procedures must be repeated. This training has been highly effective in giving a patient control of the Raynaud's without medication. It enables workers to go back to their jobs without symptoms. Although time-consuming, this training is quite useful.

It behooves employers to educate their workforce in the proper, up-to-date dress for cold weather or refrigerator box protection. Some minimum standards should be established to preclude injuries. Particular attention should be paid to hand- and footwear. Certain jobs have a higher risk and should be scrutinized more. Certain individuals are more susceptible to cold injuries, and should be watched. Worker complaints about cold should be investigated. These simple procedures will help assure a safe workplace.

References

1. Ashe WF, Cook WT, Old JW: Raynaud's phenomenon of occupational origin. *Arch. Environ. Health* 5: 333-343, 1962.
2. Futatsuka M: Epidemiological studies of vibration disease due to brush saw operation. *Int Arch Occup Environ Health* 54: 251-260, 1984.
3. Olsen N, Fjeldborg P, Brochner-Mortensen J: Sympathetic and local vasoconstrictor response to cold in vibration induced white finger. *Brit J. Indust Med* 42: 272-275, 1985.
4. Futatsuka M., Ueno T: Vibration exposure and vibration-induced white finger due to chain saw operation. *J. Occup Med* 27: 257-264, 1985.
5. Hellstrom B, Stenavald 1, Halvorsrud JR, Vik T: Finger blood circulation in forest workers with Raynaud's phenomenon of occupational origin. *Int Z angew Physiol* 29: 18-28, 1970.

6. Hellstrom B, Andersen KL: Vibration injuries in Norwegian forest workers. *Brit J Indust Med* 29: 255-263, 1972.
7. Banister PA, Smith FV: Vibration-induced white fingers and manipulative dexterity. *Brit J Indust Med* 29: 264-267, 1972.
8. Matoba T, Kusumoto H, Mizuki Y, Kuwahara H, Inanga K, Takamatsu M: Clinical features and laboratory findings of vibration disease: a review of 300 cases. *Tohoku J. Exp Med* 123: 57-65, 1977.
9. Theriault G, DeGuire L, Gingras S, Laroche G: Raynaud's phenomenon in forestry workers in Quebec. *CMAJ* 126: 1404-1408, 1982.
10. Marshall J, Poole EW, Reynard WA: Raynaud's phenomenon due to vibrating tools. Neurological observations. *Lancet* 1: 1151-1156, 1954.
11. Ungley CC, Blackwood W. Peripheral vasoneuropathy after chilling. "Immersion foot and immersion hand". *Lancet* 2: 447-451, 1942.
12. Ungley CC, Channell CD, Richards RL. The immersion foot syndrome. *Br J Surg* 33: 17-31, 1945.
13. Francis TJR. Non freezing cold injury: a historical review. *J Roy Nav Med Serv* 70: 134-139, 1984.
14. Francis TJR, Golden FStC. Non-freezing cold injury: the pathogenesis. *J Roy Nav Med Serv* 71: 3-8, 1985.
15. Blackwood W. Studies in the pathology of human 'immersion foot'. *Br J Surg* 31: 329-350, 1944.
16. Orr KD, Fainer DC. Cold injuries in Korea during the winter of 1950-51. *Medicine* 31: 177-220, 1952.
17. Hanson HE, Goldman RF. Cold injury in man: A review of its aetiology and discussion of its prediction. *Milit Med* 134: 1307-1316, 1969.
18. Sumner DS, Cribblez TL, Doolittle WH. Host factors in human frostbite. *Milit Med* 141: 454-461, 1955.
19. Meryman HT. Tissue freezing and local cold injury. *Physiol Rev* 37: 233-251, 1957.
20. Mills WJ. Frostbite. A discussion of the problem and a review of an Alaskan experience. *Alaska Med* 15(2>: 26-59, 1973.
21. Hamlet MP. Human cold injuries. In *Human Performance Physiology and Environmental Medicine at Terrestrial Extremes*, Eds. Pandolf KB, Sawka MN, Gonzalez RR, pp. 435-466. Indianapolis: Benchmark Press, 1988.
22. Blair JR, Schatzki R, Orr KD. Sequelae to cold injury in one hundred patients. Follow-up study four years after occurrence of cold injury. *J Am Med Assoc* 163: 12-3-1208, 1957.
23. Brown FE, Jobe JB, Hamlet M, Rubright A. Induced vasodilatation in the treatment of posttraumatic digital cold intolerance. *J Hand Surg* 11A: 382-387, 1986.

Lifetime incidence of frostbite, its association with cold induced white fingers, vibration exposure and outdoor activity in young Finnish men

J. Hassi, O. Ervasti, K. Juopperi, H. Rintamäki, R. Pihlajaniemi, T. Linna

Oulu Regional Institute of Occupational Health, FIN-90220 Oulu, Finland

Abstract

Lifetime incidence of frostbite is reported rarely. Sequels of frostbite are frequent. Personal associates of frostbite's are important to know for optimal prevention and protection. We clarified by a questionnaire lifetime incidence and associates of frostbite in 5836 young Finnish men of average age 19.7 (16-30) years.

Total incidence was 43.8 %, frostnip 40 % and blister grade or more severe 11.5 %. Of frost-bitten persons 45.2 % had frostbite in their hands, 31.8 % in feet and somewhere else, mostly in faces 65.3 %. Mostly were reported multiple frostbite's, only in 21.4 % had only one frostbite in their life; more than five had in 37 % of respondents.

Total frostbite were reported more common by the respondents having cold induced white finger symptoms (CWF) (57 %) than without (39 %), in hands the difference: 39.6 % vs. 13.8 % were more pronounced than in other body parts.

The increased incidences of total frostbite's associated with vibration exposure in all exposure levels increasing with exposure hours. The positive association of frostbite with vibration exposure we do not know been reported earlier Total frostbite's were almost equal in the separate classes of outdoor activity: 43.1 % in outdoor occasionally, 44.1 % in daily and 45.1 % in professional group.

The frostbite is a common consequence of cold exposure in a northern country. CWF- and vibration exposure are important to recognise in management of frostbite risk.

Risk of frostbite

U. Danielsson

Defence Research Establishment, Department of Human Sciences, S - 172 90
Stockholm, Sweden

Introduction

Nude skin exposed to low air temperatures and high wind speeds is associated with increased risk of skin frostbite. It has been known for long that if certain combinations of temperature and air speed are exceeded the risk for tissue freezing increases significantly whereas below this level the risk is minor. Classical studies in the Antarctica during the 1940s (4) suggested that this level corresponded to a cooling rate (windchill index) of about 1400 kcal/(m²•min) (1628 W/m²). This was found by measuring the time required to freeze the water in filled cylinders and by exposing the expedition members to the corresponding windchill indices and notice if and when the unprotected skin started to freeze. Later studies (5) found however that this level of exposure was not very accurate for prediction of finger frostbite and one conclusion was that air speed was a less important factor to the risk of freezing the tissue than the air temperature. The purpose of this presentation was to re-examine the Siple and Passel data (4) by applying well-known convective heat transfer relations to a cylinder of similar shape as they used. The aim was also to estimate the skin surface temperature at the commence of freezing by using similar equations and correlate these data with the frequency of frostbite presented in the literature (5). Based on these results curves were developed to assess the risk of skin tissue freezing from airspeed and temperature data.

Methods

The bare skin is protected from the cold climate by a layer of air surrounding the body. The degree of protection is related to the thickness of this still air layer. However, the thickness is strongly related to the near air speed which in turn depends on the shape and size of the body part, angle to the wind and air stream characteristics. Siple and Passel (5) derived a convection coefficient (h_c) expression, $h_c=1,16\cdot(10\cdot v^{0.5}-v+10.45)$ [W/(m²•K)], from their cylinder measurements and a windchill index (WCI) was produced according to $WCI=h_c\cdot(33-T_a)$ [W/m²] where T_a is the air temperature. The h_c -relation of a cylinder in cross air flow can be derived accurately as this area has been studied intensively during many decades. For common climate conditions $h_c=4.47\cdot d^{0.38}\cdot v^{0.62}$ (2) where d is the diameter of the cylinder and v is the undisturbed air speed. Almost the same result, $h_c=3.76\cdot d^{-0.36}\cdot v^{0.61}$, has been found valid for various nude body parts (1). From these cylinder and corresponding flat-plate h_c -equations the cooling rate of water filled cylinders was estimated. Similar expressions were also used for prediction of the temperature at various depth of the skin assuming that the major heat transportation was in the radial direction which is the case at minimum skin blood flow. There are sparsely with data in the literature where both the occurrence of frostbite and

the climate conditions are well-documented. Wilson and Goldman (5) measured finger skin temperature at various combinations of air speed and temperature and the frequency of frostbite. However, surface temperature measurements in wind often suffer from errors (3). Hence, formulas were derived for correction of skin surface temperature taking into consideration the surface characteristics, air speed and angle to the wind, surface-to-air temperature difference and sensor thickness.

Results and Discussion

The Siple and Passel cylinder h_c -expression were found deviating greatly both from the predicted equation and from other h_c -expressions obtained at human studies. The reason was that the cylinder temperature was measured inside the cylinder, but was used as the surface temperature in the calculation of h_c . This was not correct under the current climatic conditions because of the cylinder wall heat resistance. However, the calculated water cooling rates were and gave similar results as those predicted from the cylinder equations. Nevertheless, as the Siple and Passel (4) h_c -equation ($h_c=21.5 \cdot v^{0.25}$) was used to derive the 1628 W/m^2 risk-curve it could be expected that a different expression should give a slightly changed risk curve.

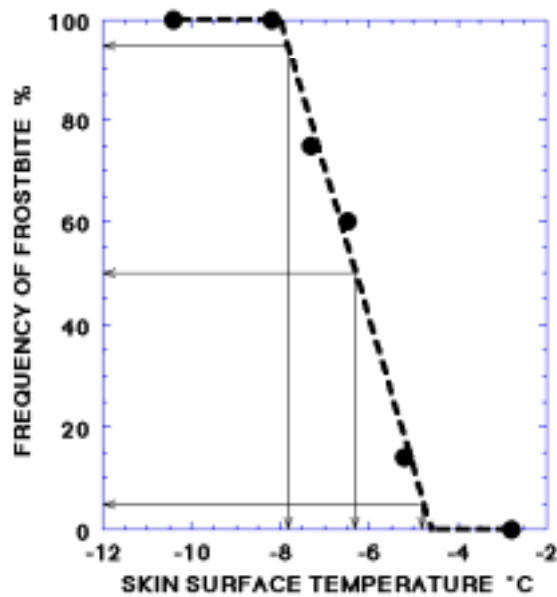


Figure 1. Relationship between calculated skin surface temperature and frequency of finger frostbite (5). Arrows denote 5, 50 and 95 % risk of tissue freezing and corresponding skin surface temperature.

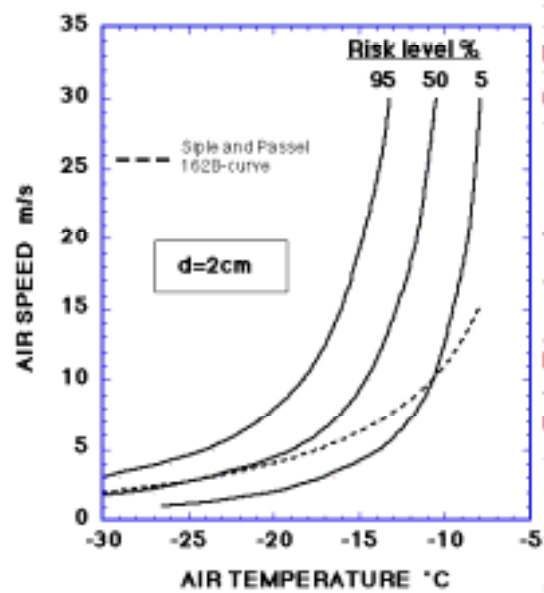


Figure 2. Risk of frostbite on windward side of a body part with a diameter of 2 cm at various air speeds and temperatures. Dotted line is Siple and Passel's (4) 1628 W/m^2 windchill index curve.

Wilson and Goldman (5) measured surface skin temperature at air temperatures and speeds ranging from $-5 \text{ }^\circ\text{C}$ to $-25 \text{ }^\circ\text{C}$ and 5 to 15 m/s, respectively. Using the temperature correction formula the estimated error, on average, ranged from $1.1 \text{ }^\circ\text{C}$ to $5.5 \text{ }^\circ\text{C}$. The corrected surface temperature at the occurrence of finger frostbite were found very similar to those predicted from the cylinder h_c -expression when the temperature between cutis and subcutis was assumed to be $-1 \text{ }^\circ\text{C}$, which is about that temperature when tissue freezes. The predicted surface temperatures at finger frostbite were related to the frequency of frostbite (5). The relation was found linear between $-4.6 \text{ }^\circ\text{C}$ (0 % risk) and $-8 \text{ }^\circ\text{C}$ (100 % risk) and can be considered as a part of a cumulative

distribution curve (Figure 1) displaying the probability of freezing the skin for those people involved in that study. A standard normal distribution curve, with a mean of -6.3 °C and standard deviation of 1 °C, gives practically the same cumulative distribution curve. From this risk curve it is possible to estimate the effect on frequency of frostbite in case of changed exposure causing a different surface temperature. Siple and Passel suggested that the WCI calculations should not be used for air speeds greater than 12 m/s. Compared with the new 5 % risk curve (Figure 2) a WCI of 1628 W/m² seems to overestimate the risk at temperatures above roughly -10 °C but underestimates the risk below this temperature. The new risk curves suggest, in case of normal body heat content, that the risk of skin frostbite is minor above -10 °C, whereas the risk is pronounced below -25 °C, except at very low air speeds.

References

1. Danielsson, U. Activity and wind-induced convective heat transfer coefficients in man. In: *Climate and Buildings*. Stockholm: Royal Institute of Technology, 1990, vol. 3.
2. Hilpert, R. Wärmeabgabe von geheizten Drähten und Rohren in Luftstrom. *Forsch. Geb. Ingenieurwes.* 4: 215-224, 1933.
3. Molnar, G. W. and J. C. Rosenbaum, Jr. Surface temperature measurement with thermocouples. In: *Temperature, Its Measurement and Control in Science and Industry*. New York: Reinhold, 1963, pt. 3, 3-11.
4. Siple, P. A., and C. F. Passel. Measurements of dry atmospheric cooling in subfreezing temperatures. *Proc. Am. Phil. Soc.* 89: 177-199, 1945.
5. Wilson, O., and R. F. Goldman. Role of air temperature and wind in the time necessary for a finger to freeze. *J. Appl. Physiol.* 29: 658-664, 1970.

Hypothermia, a report from the Swedish National Board of Health and Welfare

H. Brändström

The Swedish National Board of Health and Welfare, Stockholm, Sweden

Abstract

The variegated geography of Sweden, with its combination of mountain ranges, a long coast line, many lakes, long distances and a low ambient temperature for much of the year, entails risks of hypothermia.

Swedish medical personnel need to know more about hypothermia, its causes and treatment. This in turn demands both good and readily available factual data and the inclusion of the subject in training and exercises.

The National Board of Health and Welfare has therefore compiled a report on Hypothermia. The report is intended for training use but also as a practical help for medical personnel.

The report covers the following: epidemiology, predisposing factors, pathophysiology, presentation, laboratory evaluations, and methods of treatment.

The treatment part includes an overview of current rewarming options, cardiopulmonary resuscitation, resuscitation pharmacology and ends with a discussion of field and hospital management of the hypothermic patient.

The report has been compiled, on the Board's behalf, by Helge Brändström, Deputy Senior Consultant (Anaesthesiology Department) and Ass. Prof. Ulf Björnstig (Surgical Department), both of the University Hospital of Northern Sweden, Umeå.

Cold immersion, sustained heat production and survival

R. E. Reinertsen

SINTEF Unimed, Division of Extreme Work Environments, N-7034 Trondheim, Norway

Once insulation, as provided by subcutaneous fat, peripheral vasoconstriction and clothing, has been maximised, our capacity for cold tolerance is critically dependent on posture and heat production. Since behaviour is a factor that can be varied in an emergency situation, there is a need for better knowledge of the effects of exercise and shivering on cooling rate.

The roles of shivering and exercise in the development of hypothermia.

Current advice for survival at sea is to move as little as possible since any movement will enhance heat loss. However, although heat loss is indeed dependent on the relative motion of the body and the surrounding water (1), this may not be the best recommendation for subjects wearing well-insulated standard survival suits.

Much more heat can be generated by physical activity than by shivering. Utilising such an extra source of heat production might decrease core-cooling rate and delay the development of hypothermia.

Through a series of experiments we tested the hypothesis that the cooling rate of subjects wearing survival suits would not be affected by movement in the same way as that of less well insulated subjects (2, 3). Results obtained under two experimental conditions were compared; (A) Subjects who performed intermittent periods of mild leg cycling (40 % of VO_2 max) for 5 minutes at 20-minute intervals during immersion (6 hours; 4 °C water temperature) and (B) Subjects who did not exercise during immersion (6 hours; 4 °C water temperature). Rectal temperature and 13 skin temperatures were measured, and metabolic rate was calculated from measurements of VO_2 uptake and CO_2 output.

The core cooling rate was significantly lower in subjects following the exercise protocol, and thus the development of hypothermia was delayed. While shivering was evoked and metabolic rate rose during immersion in the “no exercise” condition, there was no increase in metabolic rate in exercising subjects between periods of leg cycling. Although the shivering was of low to medium magnitude, the condition of continuous shivering together with the sensation of skin coldness were uncomfortable for the subjects, and their tolerance was increasingly challenged as time went on. Furthermore, in spite of the falling core body temperature, the intensity of shivering fell towards the end of the experiment under the “no exercise” condition. These results indicate that periods of exercise enhance sustained heat production and thus increase chances of survival.

Metabolic changes during prolonged cold immersion.

The probability of survival during cold immersion also depends on the endurance of shivering or physical activity (4). Depletion of energy sources leads to metabolic fatigue and cessation of shivering and physical activity. Since exercise appears to lower the rate of cooling through increased heat production, it was felt to be of interest to compare the metabolic responses of individuals exposed to 6 hours of cold immersion whose heat production was increased either by continuous shivering thermogenesis or by intermittent periods of leg exercise (5). Increases in plasma free fatty acid (FFA) levels were greater in the “exercise” than the “no exercise” condition (0.86 ± 0.40 mmol/l vs. 0.49 ± 0.17 mmol/l). In lactate, glucose and creatine kinase there were no differences in the changes from pre- to post-immersion levels under the two conditions. On the basis of these results it appears that mild leg exercise does not accelerate the depletion of substrates.

Substrate mobilisation and thermoregulatory responses during cold immersion and slow body cooling.

As mentioned above, our previous studies of long-term exposure to slow body cooling showed that heat production may fall despite falling body temperatures in stationary individuals (3, 4). Thermoregulatory responses to cooling are characterised by increased adrenergic activity in which noradrenaline (NA) leads to increased mobilisation of FFAs (6). In an attempt to determine whether the decline in shivering could be explained by an inability to mobilise substrates or by inappropriate stimulation of the thermoregulatory system, plasma levels of NA, adrenaline and FFA were measured during slow body cooling and subsequent acute thermal stimulation (7). The experimental protocol involved slow body cooling followed by acute cold stimulation of either the chest (high thermal sensitivity) or femoral region (less thermal sensitivity). The cold water stimulation resulted in intense shivering and a significant increase in metabolic rate compared with the rate measured during maximum shivering activity before stimulation (15.6 ± 2.7 ml·kg⁻¹·min⁻¹ and 17.5 ± 2.1 ml·kg⁻¹·min⁻¹, $p < 0.05$, N=8 (chest); 14.3 ± 1.8 ml·kg⁻¹·min⁻¹ and 16.2 ± 2.1 ml·kg⁻¹·min⁻¹, $p < 0.05$, N=8 (femoral region)). Plasma levels of NA and FFA increased after both stimulations, and the rise was higher for chest stimulation than for femoral stimulation. The results show that it is possible to trigger increases in shivering activity and substrate mobilisation if an appropriate thermal stimulus is applied. The difference in the NA response of the two regions of different thermal sensitivity, together with the increased FFA mobilisation, strongly suggests that the cold water acted as a stimulus evoking the thermoregulatory system.

In conclusion, the role of heat production by shivering and physical activity should be considered as a means of improving endurance when protective equipment and procedures for survival at sea are being designed.

References

1. Hayward JS, *Aviat Space Environ Med*, Vol. 55, 1984, pp 206-212
2. Reinertsen RE et al, *Life in the Cold*, Westview Press, 1993, pp 15-23
3. Waag T et al, *Arctic Med Res*, Vol. 54, 1995, pp 60-64

4. Doubt TJ, Hsieh SS, *Medicine and Science in Sports and Exercise*, Vol. 23, 1991, pp 435-442
5. Hesselberg Ø et al, *Arctic Med Res*, Vol. 54, 1995, pp 65-69
6. Jensen K, *Acta Anesth. Scand.*, Vol. 24, 1980, pp. 138-143
7. Sørø V et al, *Acta Physiol Scand* Vol. 157, 1996, 27A

Mechanisms of inhibition and principles of restoration of brain functions after deadly dangerous hypothermia

*K. P. Ivanov, Yu. S. Alyukhin, N. K. Arokina, Yu. I. Levkovich,
S. V. Shevchenko, N. A. Slepchuk, A. E. Chuikin*

I. P. Pavlov Institute of Physiology, Russian Academy of Sciences, St. Petersburg 199034, Russia.

It has been commonly assumed that Ca^{2+} normally serves important functions as membrane stabilizer, metabolic regulator, and second messenger. Its content in a cell at physiological rest is 10^{-8} - 10^{-7} M. The increase in Ca^{2+} concentration to 10^{-6} M and more results in a sharp violation of the metabolism and the destruction of the cell membranes. The excess of Ca^{2+} is removed from the cells through the cell membrane into intercellular medium. Ca^{2+} concentration in the intercellular medium is about 10 thousand times greater than in the cell. To overcome such a great concentration gradient requires a relatively very large amount of energy. It is known that in homothermal organisms the quaternary structure of the cellular enzymes, participating in the ATP synthesis disintegrates at low temperature [1]. This creates a relative ATP deficit in a cooled cell. According to the theory of Hochachka [2], the violation of the Ca^{2+} transport and accumulation of Ca^{2+} in the cell is the main reason for its function paralysis and its death under hypothermia.

In our experiments ethylenediaminetetraacetate (EDTA) was introduced into the blood of cooled animals. This substance links Ca^{2+} to give a complex compound with Ca^{2+} . We expected to decrease Ca^{2+} concentration in the blood and in the intracellular liquid to decrease the concentration gradient and energy expenditure for transferring Ca^{2+} from cell to the medium.

First we performed the electrophysiological studies of the cold thermoreceptors of the rabbit skin in the nasolabial area upon a local cooling of a skin site to 0 - 5 °C. The maximal firing rate is 15 - 40 imp/s. After cooling the skin surface to the temperature 0-5 °C the firing rate decreased to 1 - 3 imp/s or ceased at all. At this time 0.140 mmol of EDTA was introduced into blood. In 2 - 8 min the firing rate attained 11 - 20 imp/s. The restoration of the work of one such thermoreceptor without rewarming the skin we demonstrated earlier [4].

Furthermore, we studied four cold skin thermoreceptors which responded also to weak mechanical irritation of the skin. They completely ceased their firing rate at the skin surface temperature 0 - 2.3 °C. In 9 - 13 min after the beginning of the EDTA injection into the blood all of them restored their firing rate to 24 - 40 imp/s at the same skin temperature (0-2.4 °C).

In the next series of experiments on rats an attempt was made to restore (to renew) the functions of the thermoregulation system as a whole. With this aim the rats were cooled to the temperature in rectum of 17 - 18 and in brain 19 - 20 °C. At this body temperature an abrupt oppression of the muscle cold shivering (Shv) occurred. The

intensity of Shv during thermoregulation reactions was estimated by the total value of muscle electrical activity with the help of an electronic integrator, which measured the total area of the biopotentials per unit of time (S, mcV·sec) [3]. The animals, which received EDTA are capable of self-rewarming.

After an abrupt oppression or complete cessation of the Shv, as the above mentioned temperature was attained, the rat vena femoralis was injected with EDTA in amount of 0.020 mmol.

In 4 - 7 min after the beginning of injection the restoration or abrupt intensification of Shv occurred at the same body temperature. In 10 - 15 min from the beginning of injection the Shv began to decrease. The repeated injection of EDTA in the same dose again intensified the Shv.

Under an accidental hypothermia the most important is to maintain or to restore the lung respiration of a cooled organism. The arrest of the lung respiration under deep hypothermia in animal and man practically means death since the respiration does not restore on its own.

In our experiments the rats were cooled to the brain temperature 18.5 ± 0.3 °C. At such a brain temperature the lung respiration quickly weakened or almost arrested. The animals were injected with 0.020 mmol of EDTA. In 20 - 25 min the same dose was injected repeatedly. In 5 - 10 min after the repeated injection of EDTA the lung respiration began to restore, though the brain temperature at this time was decreasing to 15.5 - 16.5 °C. At such a temperature in our experiments without EDTA the respiration was always absent and the animals perished. The animals, which received EDTA are capable of self-rewarming.

The stability of the breathing center can be increased with the help of increasing the blood supply of the brain being cooled. With this aim we warmed the heart a little with the help of an inner miniature thermode and sustained the arterial blood pressure at the level of 40 - 60 mmHg. In this case the lung respiration was arrested at the brain temperature of 13 - 14 °C (instead of 18.5 °C). The blood flow rate in the brain capillaries was 50 % of the norm in this case. Such animals were capable of self-rewarming.

If the arterial blood pressure is sustained in the same way at the level of 30 - 50 mmHg, the brain of rats can be cooled to 2 - 12 °C and in 2 - 3 hours all the physiological functions of an animal can be restored with the help of artificial respiration and artificial rewarming.

These experiments extend the existing ideas about the lowest temperature limits of vital activity and viability of homothermal organisms.

These data can make a contribution to the development of new efficient procedures of resuscitation of the victims of accidental hypothermia.

References

1. Hochachka P.W., Somero G.N. Strategies of Biochemical Adaptation. W.B.Saunders Co, Philadelphia - London. 1973. 400 pp.
2. Hochachka P.W. Defense strategies against hypoxia and hypothermia. Science.1986.V.231.P.234-241.
3. Ivanov K.P. The Principles of energetics in Organism. Nauka. Leningrad - Sankt-Petersburg. 1990-1993. 600 pp. (Russian).
4. Ivanov K.P. Physiological problems and functional mechanisms of the thermoregulation system. Annals of The New York Academy of Sciences. 1997. V.813. P.32-38.

Geographical variation in the lifetime cumulative incidence of frostbite in different thermal zones in Finland

*K. Juopperi, J. Hassi, O. Ervasti, H. Rintamäki, T. Linna,
R. Pihlajaniemi*

Oulu Regional Institute of Occupational Health, FIN-90220 Oulu, Finland

Abstract

There is little comparative information regarding the incidence of frostbite in thermal living zones. We used a questionnaire to estimate the lifetime cumulative incidence of frostbite in three thermal zones in Finland: southern (winter <140 days/year), middle (140-170 days) and northern (>170 days). The population comprised 3240 men aged 17-30 years old at the beginning of their military service, of whom 2866 (84.5%) answered the questionnaire. Frostbite was reported by 40.8 % in the southern thermal zone, 42.5 % in the middle zone and 60.6 % in the coldest northern zone. Superficial frostbite was reported by 35.7 %, 37.9 % and 55.8 % respectively and deeper frostbite by 11.4 %, 12.3 % and 23.6 %. Thus the incidence of frostbite was very high in all three thermal zones and especially so in the northern zone, where the total incidence was 1.5 times that found elsewhere and that of deeper frostbite twice as high as elsewhere. The results support an earlier observation that the annual occupational incidence of frostbite among Finnish reindeer herders was 1.4-1.9-fold in the north of the herding region than in the south [1]. It has also been recorded that 95 % of frostbites suffered during military training occur at temperatures below -15 °C temperatures and that the average temperature at the time when the frostbite was identified was -25 °C [2]. There are more very cold days in the northern thermal zone than in the other zones, which increases the chances of suffering from frostbite. Even though people in the north are well trained in living under cold conditions and protecting themselves against the cold, it seems that the frequency of frostbite increases markedly in areas where the environmental temperature is low in winter.

1. Ervasti et al., Frostbite in Reindeer Herders. *Arct. Med. Res.*, Vol. 50, Suppl. 6, 1991, pp. 89-93.
2. Lindholm et al., In Finnish: Varusmiesten paleltumat vv. MATINE, raporttisarja A 1991/1, Helsinki, 1993.

Pharmacological correction of hypothermic states

A. Smirnov, E. Shustov, V. Varfolomeev

Institute of Extreme Medicine, Moscow, Russia.

The professional activity of seamen is connected with a high possibility of low temperature influence and body hypothermia. Such situations occur under usual conditions of the occupation, and in failures and accidents, and can result not only in decrease of performance, but in fatal outcomes as well.

Low temperature tolerance can be increased through the use of pharmacological means (frigoprotectors) which have some special features.

First of all, under conditions of low temperature influence it is necessary to distinguish the following:

- acute cooling, at which a heat loss intensity far exceeds heat production and a man freezes to death with preserved power resources of the body.
- sub-acute cooling, at which heat loss rate is roughly equal to the rate of thermal resources, followed by a sharp reduction of heat production.
- chronic cooling over a long period of time, when the thermoregulation system maintains thermo-balance of the body at the price of metabolism intensification, which may lead to dystrophic changes or regional focal peripheral sympathomatics.

Pharmacological correction tactics in acute cooling will consist of an emergency mobilisation of direct heat-producing actions of catecholamines. Direct and non-direct adrenomimetics (ephedrine, phenocoll, sidnocarb) could be introduced for this purpose in excessive, almost toxic doses. Sidnocarb, for example, can be recommended in the doses of 30-50 mg every 3 hour, but not more than 5 intakes per day.

In case of sub-acute cooling the pharmacological correction can be done as follows:

- thermogenesis' catecholamine regulation's increase in effected tissues (muscular and adipose). Since the inhibitory role of L2 - adrenoreceptors, P1 - purinoreceptors and prostaglandids of E - group has been established in the process of norepinephrine release in synapses, we recommended non-selective adrenoblocker pyroxan and prostaglandids synthesis' inhibitors as means of cold stability increase (acetil-salicyl and mephenamin acids, indometacin, voltaren);
- catecholamines' synthesis intensification by the usage of their predecessors (L-dopha);
- increased and stable level maintenance of norepinephrine in sympathetic fissures and adrenaline level in blood (usual stimulating doses of adrenomimetics: sidnocarb, ephedrine, monoamino oxidise inhibitors-antidepressants with the stimulating effect - inpasid, nuredal, transamine, indopan). With the account of main contra-indications for the usage of these preparations' group, sidnocarb and indopan can be the choice, taken in one-time stimulating doses;
- a combined application of preparations with a mobilisation and economising effect represent a promising way to sub-acute hypothermia pharmacological correction. In

particular, a very high efficacy has been shown by a combination of psychostimulator sidnocarb (10 mg) and an actoprotector remittal (0.25) - sidnobem.

In every case of a chronic cooling the main task will be the intensification of energy resources' restoration process under the conditions of an increased energy consumption. This can be done by the application of adaptogenetic means, actoprotectors and vitamins.

Preparations like complamine and trental can be recommended for cutting off the peripheral sympathomatics related with regional changes in hemodynamics and micro-circulation. However, the application of vasodilative means without an additional stimulation for venous outflow system, will lead to the situation when the ischemic sympathomatics will be replaced by congestion signs with a secondary ischemia of tissues in the one of venous congestion. That is why it is necessary together with vasodilative means to apply the preparations of vein-dynamic effect - glivenol and glutamine acid.

Thus, frigoprotectors represent an effective means for sustaining and restoration of the thermal homeostasis in men in lower temperature environment. However, its application depends on the cold impact estimation together with some special features of developing hypothermic pathogenesis.

Human thermal condition restoration at modeling of emergencies after swimming in cold water

E. Zhilyaev, A. Chernetsov, A. Azhaev, I. Berzin, V. Grebenkin

Institute of Extreme Medicine, Moscow, Russia

The problem of people's rescue after cold water immersion is still actual. The analysis of emergencies and accidents on the water shows, that many die after rescue of deep hypothermia. The danger of intensive overcooling of people is also great when they spend a long time on rescue boats or rafts.

However, the system of the emergency medical help is not effective enough as far as hypothermia is concerned. It requires inclusion of fast restoration for cold immersion cases.

A situation of an emergency was simulated during swimming competition and experiments in cold sea water.

The latter were carried out en route: Wrangel bay - Amur gulf and through Tartar strait from island Sakhalin up to Soviet Harbour. In the first case temperature of water was 6-8 °C, in the second - 3-4 °C. The air temperature was 13-15 °C and 2-5 °C accordingly. Swimmers made 10-20 attempts, about 10 minutes each, with the distance of 300 - 500 meters. Some of the participants spent 20-30 minutes in the water of 5 °C.

Parameters of cardio-vascular activity and respiration, body temperature (rectal) and skin temperature in 7 areas were studied. Intensity of muscular thermogenesis and sequence of inclusion of muscular groups in the process of thermoregulation was estimated visually.

After staying in cold water the rectal temperature reduced from 36.8 °C to 34.0-35.6 °C. After 2-5 minutes swimmers developed muscle shivering starting from upper and lower maxillas, then the neck, thorax and hip muscles. Gradually muscle shivering covered whole skeletal musculature. In 25-40 minutes the shivering lost its intensity and disappeared in the same sequence, as it developed. Blood pressure after swimming reached 150/100 mm, pulse rate - 100-110 beats per minute. In background examinations, before swimming blood pressure was on the average 123/78 mm, pulse rate - 60 beats per minute. Breathing was difficult, air intake depth was increased, lung ventilation reached on the average 20 liters per minute (as much as 30-32 liters per minute). In background examination the lung ventilation was amounted to 5.8 liters per minute.

After staying in water with temperature 3.5-6 °C for 10-15 minutes in immovable condition rectal temperature reduced to 36.3 °C. After warming in a sleeping bag for 40 minutes it was reduced to 34.6 °C, and only in 10 minutes it raised by 0.3-0.4 °C.

For restoration of a thermal condition of swimmers after the test we applied a flow of warm air from calorifer with temperature 40-45 °C, warming up with thermoaccumulating devices, representing, mostly, thermophysical reusable warmers, which were placed in vest pockets on the back and chest, or placed all over the body in

a sleeping bag. The results were compared with those of the participants that were placed in a room with comfortable air temperature and wearing a daily two-layer uniform. The main principle in designing these warming devices is their configuration that allows to place them on the right places from physiological point of view. The body zones that needed warming most of all were defined by using thermophysical warmer. After leaving the water, swimmers would put them on different parts of their bodies and feel where the warmth felt most comfortable. 100 % preferred to warm up the back of the head, 80 % - loin, 90 % - back, 80 % - feet, 70 % - chest, 60 % - hands, 60 % - thighs.

After swimming temperature of the back, chest, loin, feet and forearms was 18-20 °C. In 30-40 minutes in a sleeping bag with warmers the skin temperature reached 30-32 °C. Without warmers it reached this value in sleeping bag only in 80-90 minutes.

Warming up the swimmers with a flow of warm air promoted fast restoration of a thermal condition. In 15 minutes chest skin temperature reached 32 °C with average skin temperature 30 °C. Right after leaving the water these parameters were 22,2 °C and 21,0 °C accordingly.

For thermal condition restoration the participants breathed helio-oxygen mixture heated to 60-70 °C (30 % oxygen and 70 % helium).

Thus, the swimmer cooling in water can serve as a model of hypothermia, in which we can choose means for human thermal condition restoration. This experiment has proved that the back of the head, loin and back need warmth most of all. The warm air flow application, warmth-accumulating devices and helio-oxygen mixture inhalation will accelerate the process of thermal condition restoration after cold water accidents.

Cold adaptation - its relevance for long term exposure

J. H. M. Bittel

Centre de Recherches du Service de Sante des Armees, Departement des Facteurs Humains, La Tronche, France

Introduction

Cold adaptation is known to have a beneficial effect to increase cold tolerance and to prevent the two major accidents observed: frostbite (local accident) and hypothermia (general accident). Consequently, it exists two adaptations: local and general cold adaptation which are integrated together. For a didactic point of view, these two types of adaptation will be exposed separately.

Local cold adaptation

Local cold adaptation is a common and relatively well known phenomenon. So, cold adaptation of the extremities has been observed in numerous studies. It has been studied in native people such as Eskimos (Brown and Page 1952; Miller and Irving 1962), Arctic Indians (Meehan 1955), Lapps (Krog et al. 1960) and Manchurian people (Yoshimura 1960). It has been investigated also in cold-exposed professional workers such as arctic fishermen, Quebec postmen (Leblanc et al. 1960; Leblanc 1975), British fish filleters (Wehms and Soper 1962), and the Amas, the Korean diving women (Paik et al. 1972; Hong 1973). This type of adaptation has also been studied in Caucasian subjects living in the Arctic (Livingstone 1976) and in subjects adapted to the cold in laboratories (Adams and Smith 1962; Savourey et al. 1992).

All the studies have shown similar results. Local cold adaptation is characterised by warmer local skin temperatures, less pain, a greater manual dexterity, an higher local blood flow and an earlier cold-induced vasodilatation at higher skin temperatures (Krog et al. 1960; Leblanc et al. 1960; Leblanc 1975; Savourey et al 1992). These changes were due to an increased peripheral cutaneous blood flow and to a greater local heat production in the muscle as shown by Savourey et al. 1992.

This local cold adaptation can be easily developed at home in putting the hand in ice water, one or two/day during one month.

General cold adaptation

Relatively few humans exhibit cold adaptation because there are many cultural and/or behavioural strategies such as migration, protective clothing, fire, modern life in well heated houses which reduce or suppress the environmental cold stress to which humans

are exposed. In fact, without these different strategies, man should stay in tropical or subtropical countries.

However, several types of cold adaptation have been described over the 50 years in studies carried out on natives in their natural environment (acclimatisation) or on Caucasians in laboratory conditions (acclimation). Metabolic adaptation characterised by a higher metabolic heat production, higher skin temperatures and normal rectal temperature was observed in Alacaluf Indians of Tierra del Fuego (Hammel et al 1960), in Arctic Indian (Elsner et al. 1963; Irving et al. 1960), in Eskimos (Hart et al. 1962), in Europeans living under primitive conditions (Adams and Heberling 1958) and in Caucasian subjects under laboratory conditions (Adams and Heberling 1958, Keatinge 1961). Insulative adaptation characterised by a lower mean skin temperature and a normal rectal temperature was observed in the coastal tribes of tropical northern Australia (Hammel et al. 1959), in people naturally adapted to cold climates (Davies and Johnston 1961) and in cold adaptation by water immersion (Boutelier et al. 1982; Skreslett and Aarefjord 1968). Hypothermic adaptation characterised by a lower rectal temperature with less metabolic compensation leading to a greater body cooling was observed in the bushmen of the Kalahari desert (Hammel et al. 1962), in Peruvian Indians living at altitude in the Andes (Elsner and Bolstad 1963), in soldiers living in cold climates during a long period (Leblanc 1956) and in cold acclimated subjects under laboratory conditions (Brück 1976; Brück et al. 1976; Bittel 1987; Savourey et al. 1996; Bittel et al. 1989). Finally, insulative hypothermic adaptation was observed in central Australian Aborigines (Hammel et al. 1960; Scholander et al. 1958), in nomadic Lapps (Lange Andersen et al. 1956), in Korean and Japanese diving women (Hong 1963; Itoh 1974) and in people adapted to cold by water immersion (Boutelier et al. 1982; Bittel 1988).

These different types of cold adaptation can be partly explained by many factors such as various experimental conditions used to develop and test cold adaptation (continuous or discontinuous exposures to moderate or severe cold stress, the time allowed to achieve cold adaptation or the period over which measurements are taken during cold test). Other factors could also be implied such as the nature of cold adaptation (natural or artificial), the effects of diet (Rodahl 1957) and body characteristics (physical fitness, body fat content) as shown by Bittel 1987 or associated stresses (i.e. cold and altitude in Peruvian Indians). So, Brück (1976) said “one may wonder whether it will be possible one day to produce the desired type of adaptation by making the correct choice of stress parameters”.

However, taking into account only the adaptative phenomena observed on natives in their natural environment, we can postulate that = a metabolic adaptation is observed for a severe cold stress associated with the possibility of a high energy intake (Eskimos); an insulative adaptation is observed for a light cold stress with a low energy intake (coastal tribes of Australia); a hypothermic adaptation is observed for a moderate cold stress associated with a low energy intake (bushmen of the Kalahari desert) and an hypothermic- insulative adaptation is observed for a moderate cold stress with a very low energy intake (Central Australian Aborigines) who must be adapted to heat during the day too.

In an other hand, some physical characteristics of the subjects (i.e. level of physical fitness and body fat content) can also influence the development of such or such a type of general adaptation as show by Bittel (1987). In this study, nine male subjects were adapted to cold by repetitive immersions in cold water during 2 months. These subjects were tested before and after cold adaptation during a standard cold test in a temperature humidity controlled chamber. It was observed, in the 9 pooled subjects, a metabolic

insulative adaptation. However, when each individual response was considered separately, only 5 of the 9 subjects exhibited an acclimation pattern reflected by the group average (metabolic-insulative adaptation). For the other 4 subjects, one subject developed a metabolic adaptation and three subjects an insulative one. Because of the limited number of subjects, it was difficult to establish a relationship between the type of adaptation and individual factors of cold tolerance.

However, it was true that the only subject who developed a metabolic adaptation presented also the higher level of physical fitness and the lower body fat content. Inversely, the highest percent of body fat was found in one of the subjects who presented one of the most important insulative adaptation. It was concluded that the level of physical fitness could well be a favourable factor in developing a metabolic adaptation and, inversely, that in subjects with limited capacity of increasing their heat production, an insulative adaptation was preferentially developed in which the percentage of body fat content could be the essential factor.

Whether it be in natural or in laboratory conditions and whether it be the type of cold adaptation, the cold adapted subjects present common criteria for general cold adaptation: an increased delay for onset of shivering and a lower level of body temperatures at the onset of shivering.

In conclusion, it can be considered that:

- i) cold stress is necessary to develop general cold adaptation,
- ii) the intensity of the cold stress conditions the development of such or such a type of cold adaptation,
- iii) cold stress is not the only factor being implied in the development of such or such a type of cold adaptation,
- iv) man is able to develop different types of cold adaptation depending on the environmental and cultural energy intake conditions (strategy to cold environment).

The hypothermic general cold adaptation appears the most appropriate type of adaptation to assume the conservation of an acceptable level of energetic reserves with a moderate hypothermia which is not life threatening in cold climatic conditions.

References

1. Adams T., Heberling E. J. : Human physiological responses to a standardised cold stress as modified by physical fitness. *J Appl Physiol* 13 : 226-230, 1958.
2. Adams T., Smith RE. : Effect of chronic local cold exposure on finger temperature responses. *J Appl Physiol* 17 : 317-322, 1962.
3. Bittel J. : Heat debt as an index for cold adaptation in men. *J Appl Physiol* 62 : 1627-1634, 1987.
4. Bittel J. : Livecchi-Gonnot G. H. Hanniquet A. M., Poulain C., Etienne J.L. : Thermal changes observed before and after J.L. Etienne's journey to the North Pole. Is central nervous system temperature preserved in hypothermia ? *Eur J Appl Physiol* 58 : 646-651, 1989.
5. Boutelier C., Livingstone S. D., Bougues L., Reed L. D. : Thermoregulatory changes to cold in pre-acclimated and non-acclimated men following an arctic winter stay. In : Koll Stoll II. Canada : Univ. of Toronto Press, 1982. pp B1 - B19.
6. Brown G.M., Page J. : The effect of chronic exposure to cold on temperature and blood flow of the hand. *J Appl Physiol* 5 : 221-227, 1952.

7. Brück K. Cold adaptation in man. In : Regulation of Depressed Metabolism and Thermogenesis, ed. by L. Jansky and X. J. Mussachia. Springfield, IL : Thomas, chap 3. p 46, 1976.
8. Brück K., Baum E., Schennicke H. P. : Cold-adaptative modifications in man induced by repeated short-term cold-exposures and during a 10-day and night cold-exposure. *Pfluegers- Arch* 363 : 12-133, 1976.
9. Davies T. R. A., Johnston D.R. : Seasonal acclimatisation to cold in man. *J Appl Physiol*. 16 : 231-234, 1961.
10. Elsner R. W. , Bolstad A. : Thermal and Metabolic Responses to Cold Exposure of Andean Indians Native to High Altitudes. Ladd AFB, AK : Arctic Aeromed Lab, (Tech Rep AAL-TOR-62-64), 1963.
11. Elsner R. W., Lange Andersen K., Hermansen L. : Thermal and metabolic responses of arctic Indians to moderate cold exposure at the end of winter. *J Appl Physiol* 15: 659 -661, 1960.
12. Hammel H.T., Elsner R. W., Lange Andersen K., Scholander P. F., Coon C. S., Medina A., Strozzi L., Milan F.A., Hock R.J. : Thermal and Metabolic Responses of the Alacaluf Indians to Moderate Cold Exposure. Ladd AFB, AK: Wright Air Develop Div, (Tech Rep 60-63), 1960.
13. Hammel H.T., Elsner R.W., Le Messurier D.H., Andersen H.T., Milan F. A. : Thermal and metabolic responses of the Australian Aborigines to moderate cold in summer. *J Appl Physiol* 14 : 605-615, 1959.
14. Hammel H.T., Hildes J. A., Jackson D.C., Andersen H.T. : Thermal and Metabolic Responses of the Kalahari Bushmen to Moderate Cold Exposure at Night. Ladd AFB, AK : Arctic Aeromed Lab, (Techn Rep 62-44), 1962.
15. Hart J.S., Sabeau H.B., Hildes J.A., Depocas F., Hammel H.T., Lange Andersen K., Irving L., Foy G.: Thermal and metabolic responses of coastal Eskimos during a cold night. *J Appl Physiol* 17: 953-960, 1962.
16. Hong S. K. : Comparison of diving and non-diving women of Korea. *Federation Proc* 22: 831-833, 1963.
17. Irving L., Lange Andersen K., Bolstad A., Elsner R., Hildes J.A., Loyning Y., Nelms J.D., Peyton L.J., Waley R. D. : Metabolism and temperature of Arctic Indian men during a cold night. *J Appl Physiol* 15 : 635-644, 1960.
18. Itoh S. : Physiology of Cold-Adapted Man. Sapporo, Japan : Hokkaido Univ Press, vol. 7 (Hokkaido Univ Med Lib Ser), 1974.
19. Keatinge W.R. : The effects of repeated daily exposure to cold and improved physical fitness on the metabolic and vascular response to cold air. *J Physiol Lond* 157 : 209-220, 1961.
20. Krog J., Folkow B., Fox R.H., Lange Andersen K. : Hand circulation in the cold of Lapps and North Norwegian fishermen. *J Appl Physiol* 15 : 654-658, 1960.
21. Lange Andersen K., Loyning Y., Nelms J.D., Wilson O., Fox R.H., Bolstad A. : Metabolic and thermal response to a moderate cold exposure in nomadic Lapps. *J Appl Physiol* 15 : 649-653, 1960.
22. Leblanc J. : Evidence and meaning of acclimatisation to cold in man. *J Appl Physiol* 9 : 395-398, 1956.
23. Leblanc J., Hildes J.A., Heroux O. : Tolerance of Gaspé fishermen to cold water. *J Appl Physiol* 15 : 1031-1034, 1960.
24. Leblanc J. : Man in the cold. Thomas, Springfield, Mass., 195 pages, 1975.
25. Livingstone S.D. : Changes in cold induced vasodilatation during Arctic exercises. *J Appl Physiol* 40 : 455-457, 1976.

26. Meehan J.P. : Body heat production and surface temperatures in response to a cold stimulus. *J Appl Physiol* 7 : 537-541, 1955.
27. Miller L.K., Irving L. : Local reactions to air cooling in an Eskimo population *J Appl Physiol* 17 : 449-455, 1962.
28. Rodahl K. : Human Acclimatisation to Cold. Ladd AFB, AK : Arctic Aeromed Lab, (Tech Rep 57-21), 1957.
29. Savourey G., Clerc L., Andre L., Vallerand., Leftheriotis G., Mehier H., Bittel J. : Blood flow and muscle bio-energetics by ³¹P-nuclear magnetic resonance after local cold acclimation. *J Appl Physio* 64 : 127-133, 1991.
30. Scholander P.F., Hammel H.T., Hart J.S., Le Messurier D.H., Steen J. : Cold adaptation in Australia aborigines. *J Appl Physiol* 13 : 211-218, 1958.
31. Skreslett S., Aarefjord A.: Acclimatisation to cold in man induced by frequent scuba diving in cold water. *J Appl Physiol* 24 : 177-181, 1968.
32. Yoshimura H. : Acclimatisation to heat and cold, chap. 5. In : Yoshimura H., Ogata K., Itoh S. (eds.) : Essential problems in climatic physiology. Nankodo, Kyoto, pp 61-106, 1960.

Human adaptability to cold

L. Janský

in collaboration with

J. Heller, V. Hošek, H. Janáková, I. Lesná, J. Parížková, P. Šrámek,
M. Šimecková, B. Ulicný, S. Vybíral, V. Zeman

Department of Comparative Physiology, Faculty of Science, Charles University,
Prague, Czech Republic

Introduction

Studies on cold adaptation in man have a long history. Yaglou (15) in 1927 was the first to show that the comfort environmental temperatures for humans were lower during winter than during summer. Over the next 70 years physiological mechanisms responsible for cold adaptation of man have been studied intensively in several laboratories. Works of O. Edholm, A. Burton, T.R.A. Davis, J. LeBlanc, S. K. Hong, S. M. Horvath, H. Yoshimura, K. Bruck, J. Bittel, A. Young and others contributed significantly to clarification of this problem. However, in spite of the enormous effort the principle mechanism of cold adaptation has not been fully described yet. Surprisingly, neither a clear-cut review summarising all the data so far obtained is available. Some aspects of the problem were reviewed by Davis (3), Hammel (4), Bittel (1) and Young (16). This presentation is aimed to summarise our 10 years experience with the subject. The main findings have been published already (6, 7, 8, 14, 10, 13).

As evident from the Newton's law of cooling all homeotherms, including man, living at temperatures below 30 °C tend to lose heat. To maintain a constant body temperature they must either compensate the increased heat loss by the increased heat production within the body, or they must introduce mechanisms preventing heat loss from the body. Consequently, the survival limits in the cold depend either on capacity of thermoregulatory heat production, or on efficiency of physiological functions affecting insulation. Thus, the *heat economy mechanisms* are to be modified in the first place to achieve cold adaptation.

Theoretically, three thermoregulatory adjustments may take place during the adaptational process (Figure 1):

1. *hypothermic adaptation* due to lowering the thermoregulatory set point, may decrease the temperature gradient between body and environment
2. *insulative adaptation* due to subcutaneous fat or due to more efficient vasoconstriction may enlarge the thermoneutral zone
3. *metabolic adaptation* due to nonshivering thermogenesis may increase the total capacity of thermoregulatory heat production by complementing shivering.

So far, there is no consent as to which extent these three mechanisms participate in cold adaptation of man. To clarify this problem, extensive studies on humans subjected to repeated cold water immersions (14 °C, for 1 hour, 3 times a week, for a period of 4 - 6 weeks) and on polar swimmers, professionally trained to swim in the cold water, were performed in our laboratory. Cold sensation, metabolic rate, deep body and skin

temperatures, heart rate, blood pressure, plasma levels of catecholamines were followed in these experiments.

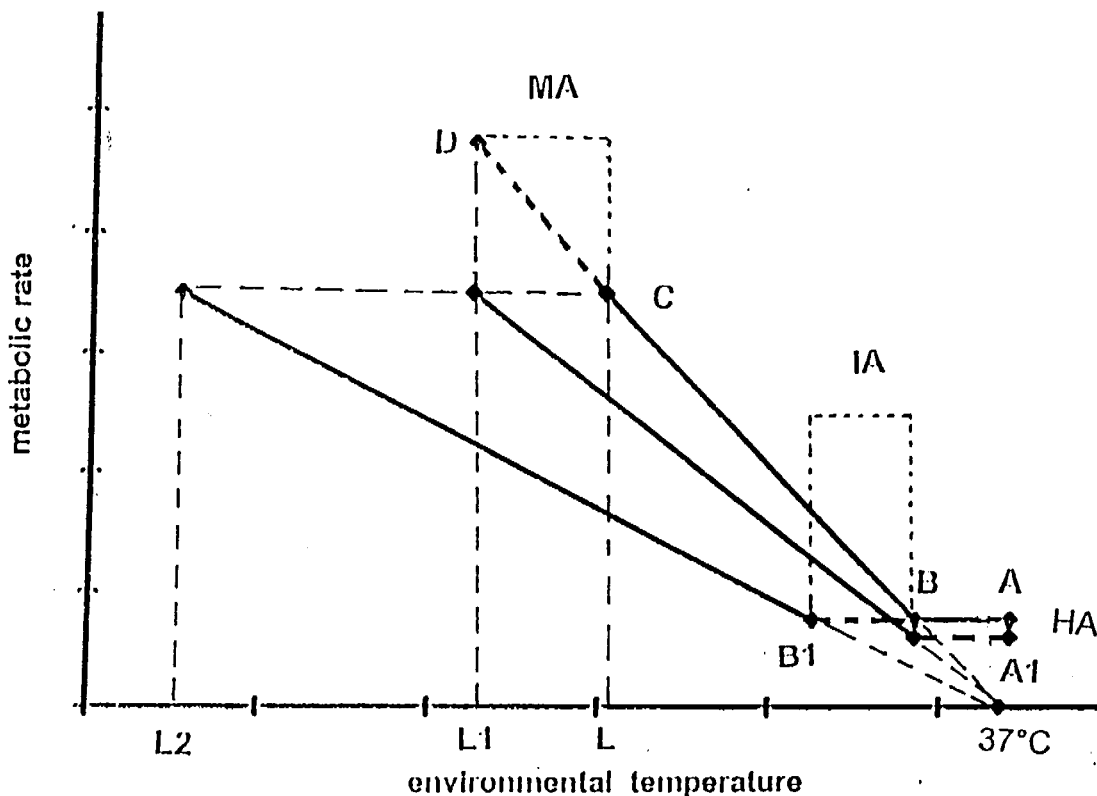


Figure 1. Scheme of metabolic (MA), insulative (IA) and hypothermic (HA) types of cold adaptation (5)

Results and discussion

Our data show that after 4 - 6 weeks of repeated cold water immersions the cold adapted subjects became less sensitive to cold stimuli (Figure 2) and exhibited less shivering (Figure 3) (6). This was due to resetting of the threshold body temperature for induction of cold thermogenesis to lower body temperatures (Figure 4). This process developed gradually and was evident after few immersions already. At the end of the adaptational process the thermoregulatory set point was about 1 °C lower than in controls. Evidently, this modification can be classified as an hypothermic type of adaptation.

Furthermore, cold adapted subjects revealed greater peripheral vasoconstriction, as indicated by lowered skin temperatures (Figure 3). Also a nonsignificant, but consistent, trend for accumulation of subcutaneous fat (Figure 5) was detected (6). Thus, insulative mechanisms of cold adaptation may also take place in humans. It is presumed that longer lasting cold exposures might strengthen the relative importance of the insulative type of adaptation.

In contrast to that, the total metabolic capacity due to muscular work (14) and the capacity of noradrenaline thermogenesis were not changed (8), indicating that these functions do not represent a basis for a metabolic type of adaptation. Adrenaline thermogenesis was not studied in these experiments. These data are in consent with previous observations of Bruck (2), Davis (3), Young (17), Kurpad (9) and others.

Studies on polar swimmers also indicated existence of insulative and hypothermic types of adaptation in humans (11). Polar swimmers, when exposed to cold, showed a lowered threshold for shivering and lowered skin temperatures. Heart rate and systolic

blood pressure were also lowered (11). After infusion of catecholamines a more efficient vasoconstriction in fingers was observed (Figure 6).

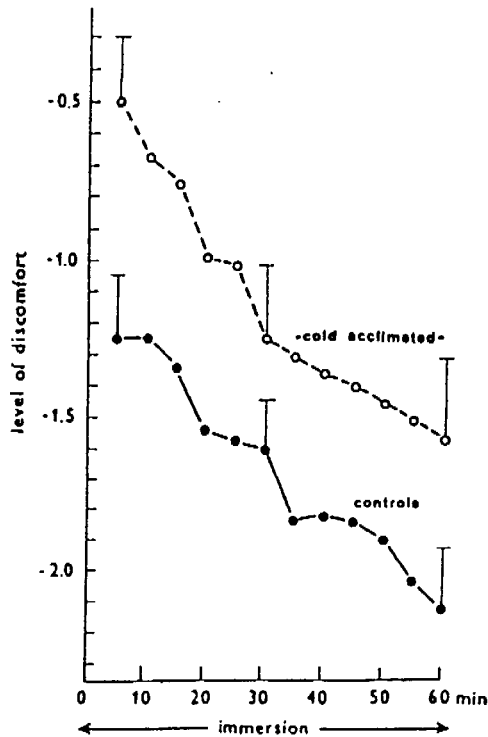


Figure 2. Changes in level of discomfort in control and cold adapted subjects during cold water immersion (6)

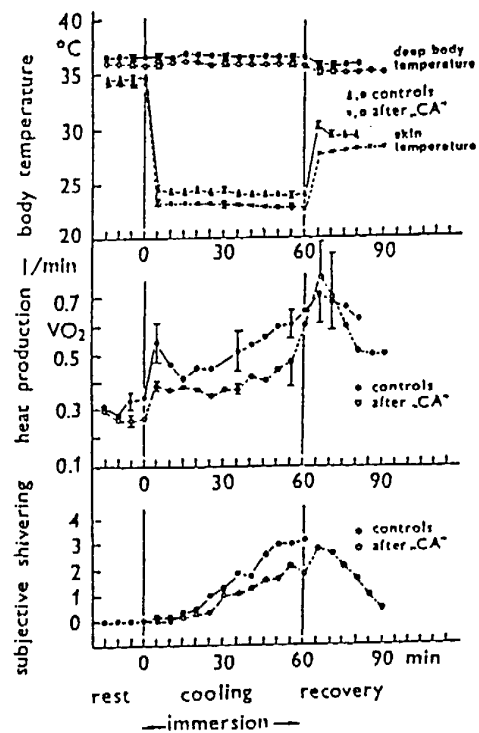


Figure 3. Changes in body temperatures, metabolic rate and subjective shivering in control and cold adapted subjects during cold water immersion(6)

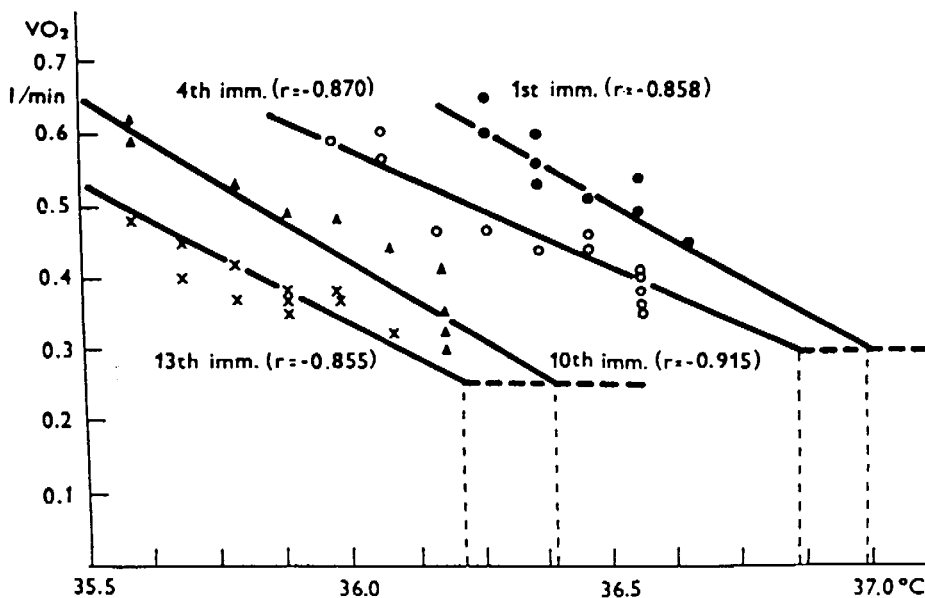


Figure 4. Relationship between deep body temperature and cold thermogenesis during the time course of cold adaptation in subjects repeatedly immersed into the cold water (6).

Additionally, these studies revealed that in polar swimmers the thermogenic action of adrenaline was potentiated by 90 %, compared to controls, while noradrenaline thermogenesis, similarly as in subjects exposed to repeated cold water immersions in the laboratory, was not affected (Figure 7) (10). Thus, the existence of the metabolic

type of adaptation due to potentiation of the capacity of cold thermogenesis was also established in humans.

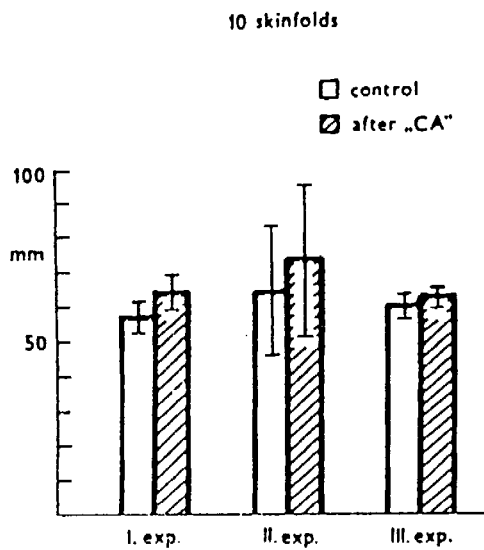


Figure 5. Average skinfold thickness in control and cold adapted subjects in 3 separate experiments (6)

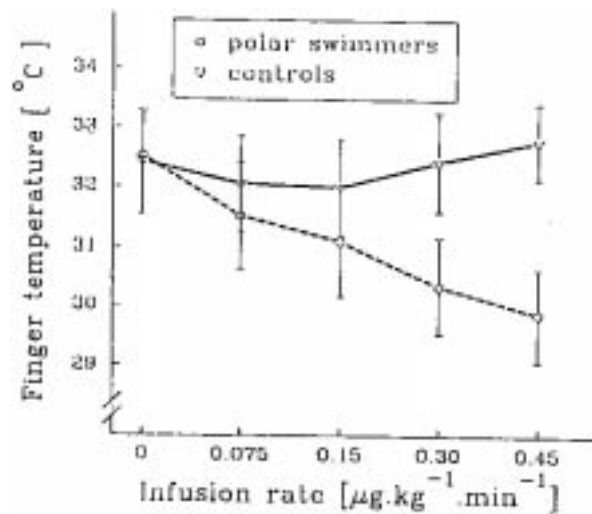


Figure 6. Changes in finger skin temperatures after infusion of different doses of separate adrenaline in controls and polar swimmers (11)

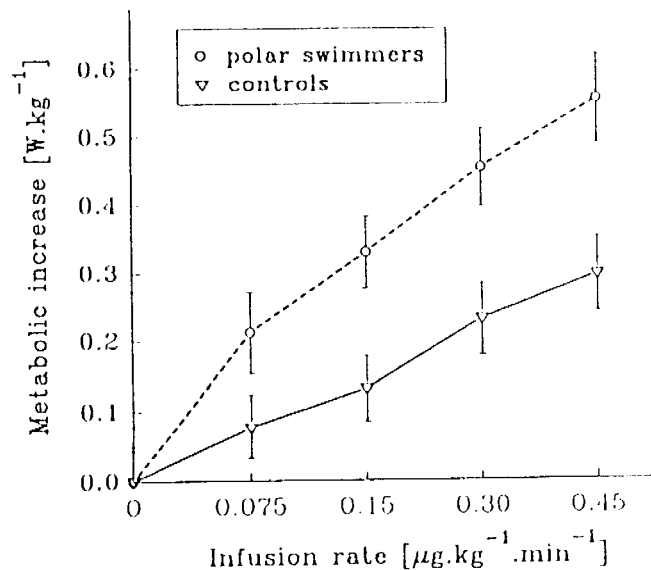


Figure 7. Metabolic response after infusion of different doses of adrenaline in controls and in polar swimmers (10).

To define participation of nonshivering thermogenesis and the role of individual adrenergic receptors in the metabolic response to cold in control subjects, a beta blocker - propranolol was applied per os in other experiments. It was found that the non-specific blockade of beta adrenergic receptors lowers cold thermogenesis by 60 - 20 % depending on the time spent in the cold (13). Evidently, some amount of nonshivering thermogenesis, mediated by beta adrenergic receptors, is already present in nonadapted humans.

Cold adaptation further increases the role of adrenergic thermogenesis in the metabolic response to cold. It should be mentioned, however, that although the metabolic response to adrenaline was clearly potentiated in polar swimmers, the blood

levels of adrenaline in cold exposed subjects were rather lowered (7, 11). This may indicate an increased activity of adrenergic receptors after cold adaptation.

Since in animals the noradrenaline nonshivering thermogenesis located in the brown fat is mediated mostly by alfa 1 and beta 3 adrenergic receptors (18), these findings support the view that the catecholamine thermogenesis in non - cold adapted man is produced outside of the brown fat, probably in muscles and in the white fat (12).

Evidently, all possible types of adaptation (hypothermic, insulative, metabolic) may occur in man. It is felt, that manifestation of individual types of adaptation may rather depend on the time course of the adaptational process than on the intensity of the adaptational stimulus. This view should be confirmed by further studies, however.

On the basis of above mentioned experiments the survival value of individual types of adaptation has been evaluated. Data indicate that the metabolic type of adaptation (due to potentiation of adrenaline thermogenesis) may shift the survival limit downwards to lower environmental temperatures by 5 °C. Hypothermic - insulative type of adaptation can save about 20 % of energy expenditure during one hour cold water immersion and enlarge the survival time, accordingly (6).

References

1. Bittel J. The different types of general cold adaptation in man. *Intern J Sports Medicine* 1992; 13: S172-S175.
2. Bruck K, Baum E, Schwennicke HP. Cold-adaptive modifications in man induced by repeated short-term cold exposures and during 10 day and night old exposure. *Pflugers Arch* 1976; 363: 159-172.
3. Davis TRA. Acclimatisation to cold in man. In: *Temperature-Its measurement and control in Science and Industry*, Reinhold Publ Corp, New York, 1963; 3: 443-452.
4. Hammel HT. Terrestrial animals to cold: recent studies on primitive man. In: *Handbook of Physiology, Section 4, Adaptation to the Environment*, Dill et al. eds., Wilber, Washington, DC, 1964: 413-434.
5. Janský L. Adaptability to cold: from mouse to man. In: *Thermal Physiology 1997*, Nielsen-Johannsen B, Nielsen R, eds., Copenhagen 1997: 163-170
6. Janský L, Janáková H, Ulicný B, Šrámek P, Hošek V, Heller J, Parizková J. Changes in thermal homeostasis due to repeated cold water immersions. *Pflugers Arch*, 1996; 32: 368- 372.
7. Janský L, Šrámek P, Šavlíková J, Ulicný B, Janáková H, Horký K. Change in sympathetic activity, cardiovascular functions and plasma hormone concentrations due to cold water immersion in man. *Eur J Appl Physiol* 1966b; 74: 148-152
8. Janský I, Vybíral S, Štich V, Šrámek P, Kvítek J, Lesná I, Šimecková M. Human humoral thermogenesis. *Ann N Y Acad Sci* 1997; 813: 689-696.
9. Kurpad AV, Khan K, Calder AG, Elia M. Muscle and whole body metabolism after norepinephrine. *Am J Physiol* 1994; 266: E877-E884.
10. Lesná I, Vybíral S, Janský L, Zeman V. Human nonshivering thermogenesis. *Am. J. Physiol* submitted for publication.
11. Lesná I. Hormonal thermogenesis in humans. PhD thesis, Charles University, Prague, 1998.
12. Simonsen L, Bulow J, Madsen J, Christensen NJ. Thermogenic response to epinephrine in the forearm and abdominal subcutaneous adipose tissue. *Am J Physiol* 1992; 263: E850-855

13. Šimecková M, Lesná I, Vybíral S, Janský L, Šrámek P. Effect of propranolol on thermoregulatory responses of cold exposed humans. *J Physiol* 1998: in press.
14. Šrámek P, Heller J, Novotný J, Ulicný B, Janský L. The efficiency of sportsmen before and after passing the programme of cold-acclimation. *Pracov. Lék.* 1996: 48: 236-239.
15. Yaglou CP. Temperature, humidity and air movement in industries. *J Ind Hyg Toxicol.* 1927: 9: 297.
16. Young A. J. Homeostatic responses to prolonged cold exposure: human cold acclimatisation. In: *Handbook of Physiology, Section 4, Environmental Physiology*, Fregly MJ, Blatteis CM, eds., 1996: 419-438.
17. Young, A. J., Muza, S. R., Sawka, M. N., Gonzalez, R. R., Pandolf, K. B. Human thermoregulatory responses to cold air are altered by repeated cold water immersions. *J Appl Physiol*, 1986: 60: 1542-1548
18. Zhao Jin. Adrenergic receptors regulating cAMP generation and thermogenesis in isolated brown adipocytes. PhD thesis, Stockholm Univ, 1997

Thermodynamics and physiological mechanisms of heat production after acclimatisation to cold

K. P. Ivanov

I. P. Pavlov Institute of Physiology, Russian Academy of Sciences, St. Petersburg, 199034, Russia

Energy consumption is the main indicator and the main condition of life. The economy of energy is the main law of the living nature. Therefore the possibility of increasing the heat production by a living organism at a relative rest after cold adaptation is a part of fundamental science problem - the origin of heat in a living tissues. Cells use energy, which they receive with food, for performing biological work: chemical synthesis, transfer of ions against electrical and concentration gradient, muscle contractions. At rest all this energy is converted into heat during the biological work. A man of middle weight and age in the absence of hard muscle activity releases about 7538 kJ of heat. What biological work in an organism demands the most high energy expenditure and liberates the most quantity of heat? Almost all the energy which an organism receives with food is used by a cell as the result of ATP hydrolysis to give ADP and P. It is easy to calculate the energy expenditures for this work, as under the so called standard conditions the efficiency of this work according to Albert Lehninger [2] is about 40 %. Consequently, at the scale of the whole organism of man only 3015 kJ from the day energy expenditure of 7538 kJ will be "accumulated" in ATP, and 4523 kJ will turn into heat during the work of the ATP synthesis. The hydrolysis of ATP releases a very small amount energy - about only 34 kJ per mole ATP. Consequently, to obtain energy from ATP at a rate 3015 kJ per day it is necessary to synthesize and subject to hydrolysis $3015 : 34 = 90$ moles of ATP. The mass of a mole of ATP is 506 g. Thus a human organism synthesized and hydrolyzed about 40 - 50 kg ATP per day.

But the calculation of the heat balance is not finished with this. The matter is that during the ATP hydrolysis and during any work about 50 % of energy turns into heat in addition. Consequently, from 7538 kJ of the day energy expenditure only 1508 kJ turns into different biological work immediately. Such is the main heat source in a living organism [1].

These simplest calculation allow us to make important conclusions. First, the value of heat production depends not only on the intensity or the volume of the work, performed in organism, but to a great extent on the efficiency of the work. Second, the variations in the efficiency of any biological work can be the physiological mechanism of regulating the heat production. The heat production after cold adaptation increases with the help of this mechanism. We will try to prove it.

We registered the electrical activity and temperature at the same point site of the animal skeletal muscle with the help of highly sensitive devices. The animals (rats) were not anaesthetized and practically not fixed. The animals from time to time changed their

posture, the muscle tone, winced from an occasional noise etc. These short periods of contractile activity of muscle were registered with the highly sensitive electromyograph and special electronic integrator, which summed up the electromyogram by the area of biopotentials per unit time. The variations in muscle temperature were registered continuously (with sensitivity 0.002 °C/mm on paper ribbon). The examination of several hundreds of such occasional events allowed a conclusion to be made that after adaptation to cold the heat production of muscle contractile activity could increase by a factor of about 1.5 - 2. After noradrenalin injection - by a factor of 2.5 - 3.

As follows from our experiments at the absence of muscle contractile (electrical) activity the heat production in skeletal muscles of the adaptive and control animals do not differ from each other. The higher is the activity, the greater are the temperature differences. After injection of noradrenaline the heat production resulting from muscle contractions increases abruptly in the adapted animals and scarcely changes in the control animals. These facts suggest that cold adaptation abruptly decreases the efficiency of the muscle contractions. In such a case it can be understood, why after cold adaptation even in a very weak muscle cold shivering gives rise to an abrupt increase in the heat production of an organism [1].

It can be supposed, however, that the abrupt increase of the temperature in muscles of cold adapted animals is associated with other factors. For example, the possibility intensifying the muscle circulation, specific, changes in muscle innervation etc. Hence we made experiments with a direct irritation of the muscles of the isolated diaphragm from cold adapted and from control rats. The diaphragms of cold adapted animals were shown to release by about 70 % more per 1 g of the developed force under standard irritation than control animals; after adding noradrenaline (8 ng/ml) to the nutritious solution - by 110 - 160 % more. These specific features show themselves only during contractile activity.

It is necessary once more to attract the attention to the fact that the increase in the heat production was calculated per unit of tension (contractile force) of the muscle. The difference between the control and adapted animals show themselves only during muscle contractions, that is at work.

These relationships show themselves most clearly when studying an isolated heart, because the mechanical work of the heart can be determined with greatest accuracy.

The calculation showed that after adaptation to cold the isolated rat heart increases its heat production per unit of mechanical work by 30 - 40 %. The greater the mechanical work, the greater is the difference between cold adapted and control animals. Arrested hearts of control and cold adapted animals have rather high but almost equal levels of energy expenditure.

Our further experiments and their analysis showed that the mechanism of decreasing the efficiency of different biological work after adaptation to cold consists of uncoupling of oxidation and phosphorylation in mitochondria and decreasing the efficiency of the chemical work of ATP synthesis. Measurements made using isolated cells have shown that a significant contribution to heat production is made by “a futile cycle” of proton pumping and proton “leak” across the mitochondrial inner membrane [3]. This is a universal mechanism. After adaptation to cold it allows the heat production to be abruptly increased with minimal cold shivering. It also forms the basis of increasing the heat production under the action of thyroxin, noradrenaline and other hormones, in brown adipose tissue, during fever. It seems to be the reason for increased heat production per unit of body mass in very small mammals.

These facts allow us to say that physiological adaptation to cold decreases the efficiency of muscle work at low environmental temperature as it results in an

increasing energy consumption. Let us note that polar animals never adapt to cold at the expense of physiological mechanisms. They adapt only at the expense of increasing their heat insulation. Such an adaptation costs nothing from the point of view of energy.

References

1. Ivanov K.P. Thermoregulatory chemical metabolism and muscle work efficiency. *J. Thermal. Biol.* 1989 : 14; 1- 18.
2. Lehninger A.L. *Biochemistry*. Worth publishers, INC., New York. 1972.
3. Porter R.K., Brand M.D. Body mass dependence of H⁺ leak in mitochondria and its relevance to metabolic rate. *Nature* 1993 : 362; No 6421; 628-630.

Seasonal characteristics of physiological and subjective thermal loads in Japanese young adult males during acute cold exposure

S. Sawada

Division of Work Stress Control, National Institute of Industrial Health, Kawasaki, Japan

Introduction

In Japan, the refrigerated warehouse industry has been growing with the development of the frozen food chain stores. The temperatures in the work environment are maintained always below the freezing point all the year round, regardless of the large seasonal changes in outdoor climates of Japan. The cold-warehouse workers are reported to feel stressful particularly in summer. However, little is known about the seasonal characteristics in their physiological thermal loads. The occupational cold exposure limits which are currently recommended by ACGIH and ISO have also little concern for the possible seasonal factors (1, 3). The primary objective of this study is, therefore, to examine the seasonal characteristics in thermo-physiological, cardiovascular and subjective thermal loads induced by cold stress in Japanese young adult men. The second objective is to discuss whether any seasonal consideration is necessary for the current cold exposure limits recommended by ACGIH and ISO.

Subjects and Methods

Subjects were twenty-one Japanese young men from the ages of 21 to 30. They rested on chairs wearing only shorts under thermoneutral condition of 30 °C for 1 hour. After that period, they were exposed to an acute cold air of 10 °C for 1 hour. The experiments were conducted for the same subjects in both summer (July, August, and early September) and winter (January, February, and early March). The average ambient temperatures during the period when the experiments were conducted were 29.2 °C in summer and 5.8 °C in winter. During each experiment, rectal temperature was measured by a thermistor probe inserted 10 cm into the rectum. Skin temperatures were taken from 12 sites of the body surface with thermistors. Mean skin temperature was calculated by Hardy/DuBois 12-point method. Metabolic heat production was determined by measuring oxygen consumption and carbon dioxide production (MMC4400tc, SensorMedics). Blood pressure was recorded by a portable blood pressure monitor (TM-2425, A&D). Stroke volume, cardiac output, and heart rate were measured by impedance cardiography (NCCOM3, BoMed). Total peripheral resistance was calculated from the values of blood pressure and cardiac output. For assessing subjective thermal loads, thermal discomfort and thermal sensation was rated by a 4-point scale (1:comfortable, 2:slightly uncomfortable, 3:uncomfortable, 4:very

uncomfortable) and a 9-point scale (1:very hot, 2:hot, 3:warm, 4:slightly warm, 5:neutral, 6:slightly cool, 7:cool, 8:cold, 9:very cold), respectively.

Results and Discussion

Thermoregulatory responses:

Rectal temperature showed minimal fall with no seasonal difference during the first 30 minutes of cold exposure. However, during the latter 30 minutes of exposure, the fall in rectal temperature became significantly smaller in winter. Metabolic heat production during the cold exposure slightly increased in summer, whereas it rapidly increased in winter. During the latter half of cold exposure, the increase in metabolic heat production became significantly greater in winter. Mean skin temperature in winter was significantly lower than summer during the first half period, but thereafter the seasonal difference disappeared. These results suggest that during the first half of the cold exposure when the body cooling is slight, an insulative type of adaptive change may occur in winter, but that during the latter half period when the body cooling becomes excessive, an metabolic type of adaptive change may occur in winter. These adaptive changes in winter may contribute to maintain the body temperature homeostasis during the cold exposure.

Cardiovascular responses:

Heart rate significantly decreased during the cold exposure regardless of season. During the latter half of exposure, heart rate tended to be higher in winter. But the difference between summer and winter was not statistically significant. Stroke volume tended to remain constant in summer whereas it tended to increase in winter. But the difference between the two seasons was also not significant. Consequently, cardiac output during the cold exposure remained constant in winter and it decreased slightly in summer. But the seasonal difference was also not significant. Mean blood pressure significantly increased during the cold exposure regardless of season, but the increase in mean blood pressure became significantly greater in summer during the latter half of cold exposure. Total peripheral resistance also significantly increased during the cold exposure regardless of season, but the increase in total peripheral resistance became significantly greater in summer during the latter half of cold exposure. These results suggest that the cardiovascular loads become greater in summer during the latter half of the cold exposure when the body cooling becomes excessive.

Subjective thermal loads:

The average subjective thermal responses tended to change from “comfortable and slightly warm” before the cold exposure to “very uncomfortable and very cold” at the end of cold exposure. During the first half of cold exposure, these subjective thermal loads had no clear seasonal differences. But during the latter half period, these loads tended to be significantly alleviated in winter.

Seasonal consideration for the occupational cold exposure limits:

ACGIH has recommended a rectal temperature of 36 °C as the highest admissible body cooling (1). On the other hand, ISO has recommended a mean skin temperature of 30 °C as the highest admissible level (3). The corresponding index is well known as DLE_{minimal}.

In the present study, the average rectal temperature in summer and winter decreased to only 37.08 °C and 37.12 °C at the end of cold exposure, respectively. This body core cooling level is much higher than 36 °C, which is the criteria recommended by ACGIH. Nevertheless, as shown above, there were the significant seasonal differences in the thermal loads during the latter half period of cold exposure. This indicates that if the criteria of ACGIH is adopted, Japanese young adults are liable to have the greater physiological and subjective thermal loads in summer.

As for ISO, the time limit for cold exposure (DLE_{minimal}) corresponding to the present experimental condition (Air and mean radiant temperatures=10 °C, Relative humidity=40-50 %, Air velocity=0.1 m/s, Metabolic heat production=45-55 W/m², Resultant clothing insulation=0.1 clo) can be estimated at 21 minute by using the IREQ computer program (2). As mentioned above, most of the measured variables had no seasonal differences during the first 30 minute of cold exposure. Furthermore, analysing the thermoregulatory, cardiovascular and subjective responses to a decrease in mean skin temperature during cold exposure showed that these physiological and subjective loads have no marked seasonal differences at mean skin temperature above 30 °C, which is the physiological criteria of ISO's cold exposure limit. Therefore, it appears that within ISO's cold exposure limit, there should be no serious seasonal differences in the thermal loads under the present experimental condition.

Summary

1. During the first 30 min cold exposure of 10 °C when the body cooling is slight, no clear seasonal differences can be found in the physiological and subjective responses except for mean skin temperature.
2. However, during the latter 30 min cold exposure when the body cooling becomes excessive, a significantly greater increase in metabolic heat production can be found in winter.
3. The improvement of this metabolic response in winter coincide with the alleviation of cardiovascular and subjective thermal loads, as well as the diminution of body core temperature decrease.
4. Therefore, this seasonal adaptive change of metabolic type in winter may be beneficial for mitigating the thermal loads, as well as for maintaining the body temperature homeostasis when the cold exposure is prolonged and the body cooling becomes excessive.
5. These seasonal characteristics of Japanese young men suggest that some seasonal consideration may be necessary for ACGIH's cold exposure limit and its physiological criteria, but not for ISO's. Because ACGIH aims at the prevention of an excessive body core cooling, while ISO aims at the prevention of a slight body surface cooling.

References

1. Cold stress. 1997 TLVs and BEIs (Threshold limit values for physical agents in the work environment), ACGIH, 1997: 125-133,
2. Holmér I, Nilsson H. Computer program for calculation of required clothing insulation (IREQ) 9208046, version 1.4, 1992
3. ISO/TR-11079. Evaluation of cold environments - Determination of required clothing insulation (IREQ), International Standards Organisation, Geneva, 1993

Inhalation of cold air increases the number of inflammatory cells in the lungs of healthy subjects

D. Gavhed, G. Tornling¹, L. Palmberg, C. Müller-Suur, I. Holmér, K. Larsson

Dept. of Occupational Medicine, National Institute for Working Life, Solna, Sweden

¹Dept. of Medicine, Karolinska Institute, Stockholm, Sweden

Abstract

Inhalation to cold air induces bronchoconstriction in asthmatic patients and a transient increase in bronchial responsiveness in healthy subjects. Long term exposure to cold air may induce a chronic asthma-like condition in healthy subjects as has been demonstrated in cross-country skiers. The aim of the present controlled study was to assess whether a short time exposure to cold air induces the airway inflammation.

Bronchoalveolar (BAL) and nasal lavages were performed after exposure to cold air (-23 °C) and normal indoor air (+22 °C) during a light, intermittent work for two hours in a cross over design in eight healthy, non-smoking, subjects. Inflammatory cell number, lymphocyte activation markers, albumin and interleukin-8 (IL-8) in lavage fluids were analysed.

The number of granulocytes in BAL fluid was higher in all subjects after cold air exposure [6.8 (4.4 - 8.2)·10⁶ cells/l, median (25th - 75th percentiles)] compared with normal indoor air exposure (p=0.01). The number of alveolar macrophages in BAL fluid was also significantly higher after cold air exposure (p<0.05). No signs of lymphocyte activation in bronchoalveolar lavage fluid was found. Cold air did not influence the number of inflammatory cells or the concentration of albumin and IL-8 in nasal lavage fluid.

Exposure to cold air for two hours increases the number of inflammatory cells in the lower airways in healthy subjects. It is possible that this only reflects an impaired adhesion of these cells to the airway epithelium. The importance of this finding and possible links to the development of asthma or an asthma-like condition in heavily exposed cross-country skiers needs to be further elucidated.

References

1. Larsson, K, Tornling G, Gavhed, D, Müller-Suur, C, Palmberg, L. Inhalation of cold air increases the number of inflammatory cells in the lungs in healthy subjects. *Eur Respir J* 1998; (in press).

Cold stress and cardiovascular reactions

K. J. Collins

University College Hospitals, London, UK

The maintenance of body temperature homeostasis in cold environments relies on efficient functioning of the cardiovascular system. The system transports metabolic reactants as well as heat, and its responses differ therefore during cold exposure at rest and in exercise. Cold-induced vasoconstriction has important physical effects on the heart increasing both the after-load by increased peripheral resistance and pre-load by central fluid shunting. With increasing cold stress, therefore, cardiac strain increases, which does not usually trouble people with a normal cardiovascular system and functional reserve. However, cold may be crippling for those with reduced cardiovascular function such as those with heart disease and the elderly with declining cardiac reserve.

In the central context of work in low ambient temperatures, the effects of cold need to be considered according to the circumstances of the exposure e.g. the intensity, duration and possible adaptive mechanisms. Seasonal differences in the effects of cold on cardiovascular morbidity and mortality are well-documented and involve consideration of confounding factors such as age, lifestyle, socio-economic and nutrition. Essential differences in cardiovascular responses are dependent on the cold exposure phase, whether there are trigeminal reflexes associated with rapid cold air movement, or full or partial immersion in cold water with attendant hydrostatic effects on the circulation. Exercise in the cold may seriously compromise an ailing cardiovascular system just as cold may have an adverse effect on physical performance. Evidence of the increased stress on cardiovascular performance comes from epidemiological findings on cardiac deaths, myocardial infarction and clinical symptoms of cardiac decompensation. It is important to know the extent and nature of harm a cold environment may inflict on the heart and circulation and what factors may increase or reduce those effects.

Effects of cold at rest

In conscious individuals, the initial response to cold is peripheral vasoconstriction, with increased skin nerve sympathetic activity, blood pressure, shivering, oxygen and energy consumption and cardiac work. With mildly cold conditions (6 - 12 °C still air) and no activity, blood pressure rises over a period of 2 h (1). The association of cardiovascular variables is particularly strong between systolic blood pressure and core temperature. Repeated exposure to 6 °C, 4 h per day, for 10 days does not appear to confer any appreciable cold-adaptive changes in blood pressure or thermoregulatory responses. Age-differences in response to cold appear to be related to initial higher resting blood pressure, reduced baroreflex sensitivity and the slightly lower body temperature induced by cold.

Short term exposure to specific cold stimuli may evoke specific cold pressor responses such as the cold pressor, facial cooling or, with immersion, the diving

response. They are powerful reflexes operating in more extreme conditions of cold stress and arousal, and in which case may override the arterial baroreflexes (2). Immersion of the hand in 4 °C cold water leads to an immediate increase in muscle and skin sympathetic nerve activity (14), tachycardia and raised blood pressure, presumably evoked from cutaneous cold and/or pain receptors. Facial cooling differs from the diving response in that apnoea is not usually an important component, but unlike the cold pressor response there is a marked bradycardia accompanying the peripheral vasoconstriction. The afferent limb of the facial cooling response is the trigeminal nerve and unlike most autonomic cardiovascular sensory inputs terminates in the trigeminal sensory nucleus rather than the solitary tract nucleus. It is suggested that cold stimulation of the face initially produces a vagal reaction and secondarily a sympathetic response. In common with other non-baroreceptor inputs inducing a pressor effect of muscle nerve sympathetic activity, such as isometric muscle work, cold pressor and the diving response, bladder distension is another potent stimulus (3) which may frequently be an indirect cause of raised blood pressure in the cold.

Effects of exercise in cold environments

Mean arterial blood pressure, pulse pressure, heart rate and cardiac output increase when a normal person exercises which ensures that the increased metabolic demands of the exercising skeletal muscles are met by appropriate increases in skeletal muscle blood flow. The major disturbance on the cardiovascular system during exercise, however, is the great decrease in total peripheral resistance caused by metabolic vasodilator accumulation and decreased vascular resistance in active skeletal muscle. Although mean arterial pressure is above normal during exercise, the decreased total peripheral resistance causes it to fall below the elevated level to which it would otherwise be regulated. Cutaneous blood flow may increase during exercise despite a generalised increase in sympathetic vasoconstrictor tone because thermal reflexes can override pressure reflexes in the special case of skin blood flow control. The skeletal muscle pump and the respiratory intrathoracic pump also promote venous return during exercise. Mean central venous pressure does not change much, if at all, during strenuous exercise because both cardiac output and venous return are shifted upwards during exercise.

During exercise in low ambient temperatures, the influences of cold are most evident during the first 10-20 min, before the increased heat production has induced dilatation of the peripheral vessels. Thermogenesis due to shivering and exercise are not additive because forcible voluntary movements tend to inhibit shivering. In studies of semi-nude subjects working in 0 °C and 10 °C environments, shivering was observed when work was performed at 300 kpm/min with oxygen uptake higher at 0 °C. When work was conducted at 900 kpm/min, oxygen uptake was identical in the two environments (6). It would appear that a critical level of heat production is required before the influence of cold-induced shivering can be counteracted. Oxygen uptake for men working at a fixed load for one hour in 25 °C was found to be 1.2 litres/min and in -29 °C it was 1.54 litres/min (7). Measurement of cardiac output and heart rate during various levels of exertion in environments of 22.5 °C and 5.5 °C showed that for a given rate of work, cardiac output was little different and heart rate slightly lower in the cold environment (Figure 1).

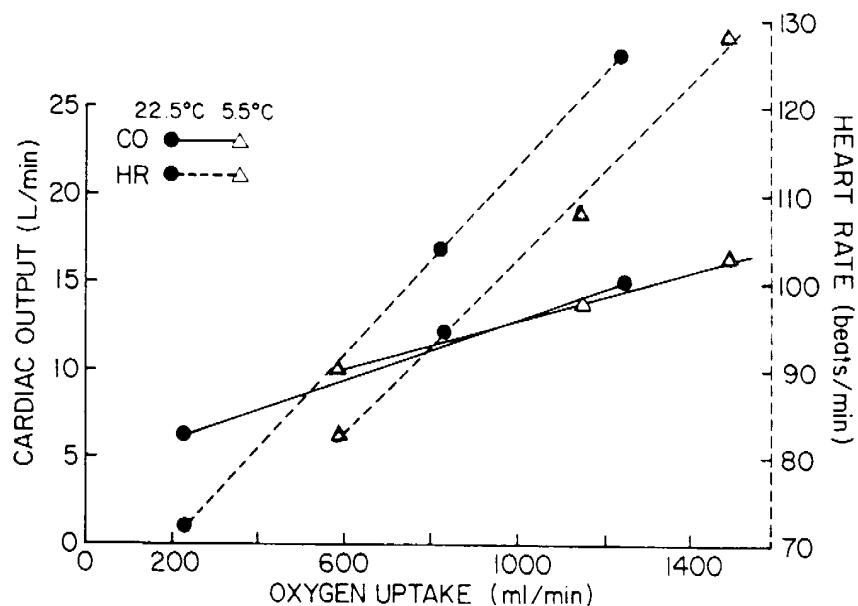


Figure 1. Effects of different levels of exertion in 22.5 °C and 5.5 °C ambient conditions on cardiac output and heart rate (From 7).

Extreme cold

The cardiovascular system only works at maximum efficiency within a limited body temperature range and if core temperature falls to hypothermic levels cardiovascular function begins to deteriorate markedly. In hypothermia, blood pressure, heart rate and cardiac output fall in a linear and progressive manner. Oxygen consumption is reduced during cooling by about 7 % per degree reduction in body temperature. However, cardiac output falls more rapidly and the lack of synchronisation results in an ischaemic acidosis. Heart rate may rise in the early stages of acute cold exposure partly in response to the demands of shivering muscle and partly through sympatho-adrenal stimulation. As body temperature falls in hypothermia, cardiac arrhythmias become increasingly common and the likelihood of ventricular fibrillation increases.

Cold stress and cardiovascular morbidity

The cardiovascular adjustments to cold exposure have been shown to increase cardiac and circulatory strain. Cold is therefore a risk factor for individuals with cardiovascular disease which is apparent from the increased morbidity and mortality. Vigorous exercise in cold weather can cause a marked rise in arterial blood pressure which in turn may lead to rupture of atheromatous plaques in the coronary circulation. In the long term, cold weather is associated with increases in hypertensive disease, ischaemic heart disease, cerebrovascular disease and cardiac failure.

Angina pectoris

Exercise in a cold environment, e.g. when shovelling snow, is considered to be particularly stressful to patients who suffer from effort angina. The mechanism by which cold produces angina remains controversial. An elevation of heart rate-blood pressure product, produced for example by a cold pressor test, increases cardiac work

i.e. myocardial oxygen demand, which is not matched by an equivalent increase in coronary blood flow (12). The discrepancy between myocardial oxygen demand and supply appears to be the basis for angina in these circumstances.

Less severe cold stimuli than the cold pressor test can also provoke angina. When coronary disease patients inhale cold air (-20 °C), some experience typical angina chest pain even though there is only minimal change in blood pressure or heart rate, no increase in myocardial oxygen consumption, no change in coronary flow, and no angiographic evidence of coronary artery constriction. It is suggested that cold air constricts minute coronary collaterals or other vessels specifically affecting blood flow to potentially ischaemic regions of the myocardium (5).

Exercise performance in cold environments has also been examined in men and with effort angina and a history of cold intolerance (9). During submaximal exercise the rate-pressure product was significantly higher and angina developed at a lower work load when the room temperature was -10 °C rather than +20 °C. Similar results were obtained by inhalation of very cold air (-35 °C) during exercise in an otherwise warm room (+20 °C). Skin cooling, however, was considered to be far more important than the inhalation of only moderately cold air (-10 °C) in stressing the heart, presumably due to greater sympathetic stimulation.

Vasospasm contributes to angina in many, if not most, patients. Endothelial dysfunction is assumed to contribute to the pathogenesis of atherosclerosis and this dysfunction might extend to endothelial dependent vasodilator functions. Thus vasospasm might result from loss of endothelial-dependent dilator function. Exercise and cold pressor testing is found to dilate normal coronary arteries but constricts both minimal and advanced stenotic lesions.

Coronary heart disease

Hospital admissions and deaths from coronary heart disease, stroke and respiratory disease are higher in winter than summer in many temperate countries. There are strong regional associations between cold exposure and high coronary mortality (4). These associations may be causative, indirect or apparent. Excess winter cardiovascular mortality has fallen in Britain in recent years but remains numerically more important than other causes of winter deaths. Disparities in baseline mortality rates, age structure and influenza epidemics are among several factors that may confuse the issue. Further, one of the recent “Eurowinter” study findings (13) indicates that it may not be the absolute winter temperature that is important, for mortality may increase more when there is a given fall in temperature in warmer regions. It was found that protective measures against unseasonal cold appeared to be used less in regions with mild winters.

The excess number of coronary events in cold environments is related to several well-recognised factors: raised blood pressure, hypercoagulability, the effect of vasoconstriction on the myocardium and peripheral blood vessels, and cardio-respiratory interactions. Respiratory diseases may aggravate existing coronary artery disease. Some deaths caused by respiratory disease may be recorded as being due to coronary heart disease. Case control studies suggest that respiratory infection is a risk factor for myocardial and cerebral infarction. A common link may be air pollution which generally increases in winter increasing the likelihood of respiratory disease. Inhalation of small particles of pollutants may cause inflammatory reactions which lead to increasing levels of clotting factors such as fibrinogen and other acute phase proteins. Deaths from bronchitis, especially in the elderly, increased greatly (ninefold) during the

London smog (freezing fog) of December 1952 and there was a parallel threefold rise in deaths from myocardial infarction.

The difference between summer and winter temperatures in Britain results in a difference of about 5 mmHg systolic pressure (10 mmHg in elderly people). Sustained differences of this order are associated with at least 21 % difference in coronary events and at least a 34 % difference in stroke (10). The raised blood pressure alters the ratio of myocardial oxygen supply to demand, and increases ventricular wall stress, cardiac work and oxygen requirements. It also reduces mechanical efficiency and may impair coronary blood flow, particularly if there are fixed stenoses. Plasma concentration of some clotting factors are increased during even mild cold exposure, together with increased platelet count and in vitro platelet aggregation (8). Hypertension itself and the effects on lipid metabolism make abnormal thrombosis more likely and has a potential atherogenic effect (15). Reduced plasma volume and increased blood viscosity in the cold also tend to promote thrombosis. Systolic blood pressure increases more than diastolic so that the pulse pressure is generally increased, although with mild cold there is usually little change in cardiac output or pulse rate. Rises in arterial pressure and pulse pressure increase the forces acting to produce deformation of the blood vessel walls. In the constricted vessels there is increased friction and shear forces. There may be acute or chronic effects and minor damage to the vessel wall may release vasoconstrictor substances such as endothelins (11).

Of the many humoral factors likely to be involved in the chain of actions leading to coronary events, increased catecholamine release in the cold is important. There is a continuing raised level of noradrenaline in plasma during the winter which may be implicated in some of the changes observed. One consequence would be a rise in plasma non-esterified fatty acids which promote platelet activation and induce thrombosis. An additional factor is the increase in circulating adrenocorticoids which may occur as the result of cold exposure, the presence of which increases the vasomotor reactivity to noradrenaline. A large proportion of cardiovascular deaths related to the effects of cold come from the elderly community. They are particularly at risk because of an age-related decrease in intrinsic β -adrenoreceptor sensitivity, higher resting levels of plasma catecholamines, and effector organ changes associated with arteriosclerosis.

References

1. Collins KJ, Easton JC, Belfield-Smith H, Exton-Smith AN, Pluck RA. Effects of age on body temperature and blood pressure in cold environments. *Clin Sci* 1985;69:465-470.
2. Eckberg DL, Sleight P. Human Baroreflexes in Health and Disease. Monographs of the Physiological Society, No 43. Oxford: Oxford University Press, 1992.
3. Fagius J, Karhuvaara S. Sympathetic activity and blood pressure increase with bladder distension in humans. *Hypertension* 1989;14:511-517.
4. Gyllerup S, Lanke J, Lindholm LJ, Schersten B. High coronary mortality in cold regions of Sweden. *J Intern Med* 1991;230:479-485.
5. Hattenhauer M, Neill WA. The effect of cold air inhalation on angina pectoris and myocardial oxygen supply. *Circulation* 1975;51:1053-1058.
6. Hellstrom B, Berg K, Vogt Lorenzen F. Human peripheral rewarming during exercise in the cold. *J Appl Physiol* 1970;29:191-199
7. Horvath SM. Exercise in a cold environment. *Exercise Sports Sci Rev* 1988;19:221-263

8. Keatinge WR, Coleshaw SRK, Cotter F, Mattock M, Murphy M, Chelliah R. Increases in platelet and red cell counts, blood viscosity, and arterial pressure during mild surface cooling: factors in mortality from coronary and cerebral thrombosis in winter. *Brit Med J* 1984;289:1405-1408.
9. Lassvik C, Areskog N-L. Angina pectoris during inhalation of cold air: reactions to exercise. *Brit Heart J*. 1980;43:661-667
10. MacMahon S, Peto R, Cutler J, Collins R, Sorlie P et al. Blood pressure, stroke and coronary heart disease. Part 1. Prolonged differences in blood pressure: prospective observational studies corrected for the regression dilution bias. *Lancet* 1990;335:765-774.
11. Milner P, Bodin P, Loesch A, Burnstock G. Rapid release of endothelin and ATP from isolated aortic endothelial cells exposed to increased flow. *Biochem Biophys Res Commun* 1990;170:649-656/
12. Mudge GH, Grossman W, Mills RM, Lesch M, Braunwald E. Reflex increase in coronary vascular resistance in patients with ischemic heart disease. *New Engl J Med* 1976;295:1333-1337.
13. The Eurowinter Group. Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease and all causes in warm and cold regions of Europe. *Lancet* 1997;349:1341-1346.
14. Wallin BG. Intra-neural recordings of normal and abnormal sympathetic activity in man. In: Bannister R, Mathias CJ, eds. *Autonomic Failure: A Textbook of Clinical Disorders of the Autonomic Nervous System*. 3rd Edn. Oxford: Oxford University Press, 1992: 359-377.
15. Woodhouse PR, Khaw KT, Plummer M, Foley A, Meade TW. Seasonal variations of plasma fibrinogen and factor VII activity in the elderly: winter infections and death from cardiovascular disease. *Lancet* 1994;343:435-439.

Seasonal changes in finger blood flow in urban citizens.

J. Hisdal, R. E. Reinertsen

SINTEF Unimed, Division of Extreme Work Environment, N-7034 Trondheim, Norway

When they are repeatedly challenged, many physiological responses adapt by becoming more effective. Previous studies have demonstrated changes in peripheral blood flow response to low temperature following exposure to extreme cold or seasonal changes (1, 3, 5, 7). The onset and magnitude of cold induced vasodilatation (CIVD) are often used as parameters to investigate changes in finger circulation caused by cold acclimatisation. CIVD is an abrupt increase in finger circulation following cold exposure of fingers. These changes in blood flow are followed by changes in finger skin temperature.

The aim of this study was to investigate whether there are any adaptive changes in finger blood flow in urban citizens living at 63°N and exposed to moderate cold during winter.

Nine healthy male students 23.5 ± 0.6 years old, 178 ± 6.6 cm in height and weighing 73.2 ± 5.6 kg, participated in summer-test (I) in August 1995, winter-test in January 1996 and summer-test (II) in August 1996. Yellow Springs Instruments 409 (YSI 409) thermistors (accuracy ± 0.15 °C) were taped to the pads of each fingertips. Subjects right forearm and hand were then immersed in 7.3 °C water for 45 minutes. Finger temperatures were measured every 15 seconds during the immersion period. Time to rise in skin temperature (TTR) as a consequence of cold-induced vasodilatation (CIVD) (6), mean finger skin temperature (MST_{finger}) and amplitude of the temperature response (AT) were measured.

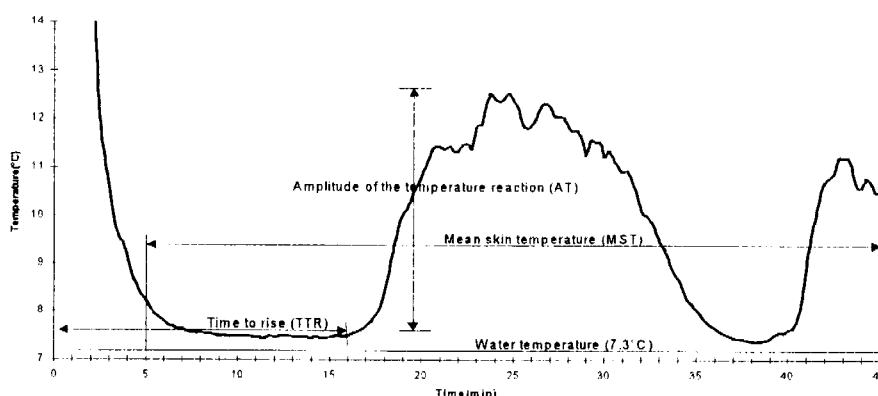


Figure 1. Skin temperature in a finger as a function of time, when the arm and hand are immersed in water at 7.3 °C for 45 minutes. Finger skin temperature before immersion was 33.5 °C.

Figure 1 shows how the finger skin temperature fluctuated in one of our subjects during immersion of the hand and arm in a well stirred water bath at 7.3 °C for 45

minutes. The form of the fluctuations in skin temperature showed individual variations in both shape and amplitude.

Our results demonstrated an increased time to rise in skin temperature and a less pronounced temperature rise upon cold immersion in winter compared with summer. TTR was significantly higher in winter acclimatised students compared with experiments performed the preceding and also the following summer (Table 1). Furthermore, the magnitude of the temperature response, measured as mean skin temperature and amplitude of the temperature response, was significantly less pronounced in winter than in summer (Table 1).

Table 1. TTR, MST_{finger}, AT in summer (I), winter and summer (II), (n=9). Values are given as means \pm SD.

	Summer (I)	Winter	Summer (II)
TTR, minutes	13.44 \pm 4.30	22.43 \pm 5.10 *●	10.13 \pm 2.95
MST _{finger} , °C	9.06 \pm 2.29	8.43 \pm 0.23 *●	9.18 \pm 0.73
AT, °C	2.57 \pm 0.61	1.38 \pm 0.29 *●	2.85 \pm 0.49

Significant difference from summer (I): * = p<0.05

Significant difference from summer (II): ● = p<0.05

The decreased CIVD response during winter probably reflects the defence of core body temperature. Previous studies have indicated that subjects habituated locally to cold, such as fishermen and fish filleters, have an earlier onset and a larger magnitude of cold induced vasodilatation upon cold immersion (4, 8). Such an adaptation results in maintenance of manual tasks that are sensitive to cold. The differences in response between these studies and the present one, is perhaps to be expected, since adaptive mechanisms tend to be specific to the stimulus experienced (2).

Many studies have demonstrated results that indicate adaptation to cold. However, the results from the vast literature on this subject have been so varied that some observers have doubted whether man can adapt to cold at all. Because of effective clothing and housing, our test subjects are rarely exposed to extreme cold during winter. They are, however, exposed to seasonal changes in both ambient temperature and photoperiod, and these could serve as cues for seasonal acclimatisation. Therefore, the observed changes in peripheral vasoactivity measured as differences in the CIVD response between summer and winter could be interpreted as an adaptation resulting from seasonal acclimatisation.

References

1. Brummermann M, Reinertsen RE. Adaptation of homeostatic thermoregulation: comparison of incubating and non-incubating Bantam hens. *J Comp Physiol* 1990;161:133-140.
2. Horwath SM, Howell CD. Organ system in adaptation; the cardiovascular system. In: Dill DB, Adolph EF, Wilber CG (eds.) *Handbook of Physiology: Adaptation to the Environment*. Am Physiol Soc, Washington DC, 1964 pp 153-166.
3. Krog J, Folkow B, Fox RH, Lange Andersen K. Hand circulation in the cold of Lapps and North Norwegian fishermen. *J Appl Physiol*, 1960;15:654-658.
4. Leblanc JA, Hildes JA, Heroux O. Tolerance of Gaspé fishermen to cold water. *J Appl Physiol* 1960;15:1031

5. Leftheriotis G, Savourey G, Saumet JL, Bittel J. Finger and forearm vasodilatory changes after cold acclimation. *Eur J Appl Physiol*:1990:60:49-53.
6. Lewis T. Vasodilatation in response to strong cooling. *Heart* 1930:15:177-181.
7. Livingstone SD. Changes in cold-induced vasodilatation during Arctic exercises. *J Appl Physiol* 1976:40:455-457.
8. Nelms JP, Soper DJG. Cold vasodilatation and cold acclimatisation in the hands of British fish filleters. *J Appl Physiol* 1962:17:444-448.

Effects of work in and outside a cold storage on circulatory functions

I. Morioka, N. Ishii, N. Miyai, K. Miyashita

Department of Hygiene, School of Medicine, Wakayama Medical University, 27 Kyubancho, Wakayama 640, Japan

Introduction

Several observations have shown that the exposure to cold affects circulatory functions (1). Recently, the work in cold environments has been not limited to the outside in winter. The work in the artificially cold environments, such as a cold storage at -20°C , has rapidly increased. Workers in the cold storage are frequently exposed to the cold environments. The large difference in the atmospheric temperature between inside and outside the cold storage (more than 50°C in summer) would be stressful to workers. The aim of the present study was to clarify the effects of the work in and outside the cold storage on the circulatory functions of workers.

Subjects and Methods

The subjects were 18 male workers operating a forklift in and outside a cold storage in Osaka, Japan. Their mean age and standard deviation was 28.2 ± 7.1 years of age. They had no past history and no present history of hypertension or other circulatory diseases. The atmospheric temperature in the cold storage was between -23°C and -20°C . The workers dressed in a garment assembly providing an Icl value of 2.5 clo. Blood pressure was measured every 15 minutes during the work by an automatic ambulatory blood pressure monitor (ABPM630, Nihon Colin, Japan). Catecholamines in blood and urine, and sublingual temperature were measured at the start and the end of work. A time-motion study was also conducted from the start to the end of work on the same day. The frequency of entering and the length of staying in the cold storage were recorded. The survey was carried out in September 1994. The atmospheric temperature outside the cold storage was between 30°C and 34°C .

Results and Discussion

The total frequency of entering the cold storage was 20 to 102 times in a day (mean frequency was 55.2 times). It showed a large individual difference. The total time of staying in the cold storage was 58 minutes to 6 hours and 4 minutes in a day (mean time was 3 hours and 36 minutes). The maximal length of each stay was 60 minutes and 35 seconds, but the length of each stay was less than 5 minutes in most cases.

Analyses on the blood pressure were made with 16 subjects, except 2 subjects because of the recorded errors of the automatic ambulatory blood pressure monitor. Seven workers showed the systolic blood pressure exceeding 160 mmHg in the cold storage, and 9 workers showed it even outside the cold storage. The subjects were divided into two groups by the total time of staying in the cold storage; 8 workers in L group (longer than the median; 32.4 ± 8.2 years of age) and 8 workers in S group (shorter than the median; 25.3 ± 5.3 years of age). The mean systolic blood pressure was higher in L group (133.6 ± 6.2 mmHg) than in S group (127.0 ± 8.0 mmHg). There was no difference in the diastolic blood pressure between the two groups (81.0 ± 5.4 mmHg in L group and 79.5 ± 8.1 mmHg in S group). The total time of staying in the cold storage by a time zone was calculated in the two groups. The difference in the blood pressure between the two groups was larger at the time when the difference in the total time of staying in the cold storage was larger. When the subjects were divided into two groups by the median total frequency of entering the cold storage, the difference in the blood pressure was not obtained. This shows that the total frequency of entering the cold storage had no effect on the blood pressure.

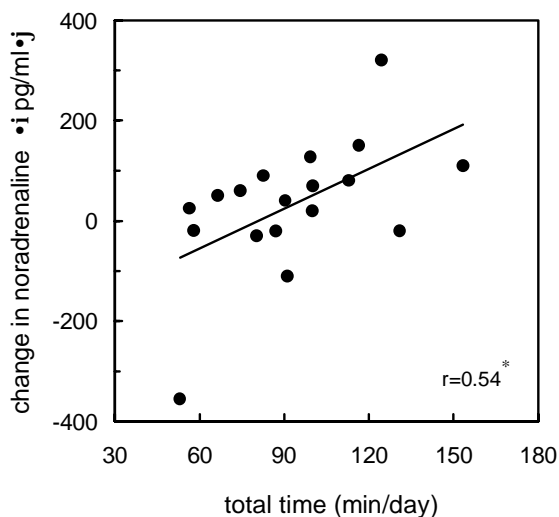


Figure 1. Relationship between the total time staying in the cold storage in a day and the change in noradrenaline concentration in blood from the start to the end of the work. * $p < 0.05$

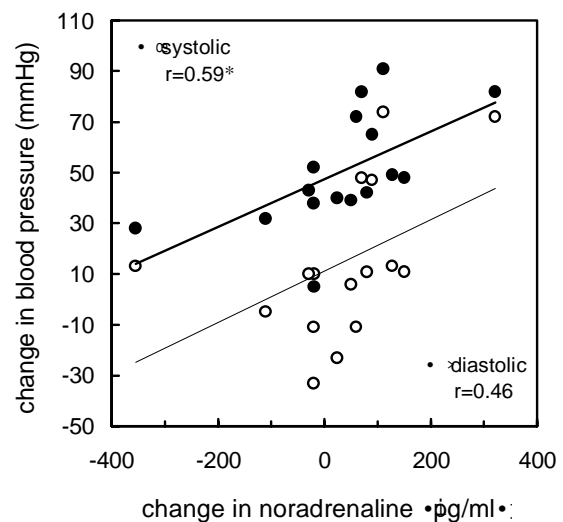


Figure 2. Relationships between the change in noradrenaline concentration in blood from the start to the end of the work and the changes in the systolic and the diastolic blood pressure. (Changes in blood pressure were obtained by deducting the minimum value from the maximum value in the cold storage.) * $p < 0.05$

The adrenaline and the noradrenaline concentrations in blood were higher at the end of work than at the start of work. (adrenaline: 68.0 ± 36.1 pg/ml at start vs. 82.6 ± 39.9 pg/ml at end, noradrenaline: 394.2 ± 143.7 pg/ml at start vs. 426.9 ± 137.9 pg/ml at end). As the total time of staying in the cold storage was longer, the change of noradrenaline concentration was significantly larger (Figure 1). The change in the systolic blood pressure in the cold storage significantly widened with increasing change in noradrenaline concentration in blood (Figure 2). The diastolic blood pressure also tended to widen with increasing change in noradrenaline concentration in blood. There was no relationship between the total frequency of entering the cold storage and the changes in adrenaline and noradrenaline concentrations in blood.

The sublingual temperature decreased at the end of work in 6 workers. The sublingual temperature changed in association with the total time of staying in the cold storage.

There was no relationship between the total frequency of entering the cold storage and the change in sublingual temperature.

In summary, the systolic and the diastolic blood pressure were increased during the work in and outside the cold storage. The increasing total time of staying in the cold storage leads to increasing adrenaline and noradrenaline concentrations, and decreased sublingual temperature. The increasing noradrenaline concentration leads to increasing systolic blood pressure and diastolic blood pressure. Thus, the circulatory functions were affected by the work in and outside the cold storage.

References

1. Tochiara I, Ohkubo C. A survey on work loads of forklift-truck workers in cold storages. Bull Inst Public Health 1990 : 39 : 29-36.

The conflicting stimuli of chilling of the face and the forearm on cardiovascular regulation

E. Schagatay, J. Andersson, B. Holm

Department of Animal Physiology, Lund University, S-22362 Lund, Sweden

Introduction

Cold water immersion of the extremities during breathing is known to induce tachycardia by inhibiting the parasympathetic activity and increasing the β -adrenergic sympathetic activity on the heart. An α -adrenergic sympathetic vasoconstriction is also induced (Frey et al 1980a; Frey et al 1980b; Allen et al 1992). Due to these two reflexes the blood pressure is increased. As the immersion continues the baroreflex returns heart rate towards the pre-immersion level, often within the first minute. That is, the β -adrenergic activity is reduced while the α -adrenergic activity continues to cause a vasoconstriction (Frey et al 1980a; Frey et al 1980b).

Facial chilling, on the contrary, initiates a vagally mediated reduction in heart rate and an α -adrenergic sympathetic vasoconstriction in selected vascular beds (Elsner and Gooden 1983; Frey et al 1980b; Gooden 1994; Heistad et al 1968). Breath-holding (apnea) is also known to induce bradycardia, vasoconstriction and, often, an increase in blood pressure. Facial chilling and apnea together induce a response of approximately twice the magnitude as observed when only one of the stimuli is present (Hurwitz and Furedy 1986). This potentially oxygen conserving response, commonly known as the diving response, is believed to be part of the general defense against asphyxia. The cardiac output is not balanced to the vaso-constriction, and the blood pressure increases. Mainly the cold-receptors innervated by the ophthalmicus branch of the trigeminal nerve are involved in initiating the response (Schuitema¹ and Holm 1988). The temperature difference between the water and ambient air is a major determinant of the magnitude of the human diving response in the temperature range 10-30 °C (Schagatay and Holm 1996).

The aim of this study was to investigate which of the conflicting stimuli from chilling of the arm and face would be expressed in the cardiovascular regulation at two respiratory conditions, 1) during breathing (eupnea) and 2) during apnea.

Methods

Series I

During eupnea, nine subjects performed three 1 min. immersions, involving face and/or arm immersion in the following combinations 1) arm immersion, 2) face immersion, 3) face immersion and arm immersion. A fourth condition was face immersion and apnea for maximum duration (Figure 1).

¹ Now Schagatay

Series II

Sixteen subjects performed four maximum duration apneas, the first without immersion. The remaining apneas were performed with face and/or arm immersion in the following combinations: 2) arm immersion, 3) face immersion, 4) face immersion and arm immersion (Figure 1).

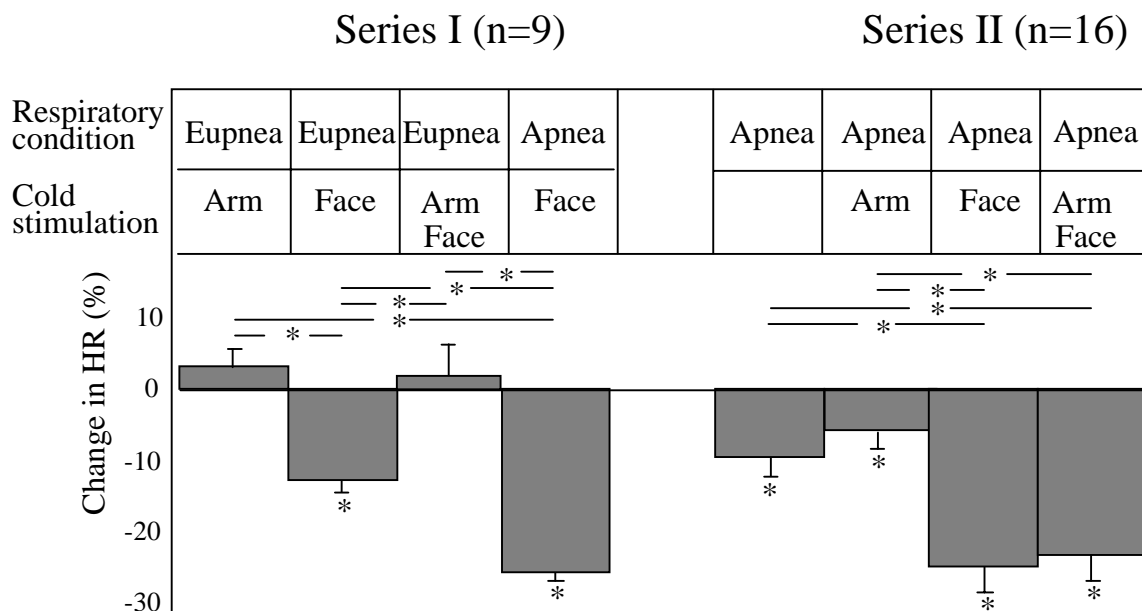


Figure 1. Percent changes in heart rate from control at the conditions indicated.

Procedures

The face and the arm were immersed in water holding 10 ± 0.5 °C. Room temperature was maintained at 22-25 °C. The subject was resting prone on a bed. Under a removable pillow, the container used for face immersion was situated. During face immersion, the entire face including forehead and chin were immersed. During eupnea and face immersion, the subject breathed through a snorkel. To the right of the bed, the container used for arm immersion was placed. During arm immersion, the right forearm and hand were immersed. Apneas were performed after a deep but not maximal inspiration, and without prior hyperventilation. The order in which the immersions were performed was randomized for each subject. The pause between each test in a series was 10 min.

Data analysis

Control heart rate was calculated from the period 90-30 s before each test condition. The relative changes from control of the heart rate 30-45 s into each test condition were compared among the breathing and apneic situations. For statistical evaluation analysis of variance was used. The level for accepting significance was $P < 0.05$.

Results

In both series apnea and face immersion triggered a heart rate reduction of more than 20 % (Figure 1). Face immersion always resulted in bradycardia, except when performed in combination with arm immersion during eupnea, when heart rate tended to increase.

Arm immersion during eupnea resulted in tachycardia. During apnea, however, the reflex bradycardia remained in spite of the arm immersion, and at simultaneous immersion of the arm and face the bradycardia was the same as when no arm immersion was present (Figure 1).

Conclusions

During eupnea the bradycardia derived from chilling of the forehead is abolished if the forearm is simultaneously chilled. Thus, the increased sympathetic activity on heart rate evoked by arm immersion has priority over the parasympathetic activity induced by facial chilling. During apnea, on the contrary, the arm immersion had no effect. Thus, bradycardia was induced by an increased parasympathetic activity whereas the sympathetic activity evoked by arm immersion was not expressed (Figure 2). It appears functional that the oxygen conserving diving response has priority over thermoregulatory responses in the threat of asphyxia. During breathing, however, bradycardia apparently would serve no purpose, since oxygen delivery is undisturbed, and thermoregulatory adjustments will be more appropriate at chilling.

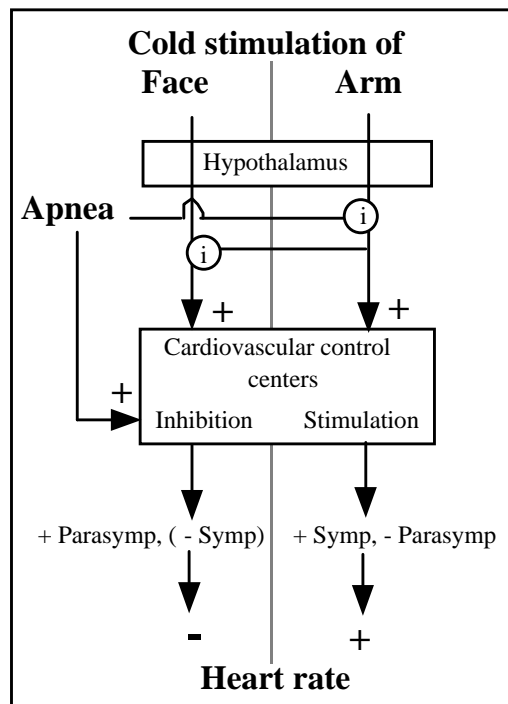


Figure 2. Proposed mechanisms of interactions between apnea and cold stimulation of the face or extremities. (From Andersson et al., in manuscript)

References

1. Andersson J, Gislén A, Schagatay E, Holm B (In manuscript) Cardiovascular responses to apnoea and cold water arm and face immersion.
2. Allen MT, Shelley KS, Boquet Jr AJ (1992) A comparison of cardiovascular and autonomic adjustments to three types of cold stimulation tasks. *Intern J Psychophysiol* 13: 59-69

3. Elsner R, Gooden B (1983) Diving and asphyxia: a comparative study of animals and man. In: Physiological Society Monograph No. 40. Cambridge Univ. Press, London
4. Frey MAB, Siervogel RM, Selm EA, Kezdi P (1980a) Cardiovascular response to cooling of limbs determined by noninvasive methods. *Eur. J. Physiol* 44: 67-75
5. Frey MAB, Selm EA, Walther JW (1980b) Reflex cardiovascular responses to cold exposure of the face or foot. *Jpn Heart J* 21: 665-679
6. Gooden BA (1994) Mechanism of the human diving response. *Int Physiol Beh Sc* 29: 6-16
7. Heistad DD, Abboud FM, Eckstein JW (1968) Vasoconstrictor response to simulated diving in man. *J Appl Physiol* 25: 542-549
8. Hurwitz BE, Furedy JJ (1986) The human dive reflex: an experimental, topographical, and physiological analysis. *Physiol Behav* 36: 287-294
9. Schagatay E, Holm B (1996) Effects of water and ambient air temperatures on human diving bradycardia. *Eur J Appl Physiol* 73: 1-6
10. Schuitema K, Holm B (1988) The role of different facial areas in eliciting human diving bradycardia. *Acta Physiol Scan* 139: 119-120

Heat and cold strain while wearing NBC protective clothing at -25 - +25 °C

S. Rissanen, H. Rintamäki

Oulu Regional Institute of Occupational Health, FIN-90220 Oulu, Finland

Introduction

Nuclear, biological and chemical (NBC) protective clothing is worn for protection against environmental contamination. Low water vapour permeability, increased thermal insulation, heavy weight and bulkiness of the NBC protective clothing have been shown to cause thermal strain both in cold and warm environments (4, 5). Combination of hot or warm working environment and heavy physical work while protective clothing is worn decreases physical performance capacity and work tolerance times and may cause an increased risk of heat illnesses. In a cold environment performance decrements are caused by whole body cooling and especially, by local cooling of the extremities. Cooling of the extremities is pronounced due to the use of thin gloves. The aim of the present study was to collect together and to present the limitations of working ability due to heat load and heat debt while wearing protective clothing at a wide range of ambient temperatures.

Methods

Data are collected from our own studies and from the literature (e.g. 2, 4). The experiments were performed at -25 to 25 °C. Semipermeable and impermeable NBC protective ensembles with face mask, boots and butyl rubber gloves were used. The range of ambient temperature was selected to represent warm, thermoneutral and cold environmental conditions. During work the metabolic rate varied from 310 to 645 W and work load was classified as light, moderate and heavy (1). During rest the subjects were standing or sitting. Thermal strain was classified as discomfort or performance degradation (3).

Results

The results show that during heavy work the working time may be restricted, due to heat strain, even up to -20 °C when NBC protective clothing is worn (Table 1). During light and moderate work, risk of heat strain disappears at about 15 and 0 °C, respectively. Cooling of the extremities at light work and at rest may cause cold discomfort at about 0 °C and at lower temperatures may reduce the tolerance time and impair manual performance. Whole body cooling at light work limits the working ability at temperatures below -20 °C.

Table 1. Thermal strain at different metabolic rates while wearing NBC protective clothing.

Ta (°C)	Rest	Light work < 340 W	Moderate work 340 - 510 W	Heavy work 510 - 680 W
25	No limits.	Working time < 4 h. Heat discomfort.	Heat strain in 60 min. Performance degradation.	Heat strain < 60 min. Performance degradation.
20	No limits.	Working time < 5 h.	Heat strain > 60 min. Performance degradation.	Heat strain in 60 min. Performance degradation.
15	No limits.	Working time > 3 h.	Risk of heat strain > 120 min. Heat discomfort.	Risk of heat strain > 60 min. Performance degradation.
10	No limits.	No limits.	Heat strain possible. Heat discomfort.	Risk of heat strain > 60 min. Performance degradation.
0	Extremity cooling in 30 min. Cold discomfort.	Extremity cooling possible.	Heat strain possible. Extremity cooling possible.	Risk of heat strain.
-10	Extremity cooling. Risk of whole body cooling.	Cold discomfort. Extremity cooling.	Heat strain possible.	Heat strain possible.
-20	Whole body cooling.	Risk of whole body cooling.	Heat strain minimal. Risk of extremity cooling.	Heat strain possible.
-25	Whole body cooling < 30 min.	Whole body cooling in 60 min. Performance degradation.	Risk of extremity cooling.	Heat strain minimal.

Conclusion

Wearing NBC protective clothing during heavy work may cause performance decrements due to the heat strain at wide range of ambient temperatures. Cooling of the extremities, especially fingers, limits the tolerance time in the cold during light and moderate work.

References

1. Andersen KL, Rutenfranz J, Masironi R, Seliger V. *Habitual physical activity and health*. WHO Regional Publications, European Series No. 6, Copenhagen, 1978.
2. Cortili G, Mognoni P, Saibene F. Work tolerance and physiological responses to thermal environment wearing protective NBC clothing. *Ergonomics* 1996;39:620-633.
3. Lotens W. Comparison of thermal predictive models for clothed humans. *Ashrae Transactions* 1988;94:1321-1340.
4. McLellan TM, Jacobs I, Bain JB. Influence of temperature and metabolic rate on work tolerance with Canadian Forces NBC clothing. *Aviat Space Environ Med* 1993;64:587-594.
5. Rissanen S, Rintamäki H. Thermal responses and physiological strain in men wearing impermeable and semipermeable protective clothing in the cold. *Ergonomics* 1997;40:141-150.

Breathing in the cold

G. Giesbrecht

Laboratory for Exercise and Environmental Medicine, Health Leisure and Human Performance Research Institute, University of Manitoba, Winnipeg, MB, Canada, R3T 2N2

Being a tropical animal, the human is poorly equipped to withstand climatic conditions that deviate far from that of warm temperate areas. Long term exposure of the naked human to temperatures below 25 °C will result in a range of responses ranging from discomfort at higher temperatures, to sustained net heat loss and eventual death at lower temperatures; the later condition may occur at 15-18 °C. While the human poorly tolerates cold stress applied to the body surface, very cold air can be breathed with little thermal consequence. Inspired air is conditioned in the airways and very efficiently warmed to body temperature and humidified. This paper which is based on a previous review (4), focuses on how acute or chronic exposure to a cold environment impacts on respiratory system functions either through direct, reflex or mediator release mechanisms.

Basic Physiology

First, cold exposure may have basic physiological effects on pulmonary mechanics, control of breathing, pulmonary circulation and morphology of the respiratory system. After a brief description of some of these effects, clinical disorders that may be precipitated by acute or chronic cold exposure will be described.

At rest, air warming and humidification occurs within the upper airway and the first 6-7 bronchial generations. This cooling and drying stimulus becomes greater and moves to more central airways as: temperature (7) and water content of the inspirate decreases; a switch from nasal to mouth breathing occurs; and/or ventilation increases. Increased ventilation (i.e. during exercise) magnifies these effects.

The response to the cold and/or drying stimulus is increased airways resistance which is due to a number of factors including contraction of airway smooth muscle, increased mucus production, decreased mucociliary clearance, vascular congestion as well as epithelial damage and vascular leakage. These responses may be mediated by either: the direct effect of airway cooling or drying; sensory receptors and vagal reflexes; and/or mediator release (Figure 1). It has been proposed that the major stimulus for airway narrowing is airway drying and subsequent hypertonicity of the airway lining fluid. However, there is mounting evidence for the additional, but not exclusive, influence of airway cooling itself.

The direct effect of cooling on airway smooth muscle is still under debate. Although ventilation with cold air causes airway constriction *in vivo* in rabbits and dogs, the isolated *in vitro* effects of cooling airway smooth muscle have been variable. If the isolated direct effect of cooling does elicit bronchospasm, it is unlikely that this factor is

a major contributor to exercise- or cold-induced asthma as the maximal bronchoconstrictive response occurs 5-15 minutes post-stimuli (see below).

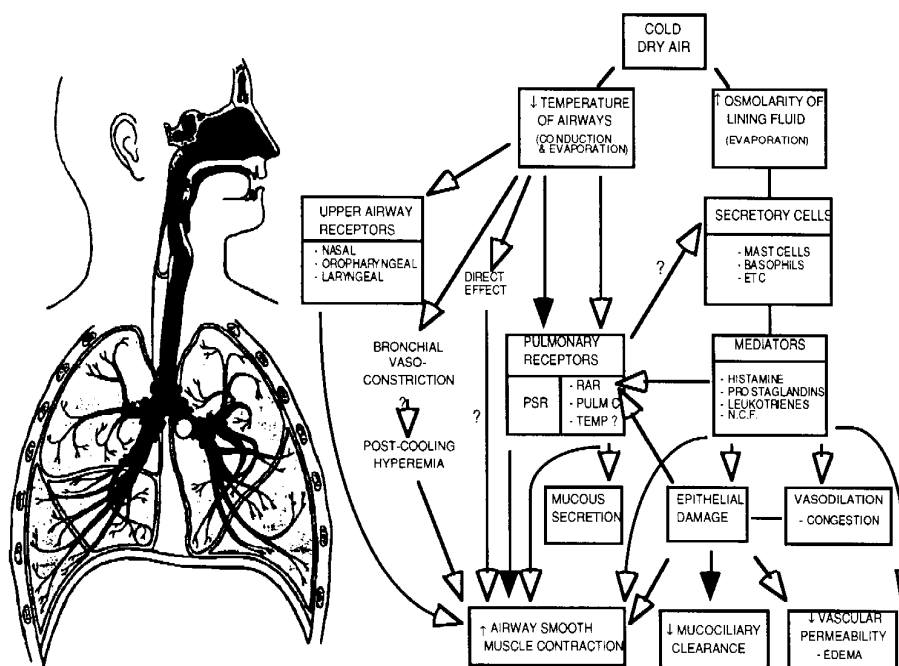


Figure 1. Effects of airway cooling and drying on the respiratory system. Open arrows, stimulatory; closed arrows, inhibitory; N.C.F., neutrophil chemotactic factor; RAR, rapidly adapting receptors; Pulm C, pulmonary C fibres; TEMP, temperature; PSR, pulmonary stretch receptor.

Various pulmonary receptors are sensitive to cooling either inspired air or pulmonary blood. The asthmatic response to cold air has been eliminated by vagotomy in sensitised rabbits and it is generally agreed that vagal reflexes at least partly mediate the response in humans. Rapidly adapting receptors in the airway epithelium are stimulated by cooling the pulmonary blood. Since rapidly adapting receptor discharge mediates bronchoconstriction (3) and mucus production, cooling would therefore be expected to initiate bronchoconstriction. Slowly adapting pulmonary stretch receptor activity is decreased by cooling either the pulmonary circulation or inspired air. As pulmonary stretch receptors inhibit airway smooth muscle activity, cold-induced inhibition of these receptors would increase airway smooth muscle tension. In fact it has been demonstrated that cooling the pulmonary circulation elicits vagally mediated reflex tracheal smooth muscle contraction and bronchial vasodilatation. There is also evidence that thermosensitive units in the nasal cavity, oropharynx, larynx, and upper trachea mediate bronchoconstriction in response to airway. Finally, application of cold air to the buccal mucosa (7), face (5), or trunk, as well as ice to the face causes a measurable amount of reflex bronchoconstriction.

As dry inspire is humidified in the airways, osmolarity of airway lining fluid increases (1). Several studies have shown that inhalation of nebulized hyperosmolar solutions induces bronchospasm in asthmatics and otherwise asymptomatic sufferers of exercise- or cold-induced asthma. As a result increased mucosal osmolarity has been postulated as the stimulus for this response. Hypertonicity stimulates rapidly adapting receptors *in vivo*. As described earlier, increased activity of these receptors stimulates bronchoconstriction and mucous production. Hyperosmolar airway fluid induces release of mediators which may stimulate airway smooth muscle may be direct or secondary to stimulation of rapidly adapting receptors. Some of these substances also increase

vascular permeability and cause epithelial damage, effects which may result in subsequent plasma transudation. Secondary effects of epithelial damage include rapidly adapting receptor stimulation and disturbed mucociliary clearance.

Again it should be noted that airway drying through evaporation will be accompanied by some degree of cooling. It is likely that both stimuli contribute to the response.

In general, isolated airway cooling decreases baseline minute ventilation (V_E) and ventilatory sensitivity to various chemical. Inhibitory effects of airway cooling are eliminated by anaesthetising the nasopharynx or larynx indicating they are reflex in nature. Cold sensitive laryngeal mechanoreceptors may mediate an inhibitory influence on the hypothalamus to decrease respiratory heat loss (2). There are also unmyelinated nerve terminal arborizations in the nasal mucosa which are sensitive to thermal and mechanical stimuli. These receptors may inhibit respiratory drive through activation of trigeminal nerve pathways. Finally, there are effects on lower airway receptors which may contribute to this inhibitory effect. Cold air below 27 °C inhibits pulmonary stretch receptor activity. Although these isolated mechanisms are no doubt active, their overall influence is probably small compared to acid-base control mechanisms. Therefore it is likely that blood gas homeostasis is unaffected by breathing cold air.

Cold exposure may exert an effect on the pulmonary circulation. It seems that cold exposure potentiates the effects of hypoxia on the pulmonary circulation and contributes to high altitude illnesses. Indeed Brisket disease is worse in winter months and symptoms can be prevented, attenuated or reversed by sheltering cattle from the cold elements at high altitude. Comparable effects are seen in humans where there is a higher incidence of acute mountain sickness and high altitude pulmonary edema in mountain climbers during seasons of lowest ambient temperatures and at similar altitudes in northern compared to tropical areas.

Acute Clinical Disorders

Exercise- and cold-induced asthma are commonly recognised respiratory disorders. The incidence of reactions to exercise in cold air is similar in children and adults and about 3-10 % of otherwise asymptomatic athletes experience exercise-induced asthma (6). Cold air hyperventilation and exercise are separate stimuli for bronchoconstriction that may act synergistically (see Early phase response).

The asthmatic response includes several factors contributing to airway narrowing and increased airway resistance (i.e., airway smooth muscle contraction, mucus accumulation, decreased mucociliary clearance, bronchial vascular congestion, as well as epithelial damage and vascular leakage). Generally, few symptoms occur during the period of exercise or cold, dry air hyperpnea itself. Rather, the effects are maximal within 5-15 minutes post-stimuli (*early phase response*). Spontaneous *recovery* usually takes place within 30 min to 2 hrs. There is usually a *refractory period* of about 1-2 hrs during which responses to further stimuli are attenuated. A *late phase response* may occur 4-10 hrs post-stimuli.

Reasons for the delayed symptoms are unknown. However, since catecholamines and other β agonists relax airway smooth muscle, the increase in plasma catecholamine levels during exercise may provide protection during and immediately post-exercise until catecholamine levels return to baseline levels. The severity of the *early phase* symptoms is mainly dependent on the thermal load placed on the airways (i.e. the level of ventilation, the temperature and water content of the inspire, and the length of exposure). These stimuli stimulate airway narrowing through bronchoconstriction,

mucus accumulation, and vascular engorgement (Figure 1). It has been demonstrated that airways obstruction declines in response to repetitive bouts of exercise within 1-2 hrs of the initial bout. Although the mechanisms are not clear, one explanation for this *refractory period* is depletion of histamine and other mediators from secretory cells during the early phase response. The existence of an exercise-related *late phase response* is controversial. In some patients airways resistance increases again 4-10 hrs post stimulus. Mediators such as histamine, a high-molecular-weight neutrophil chemotactic factor and other arachidonic acid metabolites have been reported to increase in association with the delayed response. This reaction does not occur in all patients however. There is some data to indicate an acclimatisation effect; trained asthmatics have less exercise-induced asthma than those who are untrained, and that in many individuals, symptoms are greater in early compared to late winter.

The standard and most effective single method of pharmacological prevention is the use of an inhaled β agonist 15-30 minutes prior to an exposure that the patient knows from experience will trigger an attack. Here, the bronchial changes that usually lead to an attack are not prevented but the final step, smooth muscle contraction, is attenuated through the direct action of the β agonist on smooth muscle. Inhalation of cromolyn sodium prior to exposure is act through mast cell membrane stabilisation (leading to decreased mediator release). Other agents may also be added: inhaled anticholinergic agent (i.e. ipratropium bromide, oral antihistamines (based on the likelihood that histamine release plays a major role), a calcium channel blocker (i.e. nifedipine), or inhaled nedocromil (an anti-inflammatory agent). In some subjects limiting the use of medication to prophylaxis prior to exposure is not sufficient. In such cases the regular use of inhaled corticosteroids and inhaled nedocromil are effective in reducing the inflammation usually present in these cases. At times an initial course of oral corticosteroids is required to bring the inflammation under control.

Non pharmacologic approaches are also useful and often reduce the need for medication. These include the following: 1) a 15-20 minute warm-up (i.e. submaximal exercise) prior to the vigorous exercise is often protective; 2) Use of face masks to rebreathe some of the humidified heated expired air; 3) A high level of physical conditioning; and 4) avoidance of exercise in contaminated environments is recommended.

There are other acute cold-related disorders. Bronchorrhea is but one of the many effects of cold air inhalation on the lower airways. Congestion and excessive secretion of watery mucus from the respiratory mucosa also occurs in the nasal passages. It is believed that the stimulus for secretion is the hyperosmolarity of nasal mucosa lining fluid due to evaporative water loss.

Some cold sensitive patients cough following hyperventilation or exercise in moderately cold air. Maximum cough frequency occurs within 5 min of stimulus termination. This may be another symptom of exercise- or cold-induced asthma. Cross country skiers who train heavily or race at temperatures below -20°C have a very high incidence of dry cough lasting from days to weeks. Cough may be vagally mediated through rapidly adapting (irritant) receptors. High levels of ventilation in very cold air can also cause nasal mucosal drying and damage leading to nose bleeds.

Exercise or heavy work in very cold air can cause a burning sensation in the chest which is often described as freezing of the lungs. There have been reports of frosting of the lungs in horses in extreme arctic conditions as well as sled dogs dying of edema under these conditions. Arctic hunters have also reported freezing of the lungs under heavy work loads in severely cold air. These reports are anecdotal however, and it is not known to what extent lung tissue was actually cooled or damaged. Cold air (-50 to -28

°C) has been delivered to the larynx of anaesthetised dogs for 20 to 133 min and found no freezing injury to any respiratory tissue. Even in the worst cases, inspired air temperatures rose to at least 20 °C at the carina. Although no freeze injury occurred, it was possible to cause obstructive apnea due to severe upper airway edema if the cooling was severe enough. This is consistent with a report of an aviator exposed to air temperatures of -50 °C at speeds of up to 258 km/hr. He sustained severe frostbite of the face and fingers but there was no evidence of freeze injury to the bronchi or lungs. He did however, experience obstructive edema in the mouth, nose and pharynx and had to be tracheotomized. After recovery there were no further pulmonary complications.

Chronic Clinical Disorders

There have been several reports linking cold weather to an increased incidence of upper airway tract infections. In Norway there is an increased frequency of sinusitis in northern vs. southern communities and in the autumn vs. spring). Infection rate could increase due to poorer or more crowded living conditions, or greater amount of time spent indoors during cold weather months.

Epidemiological studies have revealed a condition in older male Eskimos referred to as Eskimo lung. These men had symptoms similar to chronic obstructive pulmonary disease (COPD); decreased maximum mid-expiratory flow rate, cough, wheezing, large lung volumes, and increased pulmonary artery diameter. The symptoms of Eskimo lung have been connected to hard work in the severe cold winter, as younger inhabitants of Arctic Bay, who had not been involved in old hunting traditions, and the general population of the more modernised Inuvik did not have the high prevalence of COPD. Eskimo lung may be related to other factors (i.e. smoking) however, there is no data to correlate a higher smoking rate in the northern populations with the greater incidence of COPD.

Until recently tuberculosis was prevalent in northern communities. Although some correlation has been found with cold conditions, it is likely that crowded living conditions, and poor nutrition were equally or more responsible for the high incidence of this disease.

Conclusion

Cold exposure elicits several effects on the respiratory system. Pulmonary mechanics are worsened due to bronchoconstriction, airway congestion, secretions and decreased mucociliary clearance. The stimulus for these effects is likely a combination of direct airway cooling and hyperosmolarity of airway lining fluid when breathing cold dry air. The isolated ventilatory effects of cooling the airways are decreased baseline ventilation and ventilatory responses to chemical stimuli. However these effects are small and unlikely to compromise acid-base homeostasis. Cold exposure also elicits an increase in pulmonary vascular resistance. This stimulus is synergistic with hypoxia in mediating pulmonary hypertension and edema. Chronic exposure to cold environments results in morphological changes such as increased numbers of goblet cells and mucous glands, hypertrophy of airway muscular fascicles and increased muscle layers of terminal arteries and arterioles. Together, these latter factors may play a role in the symptoms of chronic obstructive pulmonary disease and bronchitis, high altitude pulmonary hypertension and edema, and right heart hypertrophy.

Acknowledgements

This work was supported in part by the Natural Sciences and Engineering Research Council (Canada) and the Manitoba Health Research Council.

References

1. Anderson, S. D., R. E. Schoeffel, J. L. Black, and E. Daviskas. Airway cooling as the stimulus to exercise-induced asthma: a re-evaluation. *Eur. J. Respir. Dis.* 67: 20-30, 1985.
2. Burgess, K. R., and W. A. Whitelaw. Reducing ventilatory response to carbon dioxide by breathing cold air. *Am. Rev. Respir. Dis.* 129: 687-690, 1984.
3. Coleridge, H. M., and J. C. G. Coleridge. Reflexes evoked from tracheobronchial tree and lungs. In: *Handbook of Physiology. The Respiratory System, Control of Breathing*. N.S. Cherniack and J.G. Widdicombe ed. Bethesda: Am. Physiol. Soc., p. 395-424, 1986.
4. Giesbrecht, G. G. The respiratory system in a cold environment. *Aviat. Space Environ. Med.* 66: 890-902, 1995.
5. Josenhans, W. T., G. N. Melville, and W. T. Ulmer. The effect of facial cold stimulation on airway conductance in healthy man. *Can. J. Physiol. Pharmacol.* 47: 453-457, 1969.
6. Pierson, W. E., and R. O. Voy. Exercise-induced bronchospasm in winter sports. In: *Winter Sports Medicine*. M.J. Casey, C. Foster and E.G. Hixson ed. Philadelphia: F.A. Davis Company, p. 158-166, 1990.
7. Strauss, R. H., E. R. McFadden Jr., R. H. Ingram Jr., E. C. Deal Jr., and J. J. Jaeger. Enhancement of exercise-induced asthma by cold air. *N. Engl. J. Med.* 297: 743-747, 1977.

Facial cooling and cardio-respiratory interactions

K. J. Collins, T. A. Abdel-Rahman, J. C. Easton, P. Sacco, J. Ison

University College School of Medicine, London, UK

Receptors in the nasal mucosa and the face innervated by trigeminal nerves are stimulated by face cooling (FC) and produce a reflex bradycardia and an increase in total peripheral resistance. It is suggested that the cardiovascular sequelae may contribute to cold-induced morbidity in at-risk groups such as those with heart disease and older people. The FC response resembles the 'diving' response produced by breath-holding during total immersion in cold water, but does not usually result in apnoea or profound bradycardia associated with diving (2). We found that manoeuvres such as whole-body warming or cooling, breath-holding or postural changes modify the reactions to FC (1).

Interactions between FC and cardio-respiratory and thermal reflexes have been examined in 37 healthy young (18-39 y) subjects. Approval was given by the hospital ethics committee and signed consent obtained from each subject. Subjects lay supine and were kept warm in a temperature-controlled test-bed fitted with a perspex hood enclosing the head. In studies of orthostatic reflexes, the perspex hood was attached to a lower body negative pressure (LBNP) box. Cold air (3.5 ± 1.5 °C) was blown on to the 'muzzle' area of the face with a velocity of 6m/s for periods of 6 min or 2 min. Blood pressure and heart rate were measured by a Dinamap automatic recorder, finger blood flow by photoelectric pulsometry with constant gain, and respiratory frequency and amplitude by respiration transducer.

The effects of changes in body skin temperature were studied by equilibrating the trunk and limbs to a neutral (30 °C), cold (15 °C) and warm (45 °C) environment. A warm air stream at 32 °C was used as a control stimulus to the face. During 6 min FC, the mean maximum heart rate reduction was 11 ± 4 % (neutral), 19 ± 8 % (cold) and 8 ± 7 % (warm). Arterial blood pressure increased only slightly by 5 ± 8 %, 5 ± 4 % and 3 ± 1 % in the three environments in the young subjects but significantly greater, 9 ± 6 %, 11 ± 5 % and 5 ± 5 %, in older subjects). Zero-gradient aural temperatures were not significantly changed during the procedures. Our results indicated that cardio-vascular responses to FC are enhanced by body surface cooling and diminished by warming.

In investigations of the effect of breath-holding on FC in air, subjects were asked to breath-hold for 30 sec after a maximum inspiration or expiration. Breath-holding was performed 1.5 min after a 2 min period of FC had commenced. Blood pressure increased more during breath-hold in expiration than in inspiration ($P < 0.001$). There was an even greater rise in systolic pressure when FC was combined with expiration alone. Cardiac vagal motoneurons are maximally affected during the expiratory phase of the respiratory cycle and are partly or wholly refractory during the inspiratory phase, and thus allow a greater expression of bradycardia during FC in expiration.

A third investigation examined interactions between FC in air and postural baroreflexes. After a 15 min control period, LBNP was applied for 2 min each at -20, -30 and -40 mmHg with a 3 min rest between each negative pressure (Figure 1). It was found that FC diminished the hypotension induced by LBNP at -20 and -30 mmHg but did not prevent a significant fall in systolic pressure at -40 mmHg. Heart rate increased progressively with LBNP though significantly less when LBNP is combined with FC. At -20 mmHg the effect of FC was dominant and produced a slight bradycardia. In the interaction between simultaneously induced FC and the arterial baroreflex, cardiac vagal drive is subject to the opposing effects through different brain-stem nuclei but a common efferent pathway. Intense, but not minor LBNP (-20 mmHg), reduces skin blood flow (3), presumed to be mediated by arterial baroreceptors. The possibility cannot be excluded that respiration may also affect skin blood flow.

Although we cannot take account of the full interplay between multiple cardiovascular and cardiopulmonary interactions in human studies of this kind, it is possible to demonstrate the resultant algebraic effect. The outcome may be important, for it has been suggested that the association of at least two of the variables studied, blood pressure and autonomic function, may lead to an increase in cardiovascular morbidity and mortality, especially in those at risk in cold environments.

References

1. Collins KJ, Abdel-Rahman TA, Easton JC, Sacco P, Ison J, Dore CJ. Effects of facial cooling on elderly and young subjects: interactions with breath-holding and LBNP. *Clin Sci* 1996;90:485-482
2. Daly MdB. Breath-hold diving: mechanisms of cardiovascular adjustments in the mammal. In: Baker PF, ed. *Recent Advances in Physiology*. No. 10. London : Churchill Livingstone, 1984: 201-245
3. Eckberg DL, Sleight P. *Human Baroreflexes in Health and Disease*. Monogr. of the Physiological Society. No. 43. Oxford : Oxford University Press, 1992: p.167.

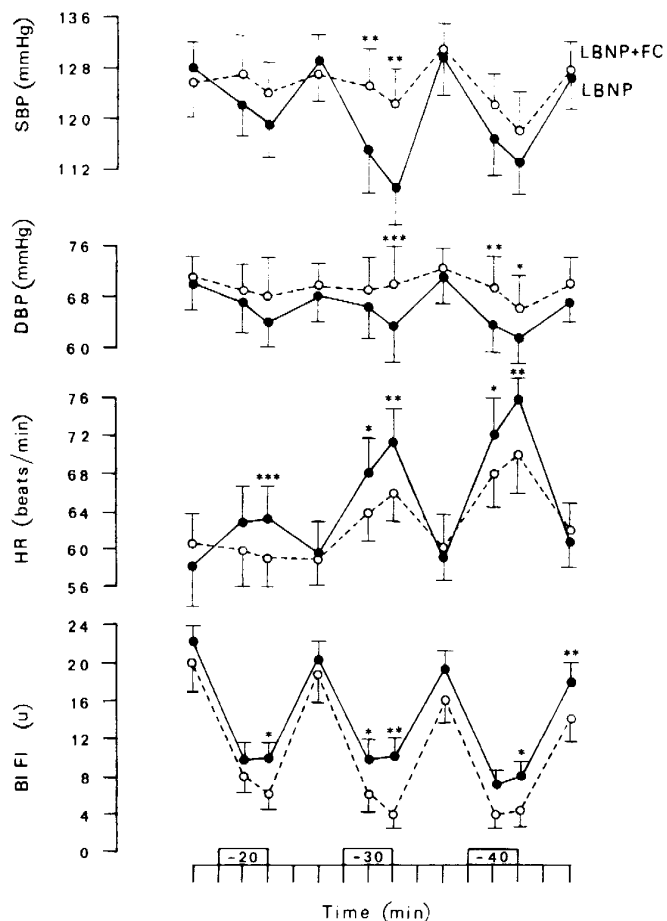


Figure 1. The effect of LBNP (●) and LBNP with FC (○) on cardiovascular responses. (n=10). Means ± SEM. Comparisons are made between LBNP with and without FC (*p<0.05, **p<0.01, ***p<0.001).

Effect of ambient temperature on the biofeedback-aided control of motor unit activity in the man

Yu. Lupandin, A. Meigal, L. Gerasimova

Department of Physiology, University of Petrozavodsk, Petrozavodsk, Russia

Introduction

Cold ambient temperature conditions are known to affect muscle performance characteristics, such as force output, power, and contraction velocity [3]. Spectral and amplitude characteristics of electromyogram (EMG) during muscle contraction are modulated by the cold and hot ambient temperature [4]. Voluntary control of single motor unit action potentials (MUAP) is known to be widely used method for investigation of fine movements. Local cold application to skin has been shown to be of contradictory impacts on the effectivity of single MUAP control [5]. General moderate cooling of the organism demonstrated very little effect on the MUAP control, even in the state of vigorous cold shivering [2]. The aim of the present study was to elucidate how does cold and hot ambient temperature influence the biofeedback-aided control of motor unit activity in the man.

Methods

Six subjects were instructed to recruit the ordered number of MUAP:s. The MUAP:s were recorded with the help of EMG device MG440 (Mikromed, Hungary) from the distal portion of the long head of *m. triceps brachii*, using surface bipolar electrodes (rectangular, 6 x 12 mm, interpolar distance 14 mm, lead). Audio and visual biofeedback was provided by the screen and loud-speaker to control the fulfilment of the task. Subjects using audio and visual biofeedback choose the most stable and large-amplitude MUAP during weak voluntary isometric contraction. After that they inhibited the activity of all the other MUAP:s, visible on the screen by changing the intensity of contraction and arm or hand position. Then the subjects were asked to demonstrate "operability" of the chosen MUAP by voluntary modulation of the firing rate of the MUAP, and by its recruitment and derecruitment.

After that subjects performed 40 attempts to recruit the ordered number of MUAP:s in each task (from 1 to 7 MUAP:s in the train). The effectiveness of the recruitment of MUAP:s was estimated by calculating the per cent of the right attempts (N) in each trial. Mean number of discharges in the attempt, mean interspike interval, mean firing rate of motor unit impulsing, and mean duration of the train were also calculated. The reference investigation was conducted at temperate conditions (after 30 min at +27 °C, thermal comfort). Investigation of MUAP:s recruitment in cold condition was performed after 40 min exposure at +10 °C, when cold shivering was observed. Measurements of MUAP control in hot condition (30-40 min exposure to ambient

temperature +45 °C) were initialised immediately after sweating started. T-tests for paired samples were used for comparison between temperate and hot conditions.

Results

At temperate conditions (+27 °C) after 30 min exposure mean skin temperature stabilised at the level of 32.3 ± 0.5 °C. The ordered number of MUAP:s was successfully recruited in all the tasks. Tasks from "1 MUAP" and "2 MUAP:s" were correctly performed in 66.0 ± 4.0 %, and it was 79.0 ± 3.0 % for the task "3" and "4" MUAP:s, while 5 to 7 MUAP:s were correctly recruited in 61.0 ± 3.0 %. The mistakes were related to the lack of one discharge (N-1). The discharge frequency of motor units depended on the task: it was 6-7 imp per sec when the task was "2 MUAP:s", and it was 10-12 imp per sec during the task "6 MUAP:s" or "7 MUAP:s".

Cold condition (+10 °C) did not significantly influence the recruitment of the ordered number of MUAP:s in spite of cold shivering observed. The firing rate of MU:s in the cold was found to be significantly lower in comparison to temperate ambient condition ($p < 0.05$) and uniform through the tasks within the range 6-7 imp/s.

After 30-40 min exposure to hot air (+45 °C) mean skin temperature increased to 37.1 ± 0.5 °C, and sweating was the characteristic of this condition. Core temperature did not significantly change. The striking specificity of the motor unit activity in the heated organism was the appearance of double spike and splitted MUAP:s at the beginning of recruitment. At least 40-50 % of MUAP:s in the train were usually doublets. These doublets were characterised by a very short interval between the first and second spikes (5-20 ms), and by prolonged intervals between the doublets (1.5-2 times longer than in regular single discharges). The other peculiarity of motor unit behaviour in the hot condition was that single spike MUAP:s which appeared at the end of the train were characterised by 20-30 % shorter interspike intervals if compared with the single spike MUAP:s in temperate conditions. Accordingly, their firing rate was 2-3 imp per sec higher in comparison with motor unit activity in temperate conditions. This peculiar behaviour of MUAP:s in the hot conditions puzzled subjects and made control of recruitment of MUAP:s extremely difficult, because total duration of the train became very difficult to be predicted. However, prolonged interdoublet intervals helped to count discharges and subjects managed to perform the task in hot conditions.

Conclusions

Biofeedback-aided control of fine movements in the man, such as recruitment of single motor unit potentials, was found to be highly effective either in control, cold and hot temperature conditions. Ambient temperature influenced the pattern of motor unit firing. Cooling increased interspike interval. In contrary, significant decrease of interspike intervals, doublets and splitted discharges were characteristics of motor unit recruitment in the heating condition. Change of firing rate of motor units in different temperature conditions might correspond with heat production characteristics of muscle contraction [1].

References

1. Gurfinkel V.S., Levic Yu.S., Poleshuk N.K., Korovin Yu.V. Dependence of heat production of skeletal muscle on the regimen of its contraction. *Fiziologia Cheloveka (Human Physiology, Moscow)* 1981:7:46-54.
2. Lupandin Yu.V. A comparative neurophysiological characteristic of cold and caudate tremor. *Neirofiziologia (Kiev)* 1981:13:257-262.
3. Oksa J., Rintamäki H., Mäkinen T. Physical characteristics and decrement in muscular performance after whole body cooling. *The Annals of Physiological, Anthropology* 1993:12:335-339.
4. Petrofsky J.S., Lind A.R. The influence of temperature on the amplitude and frequency components of the EMG during brief and sustained isometric contractions. *Europ J of Appl Physiol* 1980:44:189-200.3.
5. Wolf S.L., Letbetter W.D., Basmajian J. Effect of a specific cutaneous cold stimulus on single motor unit activity of medial gastrocnemius muscle in man. *Amer J Physical Medicine* 1976:55:177-183.

Physiological effects of exercise in cold

E. Tkatchenko, V. Divert

Institute of Physiology, Novosibirsk, Russia

Introduction

Previously we have shown that long-term cold influence on a human is accompanied by adaptive modification in both the skeletal muscles heat production and the skin and respiratory heat loss. We observed that the number of slow-twitch muscle fibres which have an increased ability of heat production had increased. Heat output under muscle contraction grew due to the decreased relation between the oxygenation and phosphorylation processes in ATP resynthesis (1). An increase in muscle thermogenesis and a decrease in heat loss provide cold resistance of the organism.

An increase in the muscle heat production after long-term cold adaptation occurs both during thermoregulatory responses and exercise resulting in increase of the energy cost of the standard muscular work (2). On the contrary, physical training increases work efficiency. At present there is no certain opinion about the combined effect of physical training and cold on the human organism.

In this study we have investigated the muscle work efficiency and thermoregulatory responses during exercise in cold-adapted subjects and in the subjects trained physically at low temperatures.

Methods

3 male groups aged 18-25 years were investigated. The control group (8 subjects) included the people without any physical training and cold adaptation; the second group included cold adapted subjects without physical training (14 subjects); the third group included subjects physically trained in cold (12 subjects). There were 2 types of standard veloergometric exercise. In the first series of experiments the exercise lasted 30 minutes and its load was 50 % of maximum oxygen consumption. This period of time was sufficient to reach new thermostability. The investigation was carried out under 19 and 13 °C of chamber air temperature. In the second series we used 3 minutes exercises of different loads (50, 100, 150, 200 W for all tested subjects, and 250 for persons only from the third group). After each load there was a rest interval up to the full recovery of cardio-respiratory indices. The air temperature in the chamber was 19 °C. Oxygen consumption was registered at rest, during all exercises and at the fifth minute of the recovery after a prolonged exercise. Besides, the tympanic, muscular and mean-weighted skin temperatures and perspiration were registered during a prolonged exercise.

Results

The air temperature decrease from 19 to 13 °C was accompanied by a decrease in skin temperatures and perspiration that was more pronounced in both cold adapted and trained in cold subjects in comparison with controls: 2.10 ± 0.35 , 1.80 ± 0.23 , 1.24 ± 0.18 °C for skin temperatures and 33.2 ± 2.41 , 40.0 ± 6.08 and 19.9 ± 4.52 ($\times 10^{-6}$ g/min·cm²) for perspiration. In the cold adapted subjects the muscle temperature decrease (1.2 ± 0.37 °C) was more marked than in control, whereas in trained in cold subjects the muscle temperature did not depend on air temperature.

At the beginning of the exercise a perspiration delay from 6 to 18 minutes and the decrease of hand skin temperature comparing to the initial temperature were especially marked in cold adapted and trained in cold persons (1.1 ± 0.42 and 0.8 ± 0.33 °C, respectively). This provided body heat accumulation in the working organism. The onset of sweating occurred when the muscle temperature achieved the same level in all groups regardless of air temperature. The tympanic and muscle temperatures rose and became stable at the new level (about 37.5 °C). The temperature of working muscles in all groups reached a constant level significantly earlier than tympanic temperature. The working muscle temperature in the end of a 30-minute exercise in trained in cold subjects remained at a constant level, regardless of air temperature, whereas in cold adapted persons it decreased when the temperature in chamber fell.

The oxygen consumption at 19 °C in cold adapted subjects was 18 % higher than in the control group; in trained in cold subjects it did not differ from that of the control group. The oxygen debt value was the highest in cold adapted persons, thus by the 5th minute of recovery the initial level of oxygen consumption had not been attained in this group. The ambient temperature decrease from 19 to 13 °C did not influence the oxygen consumption level at the end of the exercise. The oxygen debt in the cold-trained subjects, however, increased 17 % under 13 °C.

Work efficiency differed for each work load. First it increased to a maximum value with the increase of the exercise load and then it decreased. The maximum work efficiency in cold adapted persons was observed during the exercise with a smaller load, than in the control group, whereas the trained in cold persons needed a bigger load (98 ± 3.7 , 159 ± 4.4 and 129 ± 4.1 W, respectively). The maximum work efficiency value in cold adapted group was lower than in the controls and in trained in cold group.

Conclusions

Physical training at low ambient temperatures resulted in a decrease of the heat loss responses, like in case of cold adaptation. Working muscle temperature was maintained at a constant level at low ambient temperature. On the contrary it fell in cold adapted persons. Intensive physical exercise at low ambient temperature significantly decreased the cold influence on the muscular energetic and work efficiency.

References

1. Skulachev V.P. Relation between oxygenation and phosphorylation in the respiratory chain. M., AN SSSR, 1962:156.
2. Yakimenko M.A., Zhdanova F.G. Energy expenditure in humans during exercise after adaptation to cold. Fiziol. Zh SSSR, 1979;65;1626-1630.

Cold climate and regional variation in coronary mortality in Sweden

S. Gyllerup

Läkargruppen Husensjö, Helsingborg, Sweden

In Europe there is a high mortality from coronary heart diseases in the northern and north-western parts and a low mortality in the Mediterranean region. Within several European countries such as Great Britain, France, Finland, Germany, Norway and Italy coronary mortality is higher in the colder parts of the country.

Method

The 284 Swedish municipalities were used as units. Mortality from different diseases during 1975-1984 was collected from the Swedish Death Register that is based on the death certificates and was indirectly age standardised against the country.

The cold exposure during the same period was calculated as the number of measurements that were below certain cut-off points during 5 measurements daily. We also corrected for wind-chill using Siple's index. Estimations of unemployment and other demographic factors were collected from several official sources.

The associations were calculated as coefficient of determination and each municipality was weighted according to the number of inhabitants.

Table 1. Coefficient of determination for SMR in acute myocardial infarction when explained by a second degree polynomial of the logarithm of the number of temperature measurements below different cut off points.

Cut-off point (temperature)	Coefficient of determination					
	Men			Women		
	40-64 year	65-74 year	>75 year	40-64 year	65-74 year	>75 year
-10 °C	0.39	0.30	0.16	0.16	0.31	0.15
-20 °C	0.39	0.31	0.15	0.16	0.32	0.16
-10 °C compensated for wind-chill	0.29	0.21	0.11	0.10	0.21	0.10
-20 °C compensated for wind-chill	0.37	0.28	0.15	0.15	0.28	0.16

Results

There was a strong regional association between the number of times the temperature was below -10 °C and mortality in acute myocardial infarction (Figure 1). The association was not stronger when the temperature was corrected for wind-chill (Table

1). The association was strongest in men 40-64 years old and could explain 39 % of the regional variation in coronary mortality. The association was weaker in women and elderly men. The decile of the population that lived in the coldest areas, had 40 % higher mortality than the country as a whole (Figure 2). There was a weaker association between cold exposure and other diagnosis (Table 2).

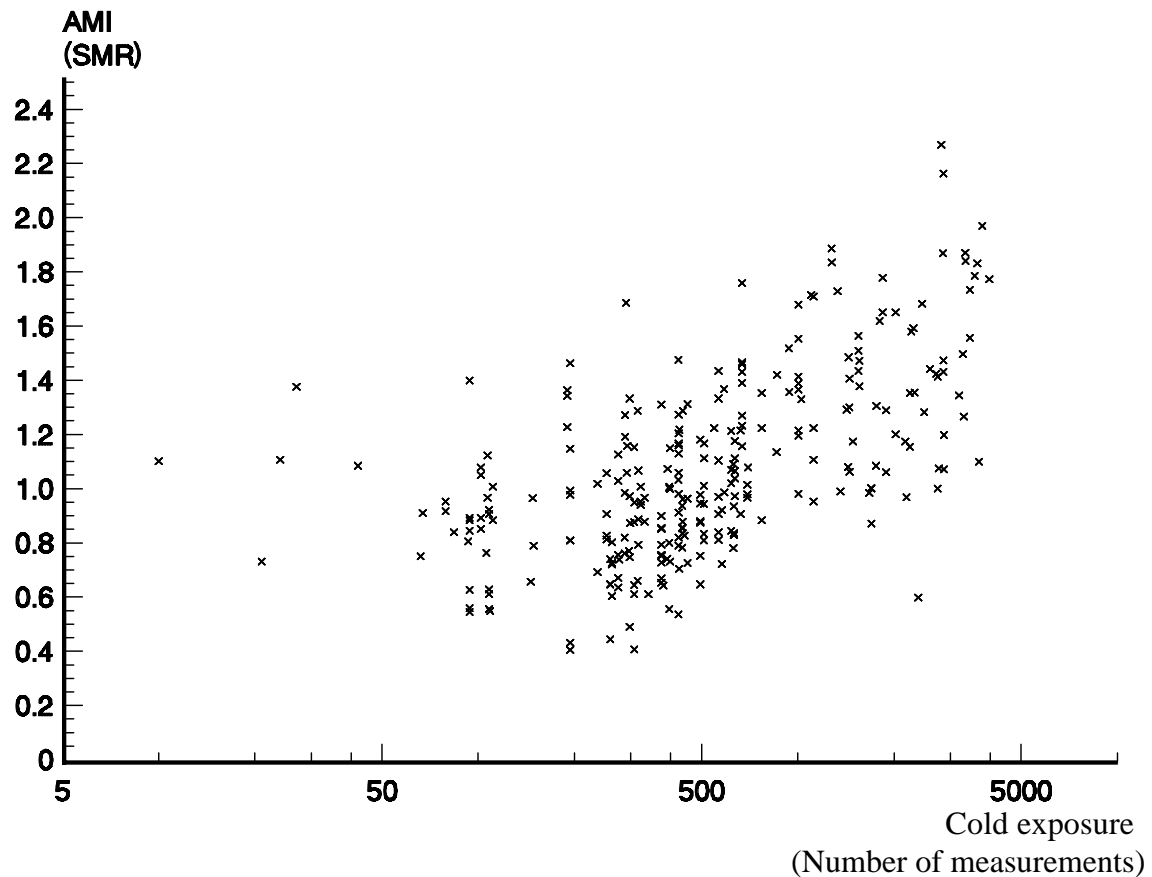


Figure 1. Standardised mortality rates (SMR) in acute myocardial infarction (AMI) 1975-1984 for men 40-64 years old and cold exposure as the number of temperature measurements below -10 °C at 5 measurements per day during daytime the same time period in 284 Swedish municipalities

A multiple regression model showed that cold exposure was the strongest factor and contributed substantially to the power of explanation in each step it was introduced (Table 3).

When looking at the mortality rates in the MONICA study there we found that the mean temperature the coldest month could explain about 15 % of the regional differences in coronary mortality (Figure 3).

Conclusions

There is a strong regional association between cold exposure and high coronary mortality in Sweden. This association could be explained by the several factors discussed during this symposium such as blood pressure, changes in the blood flow or altered metabolism.

Table 2. Coefficient of determination for SMR for men in different diagnoses when explained by a second degree polynomial of the logarithm of the number of temperature below -10 °C.

DIAGNOSIS	Coefficient of determination		
	40-64 year	65-74 year	>75 year
Total mortality	0.02	0.04	0.04
Ischemic heart disease (ICD8 410-414)	0.25	0.16	0.06
Acute myocardial infarction (ICD8 410)	0.39	0.30	0.16
Cerebrovascular disease (ICD8 430-436)	0.10	0.18	0.12
Tumours (ICD8 140-239)	0.13*	0.06*	0.03b
Pneumonia (ICD8 480-486)	0.04*	0.01	0.00
Chronic obstructive pulmonary disease ICD8 490-493)	0.00	0.05*	0.06*

* Negative association

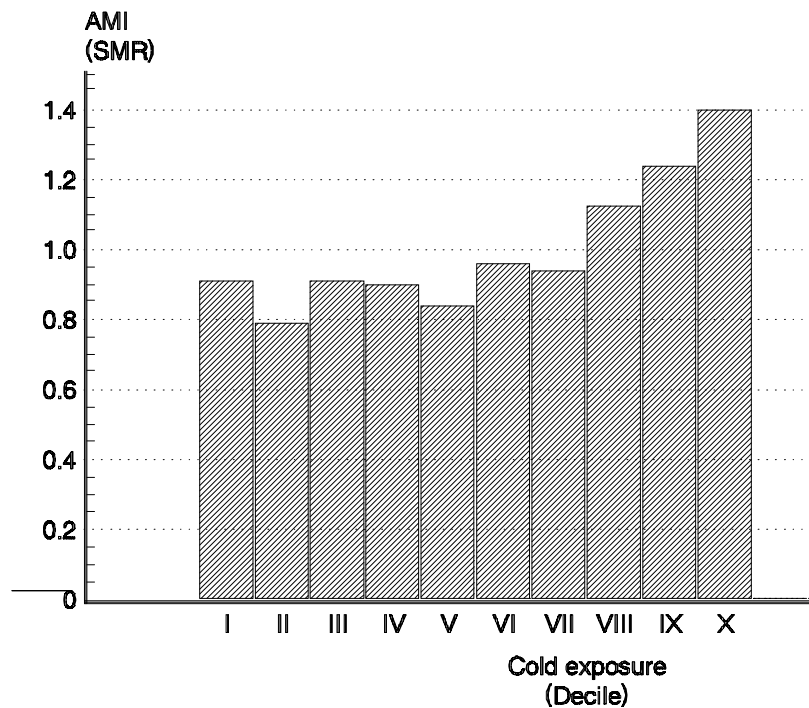


Figure 2. Standardised mortality rates (SMR) in acute myocardial infarction (AMI) 1975-1984 for men 40-64 years old during 1975-1984, when the population is divided into deciles according to cold exposure. I has the lowest and X the highest cold exposure.

Table 3. Coefficients of determination for standardised mortality ratios (SMR) from acute myocardial infarction for men aged 40-64 in 259 Swedish municipalities when explained by two sequences of models, one starting with an empty model, the other with cold index (CI), both cases with stepwise introduction of the following variables (second-degree polynomials in all cases); percentage of manual workers (MW), prevalence of taking snuff (SN), unemployment rate (UE), sales of butter (B), logarithm of drinking water hardness (DWH), sales of antihypertensives (AH), and prevalence of smoking (SM).

Explanatory variables	Without CI	With CI
CI	-	0.39
MW	0.21	0.48
MW + SN	0.28	0.48
MW + SN + UE	0.36	0.49
MW + SN + UE + B	0.39	0.50
MW + SN + UE + B + DWH	0.41	0.50
MW + SN + UE + B + DWH + AH	0.41	0.51
MW + SN + UE + B + DWH + AH + SM	0.41	0.51

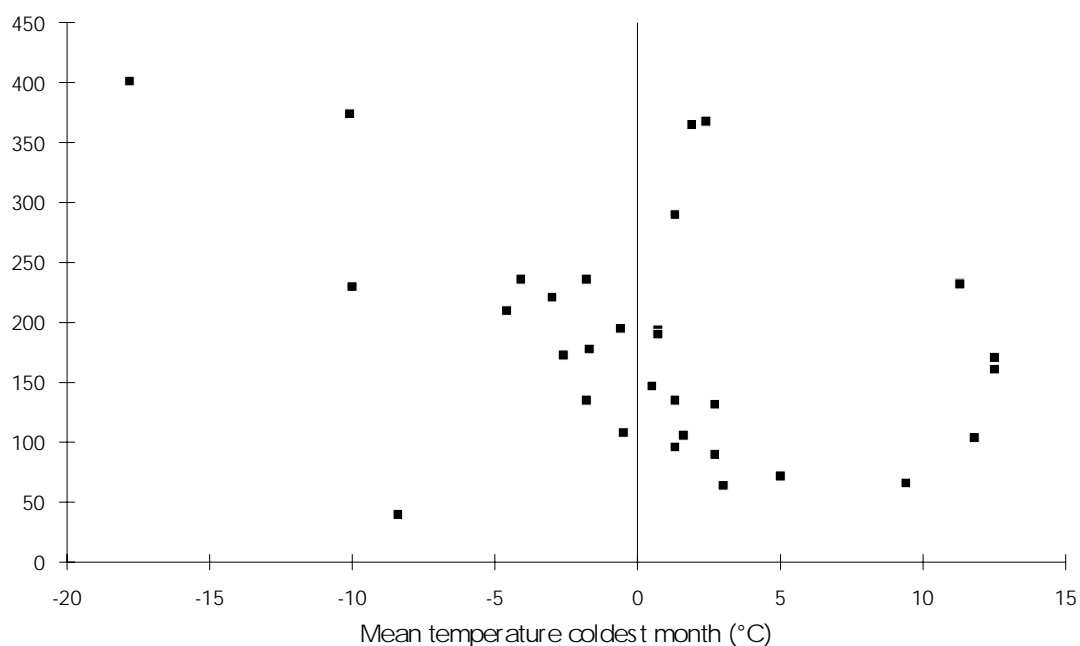


Figure 3. Age-standardised mortality per 100 000 population from ischemic heart disease (IHD) in males aged 35-64, 1984 and the mean temperature of the coldest month in 1984 in 32 MONICA centres.

Slipping and falling accidents on icy surfaces: a case study from northern Sweden

J. Abeysekera, Z. Khan

Division of Industrial Ergonomics, Dept. of Human Work Sciences, Luleå University of Technology, S-971 87 Luleå, Sweden

Introduction

Literature reveals that many pedestrians have been injured by slips and falls on frozen road surfaces in cold regions (Noguchi and Saito 1996). In Nordic countries 16 % of all accidents at work, at home and during leisure activities had been caused by slipping, out of which 2/3 of the slips had occurred on ice or snow (Raoul and Hirvonen 1992). In Sweden, every year thousands of pedestrians are injured, because of slippery pavements and roadways (Gard and Lundborg 1994). Ice and cold related injuries (all categories) have accounted for 37 % of the total cost of all injuries among the elderly in the traffic environment during one year period in Sweden (Sjögren and Björnstig 1991). Slipping and falling accidents often cause fractures and sprains (Lund, 1984). It is a common sight to see crowded orthopaedic clinics during winter in the northern part of Sweden. Expenditure for these injuries are high compared to other injuries. Healing process and rehabilitation usually also take longer time.

Investigating the causes of slipping/falling accidents on snow as well as to ascertain priorities for research on preventing slip and fall injuries, are the main goals of the present study. Ice and snow were considered major types of underfoot surface where they had slipped and fallen. The second aim is to focus the design needs of shoes and shoe materials to be used for walking on snow during winter. The third and final goal is to ascertain the needs for safe walking surfaces for the pedestrians.

Methodology

A total of 40 respondents (>21 years) answered the questionnaire. Among them 20 (14 male and 6 female), represented Swedish nationals and another 20 (15 male and 5 female) represented other nationalities.

The questionnaire analysed the prevalence of slip and fall on snow, types of injuries caused by slipping and falling accidents, effectiveness of the anti-slip materials spread on snow, anti-slip devices, design features of the proper winter footwear etc. Each respondent was explained clearly the purpose of the current investigation and given clear instructions to complete the questionnaire.

Results and Discussions

The prevalence of slips and falls on snow during the past two years is shown in Table 1. Analysis of the questionnaire showed that out of the injuries caused to 13 of the 40 respondents, about 15 % had fractures, 10 % had sprains, 15 % had back pain and bruises on skin, and rest 60 % suffered from pain, swelling and bruises of ankles and knees. The totals and the types of injuries caused by slipping and falling accidents are shown in Table 2. It is revealed that the age between 31-40 years mostly suffered from pain, swelling and bruises in the ankle and knee. Accident prone groups are particularly the age between 51-60 and over 60 years of age.

Table 1. Slipping and falling events among the respondents.

No of events	Slips	Falls
< 5 times	10	15
5-10 times	14	7
10-15 times	5	2
15-20 times	3	2
> 20 times	3	0
Total	35	26

Table 2. Injuries caused by slipping and falling accidents.

Age group	Types of injury			
	Fracture	Sprains	Back pain and bruises	Pain, swelling and bruises in ankle and knee
Total	15 (%)	10 (%)	15 (%)	60 (%)
<20	0	0	0	0
21-30	2.5	0	0	10
31-40	5	0	0	25
41-50	2.5	0	0	5
51-60	0	10	10	15
>60	5	0	5	5

The most common hazard associated with falls and slips was walking on surfaces when snow has fallen on hard ice as rated by the respondents. Next risky factor for slipping/falling event during winter was walking on frozen or icy surfaces. The least risky phase was slipping/falling on fresh snow. Figure 1 shows the mean values of ratings of risk (using a 5 point rating scale) of slipping/falling accident during various phases in winter.

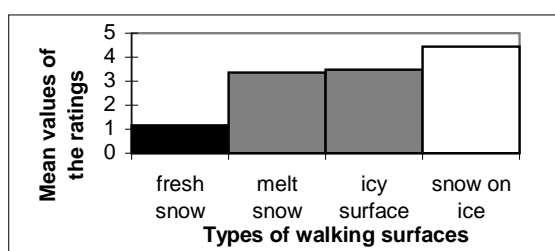


Figure 1. Risky surfaces for slipping/falling during winter.

Anti-slip materials are spread on snow to prevent slipping/falling during winter. Sand is regarded the best anti-slip material based on the respondents ratings (using a 3 point

rating scale). Next effective anti-slip material preferred is small stone and least effective is salt. Effectiveness of the different anti-slip materials spread on snow are shown in Figure 2.

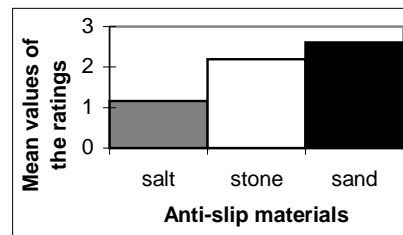


Figure 2. Effectiveness of anti-slip materials rated by respondents.

28 % of respondents adopted a special technique (i.e., taking small steps) to walk and 15 % of them walked slowly. Only 25 % of the respondents used anti-slip devices on their shoes. A study by Gard and Lundborg (1994) showed that anti-slip devices were perceived as bulky and clumsy, heavy or had too many different parts. 47 % of the respondents preferred winter shoes with anti-slip sole of coarse rubber and 20 % of them preferred sole of hard rubber with spikes. Regarding the shoe heels 53 % preferred coarse rubber and 33 % of them preferred heel of hard rubber with steel spikes. About 74 % preferred light anti-slip foot wear during winter. Light shoes require less energy consumption to walk or run compared to heavier foot wear (Martin, 1984). Big shoe with sufficient space was preferred by 40 %. In cold climate, it is important that the shoes are big enough to accommodate the thick socks (Bergquist and Abeysekera, 1994) and allow the toes to move (Nielsen, 1991). Another 40 % of the total respondents preferred aesthetic design and well fitting foot wear which was also revealed in a study by Nielsen (1991). About 60 % of the respondents suggested soft/leather material for upper shoes. 20 % of them suggested Gore Tex materials. About 7 % preferred water proof/rubber types of materials for upper part of the shoe.

Conclusions

The detailed questionnaire survey confirmed that the primary risk factor was slippery icy surface condition i. e., when fresh snow has fallen on hard ice. Notable amongst other factors mainly is the unsuitable and slippery footwear used during winter. Shoes with anti-slip qualities should be developed. The shoe manufacturers need correct information of the material to manufacture proper winter shoes. Pedestrians, especially the new arrivals from different countries should be given proper training to walk on snow. To prevent falling after a slip the balancing properties of the shoe should be improved. It is believed that if the centre of gravity of shoe is situated in-line with or very close to the centre of gravity of the wearer's foot, it may improve the wearer's balancing ability. This can be tested through objective measurement, which is proposed for future research on designing anti-slip shoes. Shoe soles made with anti-slip materials (Noguchi and Saito., 1996) are more user friendly and a more practical and a comfortable way of preventing slips and falls than fixing anti-slip devices on shoes. Other important measures to prevent slipping accidents suggested are efficient system of snow clearing and gritting in walkways. Finally, it is recommended that further research is needed to review the existing information on the aetiology of slips and falls

on snow and develop proper anti-slip winter outdoor shoes. Ideas obtained from this study should be considered in future research.

References

1. Bergquist K, Abeyssekera J. Research needs to improve wearability of personal protective devices and clothing (ppds) in the cold climate, *International Conference on Development and Commercial Utilization of Technologies in Polar Regions, (Polartech)*. 1994:369-375.
2. Gard G, Lundborg G. Pedestrians transportation problems on different slippery surfaces during winter and the functionality of different anti-skid devices, *Proceedings of International Conference on Development and Commercial Utilization of Technologies in Polar Regions (Polar-Tech)*. Sweden 1994 19-26.
3. Lund J. Accident falls at work, in the home and during leisure activities. In: Occupational Accident Research. Proceedings of the International Seminar on Occupational Accident Research. Sweden 1984:181-193.
4. Martin P E. The effect of lower extremity loading on mechanical and physiological measures of running performance (Abstract), *Medicine and Science in Sports*. 1984:16:185.
5. Nielsen R. Work clothing. *Int J Ind Erg* 1991:7:77-85.
6. Noguchi T, Saito J. Change of acceleration during gait. Tomakomai National College of Technology, Japan 1996.
7. Noguchi T, Saito J. Proper arrangement system fasten anti-slip devices on winter shoes for the disabled-basic ways of thinking and trial application. Tomakomai National College of Technology, Japan 1996.
8. Raoul G, Hirvonen M. Slip resistance of winter shoes on icy surface. In: Proceedings of Quality and Usage of Protective Clothing. 1992 123-129.
9. Sjögren H, Björnstig U. Injuries to the elderly in the traffic environment. *Accid. Anal. & Prev.* 1991:23:77-86.

Quantitative analysis of surface EMG in diphtheric polyneuropathy patients

L. Gerasimova, A. Meigal, A. Sergeev, Yu. Lupandin

Department of Physiology, Petrozavodsk State University, Petrozavodsk, Russia

Introduction

Through the years 1993-1996 in the Republic of Karelia 814 cases of diphtheria in adults were registered, 10.4 % of those were followed by neurologic complications. Polyneuropathy appears to be one of the severe complications of diphtheria, because it causes long-term disability in patients [6]. Pathological symptoms of diphtheric polyneuropathy (DPN) are based on periaxonal segmental demyelination of nerves and radicle, with axons usually being intact [7]. The same pathological process is the characteristic of some related diseases, e.g. acute inflammatory demyelinating polyradiculopathy [4, 7]. Electromyography (EMG) and electroneurography are widely used to diagnose polyneuropathy. Conventional electrophysiological study includes measurement of sensory and motor nerve conduction velocity (NCV), and analysis of motor unit action potentials [3]. Analysis of integrated EMG (IEMG) is also informative and it could contribute to quantitative assessment of the state of neuro-motor system [2, 5]. The objective of the presented study was to investigate the potential diagnostic use of the IEMG in the DPN patients.

Methods

DPN patients (n=17) were examined 1-33 months after acute diphtheria. Reference group included 7 healthy, age matched subjects (mean age 28.5 ± 2.4 yr.). DPN patients were subdivided into two groups by the severity of polyneuropathy. The first group (DPN-0) included 6 patients without motor disorders (2 males and 4 females, 34.4 ± 5.3 yr.), which were examined 14.5 ± 2.3 months after diphtheria infection. These patients had peripheral sensor disorders only. Another group (DPN-M) included 11 patients (4 males and 7 females, 37.0 ± 4.2 yr.), which were examined 7.5 ± 1.8 months after diphtheria. These patients had motor disorders in a form of moderate flaccid paresis (n=6) and weakness of hand flexors (n=5).

EMG activity of m. flexor digitorum superficialis was analysed along with increasing force (1, 2, 3, 4, 6, 8 kg) produced by weight supporting at elbow flexion (elbow joint angle 90) within 3-5 sec. Analysis of IEMG of m. gastrocnemius was performed during 8-10 trials of standing on the tip-toes. Electrophysiological investigation was performed using MG440 device (Mikromed, Hungary), with the help of surface lead bipolar electrodes. Raw EMG signal was computed using "Neuromyograph" software (MBN, Moscow, Russia). Electrophysiological session included computing motor NCV (m/s) of the ulnar nerve by measurement of latency of M-responses [3] and analysis of IEMG of m. flexor digitorum superficialis and m. gastrocnemius (lateralis). IEMG analysis

included plotting the amplitude (RMS, μV) and turns vs. the force with calculation of the regression and correlation coefficients. Peak ratio analysis was conducted both in m. flexor digitorum superficialis and m. gastrocnemius. Peak ratio is the highest value of ratio of turns to mean amplitude per 1 sec, using mean amplitude as substitution of force [2]. Student's t-test and non-parametric criteria were used to estimate the difference between electrophysiological parameters within the groups. Correlation analysis was performed to evaluate dependence of these parameters on the severity of polyneuropathy.

Results

The values of electrophysiological parameters were highly dependent on the severity of polyneuropathy. The decrease of NCV was documented in both groups of DPN patients (in DPN-0 56.42 ± 4.05 m/s, $p < 0.05$; in DPN-M 47.99 ± 1.18 m/s, $p < 0.001$) in comparison with healthy subjects (66.42 ± 2.87 m/s). The decrease of NCV significantly correlated with the severity of polyneuropathy ($r = 0.40$, $p < 0.001$).

In DPN patients EMG of m. flexor digitorum superficialis was characterised by significantly lower level of IEMG amplitude and less number of turns along with increasing force in comparison with the healthy subjects. This evidences that less number of muscle fibres are recruited into contraction [2]. This decrease of both IEMG amplitude and turns significantly correlated with the severity of polyneuropathy ($r = 0.69$, $p < 0.001$ for amplitude of IEMG and $r = 0.75$, $p < 0.001$ for turns).

The decrease of peak ratio of turns to IEMG amplitude per 1 s, as well as the decrease of IEMG amplitude of peak ratio were found to be the characteristic of m.flexor digitorum superficialis and m.gastrocnemius in DPN patients. Both peak ratio values were found to depend on the severity of polyneuropathy (m.flexor digitorum superficialis: $r = 0.67$, $p < 0.001$ for peak ratio and $r = 0.80$, $p < 0.001$ for IEMG amplitude of peak ratio; m.gastrocnemius: $r = 0.83$, $p < 0.001$ and $r = 0.88$, $p < 0.001$, respectively).

Conclusions

The presented investigation showed that analysis of surface IEMG characteristics is sensitive to reveal pathological changes in the muscle activity of the DPN patients. Surface EMG analysis could contribute to quantitative assessment of the state of neuromuscular system and could be used as additional method during a period of rehabilitation, when repetitive diagnostic tests are required to control the process of recovery.

References

1. Creange A., Meyrignac C., Roualdes B., Degos JD., Gherardi RK. Diphtheritic neuropathy. *Muscle & Nerve* 1995;18(12):1460-1463.
2. Fuglsang-Frederiksen A. Interference EMG analysis. In: Desmedt J.E. ed. *Computer-aided electromyography and expert systems*. Elsevier Science Publishers B.V. 1989:161-179.
3. Geht B.M. *Theoretical and clinical electromyography*. St. Petersburg, Nauka Publ House 1990.

4. Geht B.M., Merkulova D.M., Kasatkina L.F., SamoiloV M.I. Clinics, diagnosis and treatment of demyelinating polyneuropathy. *Neurol J (Moscow)* 1996:1:12-17. (in Russian, summary in English).
5. Haig A.J., Gelblum J.B., Rechten J.J., Gitter A.J. Technology assessment: the use of surface EMG in the diagnosis and treatment of nerve and muscle disorders. *Muscle & Nerve* 1996:19:392-395.
6. Lobzin Yu.V., Zagryadskyj P.V., Bazhukov O.A. Neurological complications of diphtheria. *Military Medical J (Moscow)* 1996:1:47-51.
7. Solders G., Nennesmo I., Persson A. Diphtheritic neuropathy, an analysis based on muscle and nerve biopsy repeated neurophysiological and autonomic function tests. *J of Neurol, Neurosurg and Psychiat* 1989:52:876-880.

Rate and special features of the blood flow in separate capillaries of brain and muscles during deep cooling and rewarming

K. P. Ivanov, S. V. Shevchenko, Yu. I. Levkovich

I. P. Pavlov Institute of Physiology, Russian Academy of Sciences, St. Petersburg 199034, Russia.

During deep accidental hypothermia the retention of viability and success of rewarming an organism depend on the microcirculation in brain and in muscles.

The studies were carried out using a cinema-TV complex for observing and microfilming minute blood vessels of brain and muscles in situ with the help of a contact dark-field objective (20×0.60). The objective was brought into contact with the object under investigation (surface of brain or muscle). The depth of vision was controlled by varying the effective length of the microscope body tube, i.e. the distance between the objective and the eyepiece. With the effective magnification of $300 \times$ we could observe and film blood vessels 2 - 5 μm in diameter and more at the tissue depth up to 70 μm [3].

The animals (rats) were cooled in water at the temperature 7 - 9 °C. We registered the temperature in brain and in rectum, arterial blood pressure, lung respiration.

Erythrocytes in a capillary move in one row one after another. Observational data indicate that at normal arterial pressure there are gaps, spaces filled with plasma, in the continuous erythrocyte flow in different capillaries of brain and muscles. Such gaps appear and pass irregularly through a vessel from time to time. As the interval between two frames was 0.025 sec we can calculate easily the rate of the gap motion and, consequently, the blood flow velocity through the capillary [1].

Observation of capillary blood flow and measurements, using the technique described, indicated that velocity of a capillary blood flow varies continuously. Therefore an average of 10 separate measurements of blood flow velocity have been performed for each capillary. The mean velocity for given capillary was deduced from these measurements. The distribution of mean velocities of blood flow in all the investigated capillaries we studied with the help of histograms. With the help of these histograms we calculated general mean blood flow velocity for all the investigated capillaries in brain or muscle at different body temperature [2].

At the very beginning of the cooling, when the temperature decreases by 2-3 °C, an increase in the arterial blood pressure and in the blood flow velocity in the capillaries of brain and muscles is observed. This is associated with the general excitation of the animal and with the initiation of shivering. Upon further cooling the blood pressure and the blood flow velocity in the capillaries of brain and muscles begin to decrease. However the most abrupt changes in the blood pressure and the blood flow velocity occur only upon a very deep cooling. At the brain temperature of 21-23 °C the blood pressure decreases by 20-30 % and the blood flow velocity in the brain capillaries decreases by about the factor of two.

However the most interesting and important events occur upon a deeper cooling. At the brain temperature of 19 - 20 °C the blood flow velocity in the brain capillaries is still about 40 % of the norm, in muscles it decreases by 20-30 %.

After the arrest of the lung respiration at the brain temperature of 18 - 19 °C the arterial blood pressure can retain for several minutes at the level of 40-60 mmHg, and the blood flow velocity in the brain capillaries still retains 40 % of the norm. In muscles the blood flow velocity in the capillaries is maintained at the same level. Therefore, even upon deep cooling after the arrest of respiration the microcirculation can still be very intensive. However, if the temperature of brain remains at the level of 17 - 18 °C and the respiration is absent, in 5 - 10 min the arterial blood pressure decreases to 20-30 mmHg. Nevertheless even at this very low pressure and very low brain temperature microcirculation in the brain capillaries persists. At this period the observations become hampered. However we were able to observe microcirculation at a very low temperature of brain in 5-10 min after the arrest of respiration. The results of one of such experiments are given in Table 1.

Table 1. The blood flow velocity in the capillaries of brain cortex.

	Initial stage. Average data. 10 measurements in every capillary. Brain temperature in the field of hypothalamus 35.6 °C. Arterial blood pressure 100 mmHg.	Hypothermia. In 8 min after the arrest of respiration. The same capillaries. Average data. 5 measurements in every capillary. Brain temperature 15.5 °C. Arterial blood pressure 30 mmHg.
Capillary No 1.	2.79±0.21 mm/sec	0.55±0.20 mm/sec
Capillary No 2.	1.77±0.40 mm/sec	0.44±0.14 mm/sec
Capillary No 3.	1.43±0.33 mm/sec	0.43±0.16 mm/sec

Microcirculation persists in brain and in muscle capillaries in spite of very low arterial blood pressure, partial aggregation of erythrocytes, increased Ht. There is no stagnation of the blood in the microvessels. During warming the microcirculation is restored very quickly. Consequently, even very deep cooling doesn't damage both erythrocytes and vessel walls. These facts, it seems to us, are very important for medical strategies during resuscitation of the victims of accidental hypothermia

References

1. Ivanov, K.P., Kalinina, M.K., Levkovich, Yu.I. *Microvas. Res.* 1981.V.22.P.143-155.
2. Ivanov, K.P., Levkovich, Yu.I., Moskovskaya, S.V., Maltsev, N.A. *Sechenov Physiol. J.* 1996. V.82. P. 86 - 92 (Russian).
3. Lewkowtsch, J.I., Ogurzowski, J.G., Maltzew, N.A. *Wiss. Film.* 1986. Nr.34/35. June. S.126-130.

Differences in cold exposures associated with excess winter mortality

W. R. Keatinge, G. C. Donaldson

Department of Physiology, Queen Mary and Westfield College, University of London., Mile End Road, London, E1 4NS, UK

During the last quarter of a century it has been increasingly widely realised that increases in mortality during winter form one of the largest groups of preventable deaths (1, 2, 3, 4, 5). It has also been obvious that the size of the excess winter mortality varies greatly between countries. This mortality has declined in most industrialised countries during this time. Reasons for the decline probably include the improvements that have taken place in home heating and car ownership, both of which reduce population exposures to cold. Evidence that any form of protection against cold is clearly associated with reduced winter mortality has, however, been lacking. Many factors other than cold can affect the crude percentage change in mortality between summer and winter. Since most of the excess mortality in winter affects elderly people, the age structure of the population is clearly important. Differences in climate provide another obvious element. Heat-related mortality in summer can mask increase of mortality due to cold in the winter. The most serious problem, though, has been lack of comparable information about home temperatures and outdoor protection against cold in the different regions. The recent development of quota methods for commercial surveys, and the availability of Europe-wide funding for large scale projects from the European Union, have now made it possible to carry out a survey of these factors for standardised age groups, and to link the results to increases in age-specific excess mortality, and to regional climate. This Eurowinter project (6) was based on active surveys of home temperatures and questionnaires, in 1000 homes in each of eight regions of Europe from the Arctic to the Mediterranean, and on mortalities provided by a research team in each region, using standardised methods, and with regional and central checks to ensure that the questionnaires carried the same meanings after translation into the regional languages.

The main summary variables extracted for each region at the first stage of analysis were the steepness of increase of each cause-specific mortality with fall in temperature from 18 °C, expressed as a fraction of mortality at 18 °C to allow for regional differences in basal mortality. These provided indices of winter mortality. Values obtained from surveys, such as evening temperature in the living-room, and outdoor clothing and activities, were adjusted by regression to a uniform outdoor temperature of 7 °C to give standardised cold exposure factors for each region. Each cause specific mortality was lagged on temperature by the number of days' delay that gave the largest effect. All summary variables for each region were calculated separately for men and for women, for age groups 50-59 and 65-74 years, and for each cause of death and each cold exposure factor.

Some of the most striking results are obvious from simple inspection of the primary results, and for combined age and sex groups in each region. Figure 1 shows the mortality-temperature relations for Athens and for South Finland, both of which had

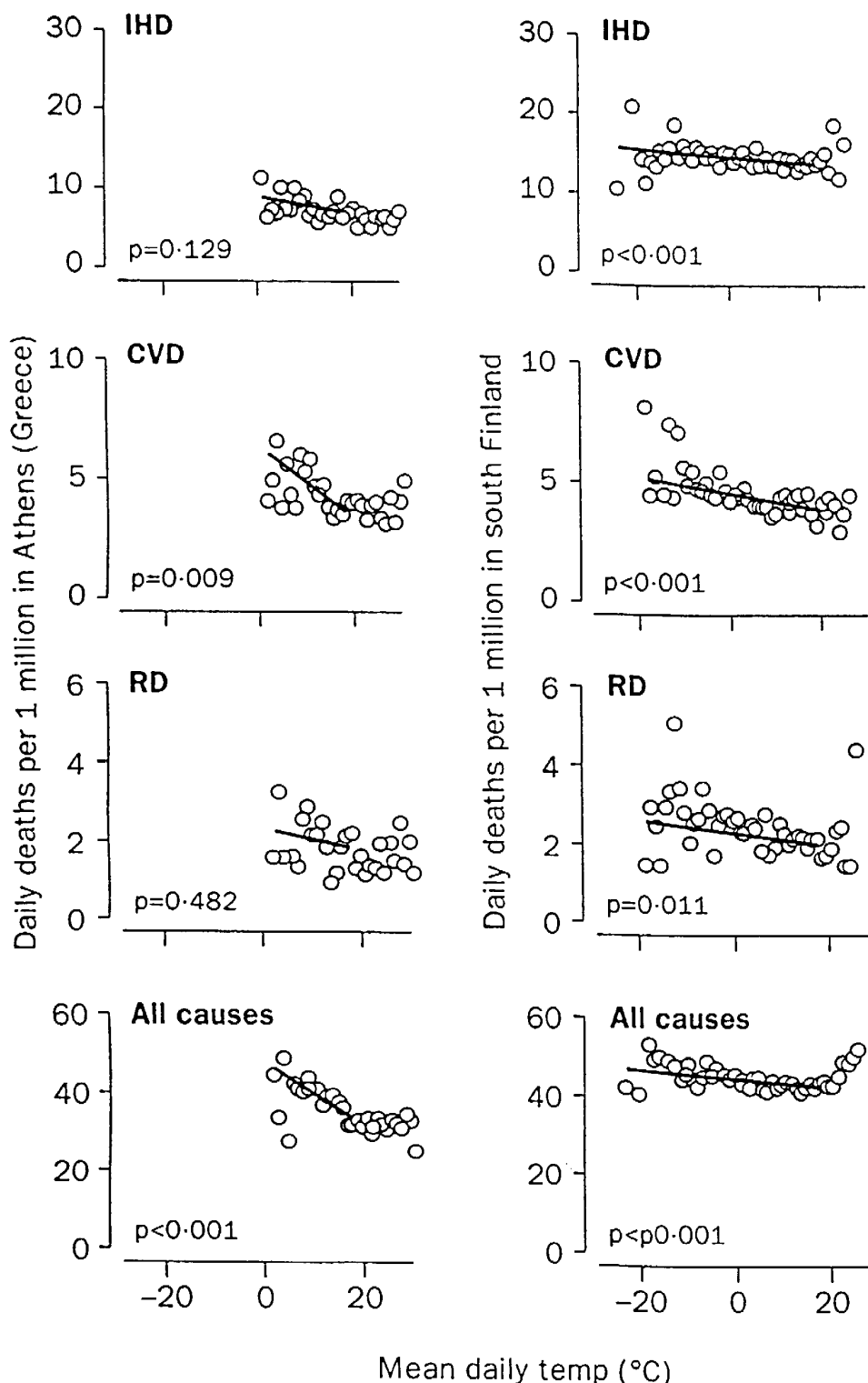


Figure 1. Deaths per day per 10⁶ population in relation to mean daily temperature in one warm and one cold region.

Age groups 50-59 and 65-74 years combined. Reproduced from "Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe" by the Eurowinter Group (W. R. Keatinge, G. C. Donaldson, K. Bucher, G. Jendritzky, E. Cordioli, M. Martinelli, L. Dardanoni, K. Katsouyanni, A. E. Kunst, J. P. Mackenbach, C. McDonald, S. Näyhä, I. Vuori) *Lancet* 1997; **349**: 1341-6.

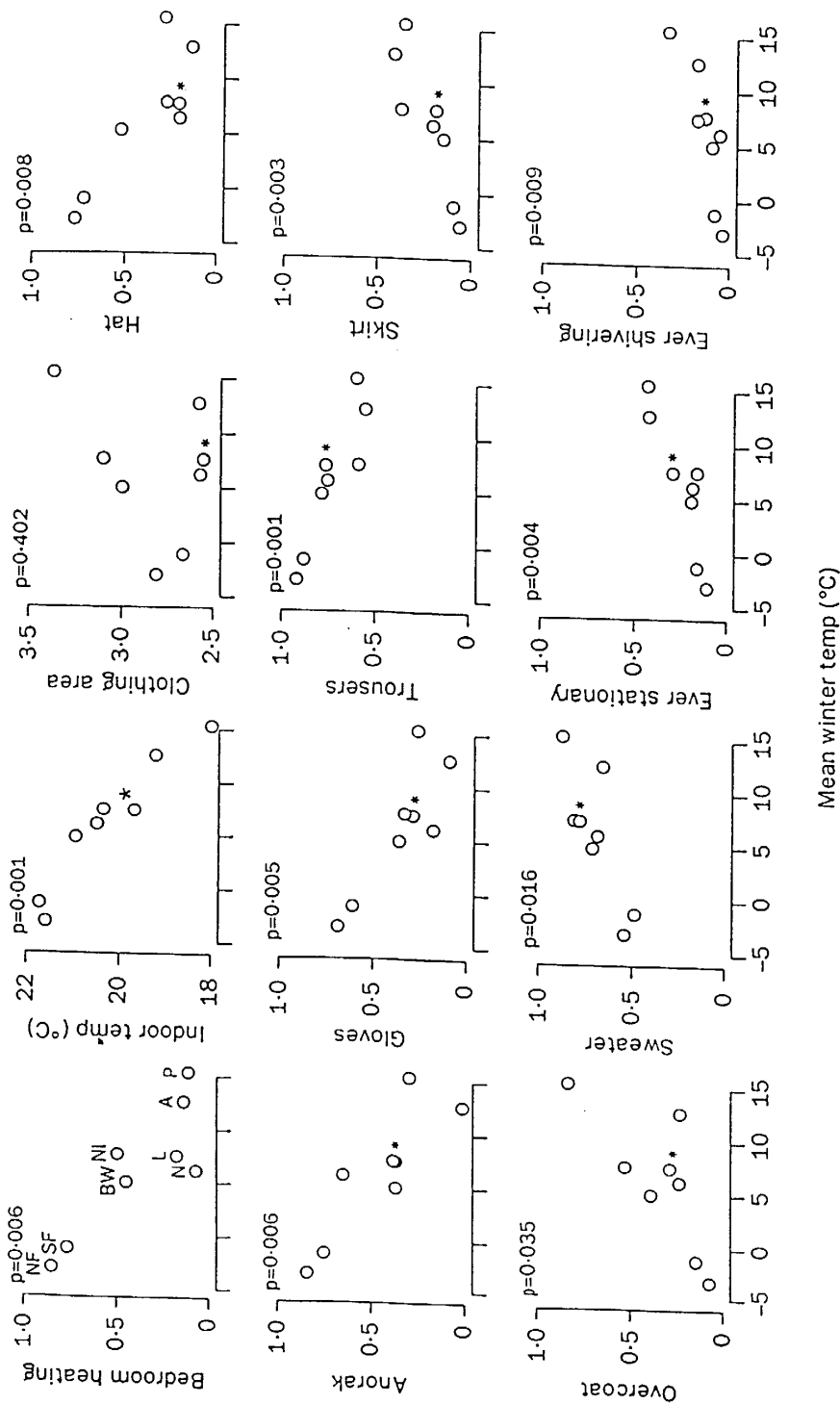


Figure 2: Personal cold exposure factors at standard outdoor temperature 7°C in relation to mean winter temperature of region
 All values for previous 24 h. Indoor temperature in living-room after 1700 h; bedroom heating ≥ 4 h=1, <4 h=0; clothing area=total area of clothing/body surface area; other variables 1=0=yes, 0=no. Skirts worn by women only. Points from left to right: north Finland (NF), south Finland (SF), Baden-Württemberg (BW), Netherlands (N), London (L), north Italy (NI), Athens (A), Palermo (P). London given asterisk to distinguish from north Italy. Mean winter temperature in latter only 0.1°C higher than London.
 Age groups 50-59 and 65-74 years combined. Reproduced from 'Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe' by The Eurowinter Group (W R. Keatinge, G.C. Donaldson, K. Bucher, G. Jendritsky, E. Cordioli, M. Martinelli, L. Dardanoni, K. Katsouyanni, A.E. Kunst, J.P. Mackenbach, C. McDonald, S. Nayha, I. Vuori) Lancet 1997; **349**: 1341-6.

large populations but in which climate was very different, with much colder winters in Finland than in Athens. For each cause of death, the mortality rose more steeply with fall in temperature in Athens than it did in Finland. This was so marked that although there were many more cold days in Finland and they extended to a much lower temperature range, even the absolute number of excess winter deaths from all causes, in these age groups, was greater in Athens. Linear regression showed that the indices of all-cause winter mortality were significantly higher in regions with warm than in those with cold winters.

Figure 2 shows that there were also striking associations between cold exposure factors and mean winter temperature of the region, all at a standardised outdoor temperature of

7 °C. At this outdoor temperature the people in regions with cold winters were much more likely to heat their bedrooms, and had higher living-room temperatures, than those in colder regions. When outdoors they were much more likely to wear a hat and gloves, to wear an anorak rather than overcoat or sweater, and in the case of women, to wear trousers rather than a skirt. A point of particular interest was that they were also more likely to keep moving while outside in the same temperatures. Together with these tendencies to wear more effective and more windproof and waterproof clothing while outdoors and to maintain more physical activity, and presumably because of them, people in warmer regions were much more likely to feel cold enough to shiver while they were outside at 7 °C.

There were also striking associations between these various protective factors against cold exposure, and low levels of winter mortality, in the groups concerned. The index of winter mortality was low in groups that had heated bedrooms, warm living rooms, and when outdoors at 7 °C wore hats, gloves, anoraks, kept physically active, and seldom shivered. All of these indoor and outdoor factors that were associated with low winter mortality will tend to reduce personal exposures to cold and each is likely to have made a contribution to reducing mortality. It would be useful to know the size of the contribution of each of these factors to mortality in winter. In practice this can not be determined with any precision, because a change in one of these factors was usually closely correlated with changes in the others. However, it was at least possible to assess separate effects of indoor and outdoor factors by multiple regression, by using either bedroom heating or living-room temperature as an indicator of indoor protection against cold, and using shivering while outdoors as an indicator of outdoor cold exposure. This showed significant effects of indoor heating on mortality independent of outdoor exposures, and also of outdoor exposure independent of indoor heating.

Perhaps the most important aspect of these findings is that they show for the first time a clear association between protective measures against personal cold exposure on the one hand, and winter mortality on the other. This has obvious implications for practical policies to prevent winter mortality. The statistical association do not, of course, prove a causal relationship, but they are an essential step in establishing this, and together with other available evidence make a causal relationship very probable. Close time relations that were demonstrated between cold weather and mortality in a separate study provide strong evidence that personal cold stress is an important factor. Mortality from ischaemic heart disease rises rapidly to a peak within two days after the peak of a cold spell, while respiratory mortality rises more slowly and peaks only after about 12 days (7, 8). A probable explanation for the rapid increase in ischaemic heart deaths is provided by the fact that cold exposure of volunteers causes increased concentration in the blood of a variety of thrombogenic agents, including red cells, platelets, and fibrinogen (9, 10). This happens as a direct consequence of physiological vascular adjustments to cold. Respiratory infections, which are common in winter, can also increase ischaemic heart disease, probably through the increase in plasma fibrinogen produced by infections of many kinds (11). It is possible that entirely different factors such as reduced intake of vitamin C in winter also contribute to winter mortality (12), independently of direct effects of cold on people. However, direct effects of cold are clearly a central element.

Another important point is that both indoor and outdoor factors appear to contribute. Home heating has long been assumed to be an important factor in relation to winter mortality, but its role has been questioned, and there have even been suggestions that it could contribute positively to winter mortality by increasing the cold shock when people go from an indoor to a cold outdoor environment. As regards the role of outdoor

cold the Eurowinter evidence, together with earlier findings that elderly people living in well heated accommodation can show high levels of winter mortality (13), gives evidence of its importance. The overall evidence therefore now strongly suggests that both indoor heating and outdoor protection against cold are important in prevention. It is not possible to distinguish clearly effects of bedroom heating from those of living room heating during the day, but it seems likely that both can contribute to the control of winter mortality.

As a matter of practical policy, there is clearly a need to increase awareness among middle-aged and elderly people of the importance both of sufficient clothing and of exercise to prevent cold stress while outdoors, and of maintaining at least a small living area indoors at fully comfortable warmth. This is not as easy as it sounds. Elderly people can react with irritation if given advice that appears to them to be obvious. One of the most important consequences of the recent studies may be that they enable such people to be given evidence that, particularly in regions with mild winters, many people do in fact fail to take effective measures against cold, and that this is associated with high mortality. Apart from giving such advice, and continuing general support for home heating and insulation, governmental and charity organisations could play an important role both in promoting measures such as windproof bus shelters that enable people to avoid cold exposure outdoors, and in specifically promoting provision in all housing of at least a limited core area that can economically be heated to full comfort level in winter.

References

1. Bull GM, Morton J. Environment, temperature and death rates. *Age Ageing* 1978; **7**: 210-224.
2. Bainton D, Jones GR, Hole D. Influenza and ischaemic heart disease - a possible trigger for acute myocardial infarction? *Int J Epidemiol* 1978; **7**: 231-239.
3. Alderson MR. Season and mortality. *Health Trends* 1985; **14**: 87-96.
4. Keatinge WR, Coleshaw SRK, Holmes J. Changes in seasonal mortalities with improvement in home heating in England and Wales from 1964-1984. *Int J Biometeorol* 1989; **33**: 71-76.
5. McKee CM. Deaths in winter: can Britain learn from Europe? *Eur Epidemiol* 1989; **5**: 178-82.
6. The Eurowinter Group: Keatinge WR, Donaldson GC, Bucher K, Cordioli E, Dardanoni L, Jendritzky G, Katsouyanni K, Kunst AE, Mackenbach JP, Martinelli M, McDonald C, Näyhä S, Vuori I. Cold exposures associated with winter mortalities from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all-causes, in warm and cold regions of Europe. *Lancet* 1997; **349**: 1341-6.
7. Mackenbach JP, Looman CWN, Kunst AE. Air pollution, lagged effects of temperature, and mortality: the Netherlands 1979-87. *J Epidemiol Community Health* 1993; **47**: 121-126.
8. Keatinge WR, Donaldson GC. Time courses of mortalities after cold weather. *Proceedings of the 33rd International Congress of Physiological Sciences*, June 1997, St. Petersburg.

9. Keatinge WR, Coleshaw SRK, Cotter F, Mattock M, Murphy M, Chelliah R. Increases in platelet and red cell counts, blood viscosity and arterial pressure during mild surface cooling: factors in mortality from coronary and cerebral thrombosis in winter. *Br Med J* 1984; **289**: 1405-1408.
10. Neild PJ, Syndercombe-Court D, Keatinge WR, Donaldson GC, Mattock M, Cauce M. Cold-induced increases in erythrocyte count, plasma cholesterol and plasma fibrinogen of elderly people without a comparable rise in protein C or factor X. *Clin Sci* 1994; **86**: 43-48.
11. Woodhouse PR, Khaw K-T, Plummer M, Foley A, Meade TW. Seasonal variations of plasma fibrinogen and factor VII activity in the elderly: winter infections and death from cardiovascular disease. *Lancet* 1994; **343**: 435-439.
12. Gale CR, Martyn CN, Winter PD, Cooper C. Vitamin C and risk of death from stroke and coronary heart disease in cohort of elderly people. *Br Med J* 1995; **310**: 1563-66.
13. Keatinge WR. Seasonal mortality among elderly people with unrestricted home heating. *Br Med J* 1986; **293**: 732-733.

Precise motor coordination during cold induced shivering in the man

A. Meigal, L. Gerasimova, J. Oksa, H. Rintamäki**

Department of Physiology, University of Petrozavodsk, Petrozavodsk, Russia

*Oulu Regional Institute of Occupational Health, Oulu, Finland

Introduction

Cold shivering and motion activity of the motor system recruit one and the same type of motor units, and they probably stay under competition to each other for the final common pathway, i.e. for the spinal motoneurons. The intensity of cold shivering, quantified by surface EMG, showed that in the proximal muscles it ranged from 5 to 16 % of maximal voluntary contraction [1], and this may evoke disturbances in muscle performance in cold. In 1996, Meigal et al. [2] demonstrated that neck and labyrinthine tonic reflexes influence the intensity of thermoregulatory muscle tonus in human muscles, while cooling and heating conditions influence after-contraction tonus [3]. However, the influence of cold shivering on the precise voluntary movements in man have not been yet quantified. The aim of this study was to find out whether thermoregulatory muscle tonus and cold shivering influence biofeedback aided control of force output, and to quantitatively evaluate this influence by force and electromyographical characteristics.

Methods

Before the tests, the subjects ($n=6$, mean age was 39 ± 8 years, height 176 ± 9 cm, weight 71 ± 6 kg and body fat $15\pm \%$).sat for 30 min at $27\text{ }^{\circ}\text{C}$ (thermoneutral air reference). After that they were exposed to $10\text{ }^{\circ}\text{C}$ (cold air condition) for further 30 min. To produce intensive shivering the subjects were instructed to drink 1 litre of cold water ($8\text{ }^{\circ}\text{C}$, within 1-5 min) after the exposure to cold air (cold air/cold drink). After that subjects were exposed to cold till the end of the tests (15-20 min). Totally cold exposure lasted for 50-55 min. The subjects were dressed in shorts and jogging shoes. Mean skin temperature (T_{sk}) and rectal temperature were followed (T_r).

The EMG activity of m. brachioradialis, m. brachialis, m. biceps brachii, m. triceps brachii, mm. pectoralis major dex et sin, m. latissimus dorsi and m. deltoideus were measured. EMG signals from the skin above the working muscles were acquired with a help of ME4000 device (MEGA Electronics Ltd, Kuopio, Finland), using pre-gelled bipolar surface electrodes (Medicotest, M-OO-S, Olstykke, Denmark). The integrated EMG (IEMG) and mean power frequency (MPF) were calculated. Subjects kept constant force (F, 10, 20, 40, 80 % of MVC) for 15 sec during elbow flexion in all three temperature conditions. The F production was measured with a strain gauge (Newtest Ltd, Finland). Mean level of force (F) and coefficient of force variation (FCv, SD

divided by mean) were analysed. The analysis was done by using Isopack software analysis system (Newtest Ltd, Finland).

Paired t-test was used to test the differences of force and EMG values from the cold air condition and cold air/cold drink condition against the results obtained from thermoneutral air condition. Significance was accepted at the 0.05 level.

Results

Thermoneutral air stabilised T_{sk} by the 20th min on 33 °C; T_r was 36.9±0.2 °C throughout the exposure. During cold air exposure T_{sk} decreased to 27 °C by the 30th min, while T_r did not change. Cold air/cold drink condition provoked a decrease in T_r to 36.4 °C within the following 20 min causing visual shivering, while T_{sk} decreased a further 0.5 °C.

The F output control using visual feedback was effective in all thermal conditions. The FCv was 2 - 5 % for all F, and the average force was 83 - 90 % when the task was 10-20 % MVC and it was 94-95 % at 40-80 % MVC in thermoneutral condition, and it was not significantly influenced by cold shivering.

The IEMG at rest in thermoneutral condition was 3 - 4 µV in all investigated muscles. The control of F output in different tasks in thermoneutral condition recruited a specific pattern of activity of the upper limb muscles. During test performance in thermoneutral condition IEMG progressively increased along with the growth of F. It was the highest in the prime moving muscles (*m. brachioradialis*, *m. brachialis*, *m. biceps brachii* up to 1800 µV at 80 % MVC). In auxiliary muscles IEMG was less than 200 µV.

Thermoregulatory muscle tonus during cold exposure was 5-15 µV in all muscles, while cold shivering was the most intensive in the proximal muscles (50-100 µV). Both during thermoregulatory muscle tonus and cold shivering IEMG increased during test performance, in all muscles. However, this increase was higher in auxiliary muscles which did not contribute much to fine motor control, but they were recruited to cold shivering. IEMG increase correlated with the decrease of MPF in all muscles.

Conclusions

The present investigation showed the ability of man to keep precise F output during cold shivering. The competition of shivering with voluntary motor activity (F output control) seems to be avoided by recruitment of different sets of muscles to voluntary and thermoregulatory activity. increased EMG activity may compensate mechanical disturbances originating from cold shivering in the proximal muscles.

References

1. Bell, D.G., Tikuisis, P. & Jacobs, I. Relative intensity of muscular contraction during shivering. *J Appl Physiol* 1992;72:2336-2342.
2. Meigal, A.Yu., Lupandin, Yu.V. & Hanninen, O Head and body positions affect thermoregulatory tonus in deltoid muscles. *J Appl Physiol* 1996;80:1397-1400.
3. Meigal, A.Yu., Lupandin, Yu.V. & Hanninen, O Influence of cold and hot conditions on postactivation in human skeletal muscles. *Pflg Arch - Eur J Physiol* 1996;432:121-125.

Decrease in muscular performance due to cooling is dependent on exercise type

J. Oksa, H. Rintamäki

Oulu Regional Institute of Occupational Health, Laboratory of Physiology, FIN-90220 Oulu, Finland

Abstract

To what extent cooling decreases muscular performance in different exercise types is not well studied. The purpose of this study was to compare the effects of standard cooling on muscular performance utilising slow eccentric-concentric [1], concentric [2] and fast eccentric-concentric [3] muscle contractions.

In three different studies the subjects (n=32), wearing shorts and jogging shoes, were exposed to 27 °C and 10 °C for 60 min. After the exposures the subjects performed one of the three exercises: maximal 60 s rebound jumping (slow eccentric-concentric muscle contraction, duration of one contraction ca 0.7 s), maximal overhead ball throwing with both hands (concentric muscle contraction, duration ca 0.2 s) or maximal drop-jump (40 cm bench) with minimal knee bending (hopping, fast eccentric-concentric muscle contraction, duration ca 0.2 s). From the jumping exercise the average muscle power was calculated, from the ball throwing exercise the velocity of the balls were measured and from the drop-jump the time spent in the air (jump height) was measured.

When taken as an average from the three studies the exposure to 10 °C decreased mean skin temperature significantly ($p < 0.001$) from 31.6 ± 0.2 °C to 25.5 ± 0.5 °C. The temperature of the working muscle tissue decreased to an average of 3.4 ± 0.9 °C (3 cm depth, $p < 0.05$). After cooling the average decrease in muscular performance during concentric muscle contraction was 9 % [1], during slow eccentric-concentric muscle contraction 11 % [2] and during fast eccentric-concentric muscle contraction 22 % [3].

It is concluded that concentric muscle contraction is least affected and fast eccentric-concentric muscle contraction, prominently utilising also elastic components of the muscle, is most affected by cooling.

References

1. Rintamäki et al., Proceedings ICHES'91, 1991, pp. 547-550
2. Oksa et al., *Aviat. Space Environ. Med.*, Vol. 66, 1995, pp. 26-31
3. Oksa et al., *Acta Physiol. Scand.*, Vol. 157, 1996, pp. 71-78.

Respiratory response to local skin cooling at artificial modulation of skin thermoreceptors

T. G. Simonova, T. V. Kozyreva

Institute of Physiology, Novosibirsk, Russia

Introduction

It is well known that respiration can be changed at peripheral thermal stimulation (5). The magnitude of the input signal from skin cold receptors depends on the impulse frequency and the number of active receptors. The latter could be estimated in human by the number of sensitive cold or warm spots (1).

Our previous studies revealed dependence of some respiratory parameters appointed in thermoneutral conditions on the number of active cold receptors in forearm skin. A great number of these receptors was accompanied by high minute volume and respiratory rate but low oxygen consumption. Moreover it was found that after the adaptation to cold the subjects having a lower number of active skin cold receptors in forearm area had a lower minute volume and a higher oxygen consumption in comparison with non-adapted ones (3).

Then it was shown that acute local skin cooling caused transient but significant shift of respiratory indices. Expression and even direction of these shifts depended on localisation of the cooled area (forearm, hand, face or foot). A relation was also demonstrated for skin temperature at the moment of respiratory response to cooling with the number of active cold receptors (3).

According to experimental data on animals some substances, including noradrenaline, can affect the impulse activity of skin cold receptors (2). The questions arise: if thermoreception in human can be affected by noradrenaline and how the artificial modulation of the skin thermoreceptors influences on the respiratory response to local cooling.

Method

To investigate the effect of local cooling of the skin on respiratory parameters each lightly clad subject (17 healthy volunteers) sat in a thermal chamber (26 ± 1 °C) about twenty minutes. The number of cold sensitive spots on 25 cm^2 area on the forearm skin was counted. Brass thermode with thawing ice inside was applied to this area for ten minutes. Minute volume, respiratory rate and tidal volume were measured in 30 s intervals before, during and 10 minutes after the cooling. Skin temperature was measured continuously by thermistor. This data served as control. Another day this procedure was preceded by noradrenaline iontophoresis (4 mA, 20 min) on the same area of forearm skin.

Results

In the thermoneutral conditions noradrenaline iontophoresis didn't change respiratory parameters, but caused decrease the number of cold spots by 30 % (Table 1) without significant changes of skin temperature in this area.

The most pronounced respiratory response under forearm skin cooling was a tidal volume decrease. We have shown that tidal volume decrease with forearm cooling was conversely proportional to the number of cold spots in this area.

After the artificial decrease of the number of cold sensitive spots by noradrenaline iontophoresis the inverse dependence of the tidal volume decrease on number of the cold spots remained, and the diminishing of the tidal volume at local forearm cooling became more considerable (Table 1). Nevertheless, this response occurred at higher skin temperature than without noradrenaline. This is in agreement with our data obtained in animals: noradrenaline modulation of skin thermoreceptors caused the decrease of threshold temperature and intensification of cold-defence responses.

Table 1. Some parameters in human before and after the local noradrenaline iontophoresis in the area of forearm.

PARAMETERS	BEFORE	AFTER
	NORADRENALINE IONTOPHORESIS	NORADRENALINE IONTOPHORESIS
Forearm number of cold spots in thermoneutral conditions	35.9±4.6	25.7±4.4
	P<0.05	
	RESPONSE TO LOCAL COOLING OF FOREARM	
Tidal volume decrease (% of initial)	-14.4±1.30	-21.1±1.76
	P<0.05	
Skin temperature at maximum tidal volume shift (°C)	28.3±0.33	29.6±0.47
	P<0.05	
Skin temperature decrease at maximum tidal volume shift (°C)	5.43±0.31	3.09±0.29
	P<0.01	

Conclusions

The peripheral skin thermoreceptors are important for respiratory modulation. Artificial decreasing of the sensitive skin cold receptors by noradrenaline in the area of forearm causes changes in the respiratory response to local cooling of this area.

References

1. Kenshalo D.R., Gallegos E.F. Multiple temperature sensitive spots innervated by single nerve fibres. *Science*. 1967;158:11:1064-1065.
2. Kozyreva T.V. Two periods in the response of skin cold receptors to intravenous infusion of noradrenaline. *Annals of New York Academy of Sciences. Thermoregulation*. Ed. Blatteis C. 1997;813:176-183.
3. Kozyreva T.V., Simonova T.G. Peripheral thermal input and respiratory regulation in men. *Proc. Sixth Int. Conf. on Environmental Ergonomics*. 1994: 38-39.

4. Kozyreva T.V., Tkachenko E.Ya., Kozaruk V.P. The influence of skin thermoreceptors modulation by noradrenaline on thermoregulatory response to cooling. *Bul. SB Russian Academy Medical Science.* 1997:3:29-34.
5. Melville G.N. Cold II: Nervous pathways in the respiratory responses to facial cold. *Environ. Physiol. Biochem.* 1972:2:179-187.

Cold environments and health problems

Summary of panel discussion

H. Lundgren, B. W. Johansson¹

Health Care Center, Borrby, Sweden

¹Heart Section, Dept of Medicine, General Hospital, Malmö, Sweden

Cold has many implications on the human being. Some physiological responses such as vasoconstriction, rise in blood pressure and increased blood viscosity are well-known. Cold can also induce attacks of angina pectoris and probably myocardial infarction. It is also known that endocrinological changes occur during cold stress, such as rise in cortisol and decrease in aldosteron levels.

New knowledge comes from tests of facial cooling, especially the forehead (diving response), which showed bradycardia, apnea and rise in blood pressure. This response could certainly be of clinical interest for patients with coronary heart disease. Cold is not only a problem for the vascular system but also for the respiratory system. For example cross country skiers have a high prevalence of bronchial asthma and hyperreactivity.

Cold will also induce an inflammatory process locally. Example of this is draught problems. This would yield pain from muscles, tendons and mucous membranes.

Studies on cold effects on humans raise many problems such as difficulty to find correct variables for cold exposure with change in human behaviour. Few of the medications used by our patients have undergone any tests for their action in connection with hypothermia, for example the beta-blocking agents and the tranquillisers.

Future studies/problems which are of high interest will now be listed:

In the cardio-vascular area:

1. Prospective longitudinal studies are needed to find out the etiology behind cold and different diseases, for example myocardial infarction.
2. Have drugs, such as the beta-blocking agents and tranquillisers any unknown side-effects/ risk for patients living/working in cold areas?
3. What is the significance of the rise in blood pressure, especially among elderly persons exposed to cold?
4. Could cold stress give rise to cardiac arrhythmias?
5. Patient risks unprotection by different headgear.
6. How does exercise influence physiological reactions in cold
7. environments?

In the respiratory field area:

1. Inhaling great amount of cold air gives rise to hyperactivity in the lower respiratory tract. Does the way of inhalation, through mouth or nose, play any role in this case? Is it the dry air or is it the cold per se which are causal?
2. Effect of air pollution in addition to cold on respiratory infections and myocardial infarction

Remaining:

1. Response of the immune systems to cold not least T-cell function
2. Hypothyroidism - underdiagnosed in cold climate?
3. Interrelation between infection, vitamin C, haemostatic factors and cardiovascular disease in cold winters.

Acknowledgement

The comments on research needs by Ken Collins are greatly appreciated.

Working in Antarctica: current medical practice and human biology research.

D. J. Lugg, P. Sullivan

Polar Medicine, Australian Antarctic Division, Kingston, Tasmania, Australia.

Medical Practice

The wide-ranging nature of health care on the Australian National Antarctic Research Expeditions (ANARE) has previously been described by Lugg (1). Pre-departure medical screening and medically-related training of staff are important for the maintenance of health in Antarctica as in most instances only one medical practitioner accompanies each group.

In 50 years of ANARE, emergencies have included a polio-like illness (2), a ruptured intracranial aneurysm (3), an intestinal haemorrhage (4), an acute abdomen (5), and an accident involving two cases of hypothermia and frostbite (6) and a variety of other serious conditions (7). A simple form of telemedicine was used in the early years, and with the increasing use of satellite communications and digitalised imaging has become an integral part of the doctors' armamentarium (8). As the stations are totally physically isolated for most of the year, evacuation is neither a routine nor reliable option. In addition, the doctor is responsible for the health care of small field parties - which may be hundreds of kilometres away from the station.

The advent of a computerised ANARE Health Register (9, 10) has laid the foundation for accurate epidemiological data collection. In the period 1988-1997 over 3500 scientists and support staff travelled to Antarctica with ANARE. Some stayed only short periods, others for up to 17 months. In all, some 1967 person-years were recorded in this period. The data indicate that 5462 (58 %) illnesses and 3910 (42 %) injuries were reported. Table 1 shows the distribution of illnesses and injuries according to ICD-9 Classification.

The most common conditions registered were upper respiratory tract infections; sprains and strains of lumbar spine, ankle and knee; open wounds of the fingers; foreign bodies in the eye; dermatitis; and dental problems. Of the injuries, only 77 (2 %) could be considered as cold injuries, the great majority being minor. However, cold, icy surfaces did contribute to a large number of sprains, strains and fractures, and the low relative humidity frequently contributed to skin problems. Table 2 gives an analysis of the cold injuries.

ANARE biomedical studies

As ANARE and most countries working in Antarctica rely on a sole medical practitioner, and in almost all cases the research is performed by this doctor there is a close nexus between clinical practice and human biology research. During 1997, the fiftieth year of ANARE, reviews of all scientific disciplines have been carried out. Biomedical studies (11) suggest personnel are subject to significant disturbance of their

internal milieu while working in confined, small groups in the unique Antarctic environment. As transient visitors they live in a harsh environment subject to extreme cold and photoperiodicity.

In the 1960s and early 1970s the research concentrated on thermal stress and acclimatisation to cold (12, 13). Over the past 25 years, as technology and attitudes to research have changed, many more topics of research have been introduced to the multidisciplinary program with the greatest emphasis now being placed on studies that facilitate living and working in Antarctica (14). Research has included projects relevant to medical management (10, 15), nutrition (16, 17), cardiovascular (18) and endocrine systems (19).

Table 1. Distribution of illnesses and injuries in the ANARE Health Register July 1988 - June 1997. Grouped according to the International Statistical Classification of Diseases, Injuries and Causes of Death (9th Edition).

ICD Group		Number of Cases	Rate (per 1000 person years)	%
I.	Infections and Parasitic Diseases	682	347	7.3
II.	Neoplasms	77	39	0.8
III.	Endocrine, nutritional and metabolic	31	16	0.3
IV.	Blood and blood-forming organs	5	2	0.05
V.	Mental disorders	217	110	2.3
VI.	Nervous system & sense organs	702	357	7.5
VII.	Circulatory System	105	53	1.1
VIII.	Respiratory System	910	463	9.7
IX.	Digestive System	691	351	7.4
X.	Genitourinary System	130	66	1.4
XI.	Complications of Pregnancy & Childbirth	0	0	0
XII.	Skin and Subcutaneous Tissue	899	457	9.6
XIII.	Musculoskeletal and Connective Tissue	667	339	7.1
XIV.	Congenital	11	6	0.1
XV.	Perinatal	0	0	0
XVI.	Symptoms & Ill-defined Conditions	335	170	3.6
XVII.	Injury and Poisoning	3910	1988	42

Table 2. Analysis of cold injuries on ANARE 1988-1997

Condition	Number of Cases
Frostbite of face	17
Frostbite of hands	23
Frostbite of feet	6
Frostbite - other and unspecified	21
Total Frostbite	67
Non-freezing cold injury	1
Chilblains	2
Hypothermia	2
Unspecified effects of cold	5
Total Cold Injuries	77

Australian involvement in the International Biomedical Expedition to the Antarctic (IBEA) (20) has led to a significant immunological program. Carried out in austral

summer 1980/81, the IBEA was the first Antarctic expedition organised solely for human biological studies. The program was multidisciplinary with wide-ranging projects in physiology, psychology, psycho-physiology and clinical. A large number of scientific publications, a book and films resulted from IBEA. On IBEA it was found that a number of subjects who did not react to the delayed hypersensitivity skin test using the mycobacterium antigen, purified protein derivative (PPD) before the expedition, did react strongly during the field phase (21).

Follow up studies assessed the cell mediated immunity (CMI) at quarterly intervals over a year at Mawson on the Antarctic Continent and at sub-Antarctic Macquarie Island. While the response of the Macquarie Island group was similar to healthy, normal populations from other parts of the world, the Mawson group showed decreased cutaneous responses with significant anergy and hypoergy (22). An explanation for the Mawson group findings, as opposed to the Macquarie Island group, was that some combinations of cold, total isolation, reduced environmental immunological triggers, and other stressors caused a diminished immune function.

This was further investigated when twelve Antarctic and sub-Antarctic wintering groups were studied over the period 1984-1992, using the CMI Multitest. Two hundred and twenty five expedition personnel volunteered for this study. The results (23) paralleled the original study and found that while the Macquarie Island population had levels of responsiveness and hypoergy (9 %) comparable to healthy populations in temperate zones, 36 % of the Antarctic continental groups showed levels of hypoergy. There was no seasonal variation in the pattern of decreased immunological responsiveness.

In order to investigate whether the diminished immune function was present in the first weeks in Antarctica, a large summer study was performed (24). One aspect of this was to incorporate psychological studies. As Ursin et al (25) have reported, observations showed anxiety was greater before and after the expedition than during the time in Antarctica and there was a significant negative correlation between CMI and anxiety, as had been reported by Donovan (26).

Other related studies have included assessment of vascular changes in cutaneous blood flow using a laser Doppler blood flowmeter (27), and of various hormones which may mediate the responses. These include adrenal steroids, enkephalin-endorphins, vitamin D and sex hormones (19, 28, 29). A further extension to this research commenced in 1991 with quantitative assessment of mucosal immune competence in expedition personnel, and correlation of this with alterations in systemic immunity. The first preliminary data have shown some interesting results (30), with specimen processing still continuing.

In 1993 a collaborative agreement between NASA and the Antarctic Division was signed. The first research to come from this agreement was that of Tingate et al (31) who found alterations of T cell function, including depression of CMI responses and a peak 50 % reduction of T cell proliferation to the mitogen PHA. T cell dysfunction was mediated by changes within the peripheral blood mononuclear cell (PBMC) compartment, including a paradoxical atypical monocytosis associated with altered production of inflammatory cytokines (a reduction in TNF- α and changes in IL-1, IL-2, IL-6, IL-1 α and IL-10). Antarctic isolation was associated with altered latent herpesvirus homeostasis, including increased herpesvirus shedding and expansion of the polyclonal latent Epstein-Barr virus infected B cell populations.

A follow up study was successfully completed at Mawson in 1996; this made use of a FACScan flow cytometer (Becton Dickinson) among other equipment, and was the most sophisticated and complex medical research program ever done on ANARE.

Specimens and data are currently being processed at five centres in Australia and two in USA.

Findings of suppression of the human immune system by UV-B and suggestions that immune suppression by UV-B may be modulated by urocanic acid in mammalian skin led to Aldous and DeLeacey (27) studying the relationship of cis and trans urocanic acid in skin from March to November in Antarctica. There was a Winter drop of urocanic acid and a Spring rise of the cis to trans ratio. Comparisons with a control group in Southern Australia showed that the results for Spring in Antarctica were greater than those in Southern Australia. Correlation of the urocanic acid levels with UV-B was not possible as the UV-B measuring system was not then in place.

In 1986/87 an ultraviolet program was initiated by the Australian Radiation Laboratories and the Antarctic Division and all four stations now have continuous broad band measurements of solar radiation, solar ultra-violet radiation (UV-R, UV-B, and *actinic UV-B*) (32). The effect of seasonal radiation fluctuations on humans in Antarctica can now be monitored (29), and with the recent addition of a UVR spectroradiometer at Davis, more accurate measurements can be made.

With the advent of the NASA collaborative agreement and the need to investigate behavioural adaptation and its influence on immune changes a joint study commenced between NASA and the Antarctic Division studying participants on the six-man, 100 day traverses around the Lambert Glacier Basin in summers 1993/94 and 1994/95. Using an Integrated Field Recording System (IFRS) the study aimed to characterise trends and changes in individual adaptation and team function in remote, isolated and confined environments (33). The subjects completed twice-weekly computerised questionnaires relating to adaptation and performance of the team.

The IFRS was modified for use with ANARE winter groups and the initial assessment of 12 ANARE wintering groups and data from other analogue and space simulations at Johnson Space Centre has commenced. Initial data reduction suggests that personal factors of the individuals, the unique combinations of those factors and behaviours in each group; and local events are the primary causes for the changes observed in these varied groups, with the degree and length of isolation also being important factors (34).

Although no diseases have yet been associated with these immune changes the findings may well have relevance to health. These studies suggest that Antarctica is an excellent environment for future immune, viral and remote medical research related to ground-based analogue studies of long-duration space flight.

Human biology research - Antarctica

Reviews of international human biology research in Antarctica (35, 36, 37, 38) reveal a multidisciplinary program which compares favourably with other Antarctic research disciplines. More recent reviews (39, 40) show the changing nature of the research. A detailed appraisal is beyond the scope of this paper, but much of the research is providing valuable data which has relevance beyond Antarctica, even to Outer Space. An important factor in Antarctic research is that the environmental factors are not totally reproducible in temperate laboratories. Table 3 lists some of the fields of research topics recently undertaken in Antarctica, as indicated by a computerised literature search.

Cold studies in Antarctica

Numerous studies have investigated adaptation to cold in people living long-term in Arctic and circum-Arctic regions. Antarctica differs in that all expeditioners are short-term inhabitants only, and often come from temperate and even tropical environments. In the late 1980's Budd carried out a review of cold research undertaken on eight Antarctic expeditions (41). Changes in subject's responses to standardised whole-body cold exposure show that general acclimatisation to cold develops as an increase in tissue insulation, which is mediated by an enhanced vascular response to cold. Comment was made on the contrast between laboratory studies on responses to cold and the 'ergonomic' aspects of the Antarctic field laboratory that modify the impact of a cold environment on health, comfort and performance. It should be noted that all the research reviewed was performed in Antarctica before 1981.

Over the last decades there has been a decline in the amount of research conducted in Antarctica into human responses to cold. In part this reflects the low incidence of serious cold injuries in Antarctic populations, as well as the perception from previous research that any physiological or adaptive responses to the cold environment are not clinically significant. An emphasis on pre-departure indoctrination on avoidance of cold injury may also impact on the incidence of cold injury.

Table 3. Current human studies in Antarctica

Thermal adaptation
Immunology
Microbiology
Hormone adaptation to cold
Biorhythms
Fitness and health
Cardiovascular studies
Nutrition and energy balance
Photobiology
Epidemiology
Evaluation of stressors
Psycho-social and behavioural adaptation
Neuro and psychophysiological changes
Group dynamics
Sleep

Recently published cold research from Antarctica include that of diving (42, 43), responses to whole body and finger cooling before and after 53 days in Antarctica (44), and alterations to the finger skin temperature and blood flow of 64 subjects before and after cold immersion on exposure to an Antarctic environment for eight weeks (45).

Work from Reed et al suggesting links between changing thyroid hormone economy and cold adaptation in personnel living for extended periods in Antarctica, *The Polar T3 Syndrome* (46, 47). This demonstration of alterations in the hypothalamic-pituitary-thyroid axis may be the start of a revival of cold adaptation studies in Antarctica. The work has certainly stimulated laboratories in Europe to show the syndrome present under laboratory conditions (48, 49).

Future

The Proceedings of the Nordic Conference on Cold (50) and the publication resulting from the Scandinavian course on *Work in Cold Environments* (51) show the considerable cold research being currently undertaken in Europe in both clinical cold studies as well as basic thermal research. In view of recent advances in clothing, concepts (for example, Determination of Required Clothing-IREQ), and research technology (including sophisticated thermal manikins and computerised modelling), perhaps it is time to revisit some of the earlier Antarctic field studies.

Also worth noting is the exponential growth of Antarctic tourism over the last decade. This has more than doubled the number of people annually travelling to Antarctica and may act as a further stimulus to investigate human responses to Antarctic conditions.

Both field experience and laboratory studies indicate that there is a need to improve knowledge on environmental ergonomics and it is considered that there would be advantages to a combined Arctic/Antarctic approach to further cold research, particularly in the field of living and working in extremely cold regions. With more Arctic medical researchers now becoming involved with the Scientific Committee on Antarctic Research (SCAR) Working Group on Human Biology and Medicine and that group being represented on the International Union for Circumpolar Research and having interaction with the International Arctic Science Committee (IASC), now would seem an opportune time to commence such studies.

References

1. Lugg DJ. Antarctica: Australia's remote medical practice. Hobart: Antarctic Division, 1993: 12 pp.
2. Budd GM. A polio-like illness in Antarctica. *Med J Aust* 1962;1:483-486.
3. Pardoe R. A ruptured intracranial aneurysm in Antarctica. *Med J Aust* 1965;1:344-350.
4. Podkolinski MT, Semmens K. Intestinal haemorrhage in Antarctica: a multi national rescue operation. *Med J Aust* 1979;2:275-277.
5. Priddy RE. An "acute abdomen" in Antarctica - the problems of diagnosis and management. *Med J Aust* 1985;143:108-111.
6. Sullivan P. Accidental hypothermia in Antarctica - an incident involving two cases of hypothermia and frostbite. *Med J Aust* 1987;146:155-158.
7. Taylor DMcD, Gormly P. Emergency medicine in Antarctica. *Emerg Med* 1997; 9(3): 237-245.
8. Sullivan P, Lugg DJ. Telemedicine between Australia and Antarctica: 1911-1995, SAE Technical Paper 951616, 25th International Conference on Environmental Systems, San Diego 1995.
9. King H. A new health register for Australian National Antarctic Research Expeditions. *Polar Rec* 1987;23:719-720.
10. Sullivan P, Gormly PJ, Lugg DJ, Watts DJ. The Australian National Antarctic Research Expeditions Health Register: three years of operation. In Postl B, et al, eds. *Circumpolar Health 90*. Winnipeg: University of Manitoba Press, 1991:502-504.
11. Lugg DJ. ANARE Medical Research: what did happen to all those specimens, Doc? In: Marchant H, et al, eds. *Proceedings of the ANARE Jubilee Science Symposium*. Hobart: Antarctic Division, In Press.

12. Budd GM. Physiological research at Australian stations in the Antarctic and sub-Antarctic. In: Gunderson EKE, ed. Human adaptability to Antarctic conditions. Washington DC: American Geophysical Union, 1974: 27-54.
13. Bodey AS. Human acclimatisation to cold in Antarctica with special reference to the role of catecholamines. Melbourne: University of Melbourne Thesis, 1979: 286 pp.
14. Lugg DJ. Current international human factors research in Antarctica. In: Harrison AA, Clearwater YA, McKay C, eds. From Antarctica to outer Space: life in isolation and confinement. New York: Springer-Verlag, 1991: 31-42.
15. Kibby J, Sullivan P. Evaluation and use of a dry chemistry analyser in Antarctica. *Int J Circumpolar Hlth*, In Press.
16. Taylor DMcD. Modification of the type of dietary fat at an Antarctic station: impact on cardio vascular risk factors. *ANARE Res Notes* 86, 1992: 156 pp.
17. Matheson B, Walker KZ, Taylor DMcD, Peterkin R, Lugg DJ, O'Dea K. The effect on serum lipids of the substitution of monounsaturated oil and margarine in the diet of an Antarctic Expedition. *Amer J Clin Nutr* 1996: 63: 933-938.
18. Deakin GD. Cardiovascular research in Antarctica. *ANARE Res Notes* 84, 1992: 102 pp.
19. Williams DL. Health, hormonal and stress-related studies on Australian National Antarctic Research Expeditions (ANARE). *ANARE Res Notes* 66, 1989: 117 pp.
20. Rivolier J, Goldsmith R, Lugg DJ, Taylor AJW, eds. Man in the Antarctic - the scientific work of the International Biomedical Expedition to the Antarctic (IBEA). Taylor & Francis, London, 1988.
21. Roberts-Thomson P, Lugg DJ, Vallverdu R, Bradley J. Assessment of immunological responsiveness in members of the International Biomedical Expedition to the Antarctic 1980/81. *J Clin Lab Immunol* 1985: 17: 115-118.
22. Williams DL, Climie A, Muller HK, Lugg DJ. Cell mediated immunity in healthy adults in Antarctica and the sub-Antarctic. *J Clin Lab Immunol* 1986: 20: 43-49.
23. Muller HK, Lugg DJ, Quinn D. Cell mediated immunity in Antarctic personnel: 1984-1992. *Immunol Cell Biol* 1995: 73: 316-320.
24. Muller HK, Lugg DJ, Ursin H, Quinn D, Donovan K. Immune responses during an Antarctic summer. *Path* 1995: 27: 186-190.
25. Ursin H, Bergan T, Collet J, Endresen IM, Lugg DJ, Maki P, Matre R, Molvaer O, Muller HK, Olf M, Pettersen R, Sandal GM, Vaernes R, Warncke M. Psychobiological studies of individuals in small, isolated groups - in the Antarctic and in Space analogues. *Environ Behav* 1991: 23: 766-781.
26. Muller HK, Lugg DJ, Williams DL. Cutaneous immune responses to Antarctica: a reflection of immune status? *Arctic Med Res* 1988: 47 (Suppl-1): 249-251.
27. Lugg DJ. Human interaction with the Antarctic environment: studies in immunology, photobiology and epidemiology. *Arctic Med Res* 1994: 53 (Suppl 2): 407-409.
28. Pitson GA, Lugg DJ, Muller HK. Seasonal cutaneous immune responses in an Antarctic wintering group: no association with testosterone, vitamin D metabolites, or anxiety score. *Arctic Med Res* 1996: 53(3): 118-122.
29. Pitson GA, Lugg DJ, Roy C. Effect of seasonal ultraviolet radiation fluctuations on Vitamin D homeostasis in Antarctic expeditioners. *Eur J Appl Physiol* 1996: 72: 231-234.
30. Gleeson M, Cripps AW, Clancy RL. Modifiers of the human mucosal immune systems. *Immunol Cell Biol* 1995: 73: 397-404.
31. Tingate TR, Lugg DJ, Muller HK, Stowe RT, Pierson DL. Antarctic isolation: immune and viral studies. *Immunol Cell Biol* 1997: 75: 275-283.

32. Roy CR, Gies HP, Tomlinson DW, Lugg DJ. Effects of ozone depletion on the ultraviolet radiation environment at the Australian stations in Antarctica. In: Penhale P, Weiler CS, eds. *Ultraviolet radiation in Antarctica: measurements and biological effects*. Washington DC: American Geophysical Union, 1994: 1-15.
33. Wood JA, Eksuzian DJ, Lugg DJ, Harm DL. Psychological considerations for humans in bio-regenerative life support systems. Abstract in *Proceedings of International Committee on Space Research*. Birmingham: COSPAR, 1996.
34. Wood JA, Lugg DJ, Eksuzian DJ, Harm DL, Shepanek M. Psychological adaptation in groups of various sizes and environments: old questions and new issues. Abstract in *Proceedings of the 12th Man in Space Symposium*. Washington DC: International Academy of Astronautics (IAA) 1997.
35. Wilson O. Human adaptation to life in Antarctica. In: Van Oye P, Van Mieghem J, eds. *Biogeography and Ecology in Antarctica Monographiae Biologicae* 1965: 15: 690-752.
36. Gunderson EKE, ed. *Human adaptability to Antarctic Conditions*. American Geophysical Union, Washington DC, 1974.
37. Edholm OG, Gunderson EKE, eds. *Polar Human Biology*. Heinemann, London, 1973.
38. Koerner FC. *Polar Biomedical Research*. Appendix: Polar Medicine - a literature review. National Academy Press, Washington DC, 1982.
39. Lugg DJ. Humans on ice: a review of research on those living in Antarctica since IGY 1957-58. In: Postl B, et al, eds. 1991: 499-501.
40. Lugg DJ. Antarctica as a Space Laboratory. In: Hempel G, ed. *Antarctic Science: global concerns*. Springer-Verlag, Berlin, 1994: 229-242.
41. Budd GM. Ergonomic aspects of cold stress and cold adaptation. *Scand J Work Environ Health* 1989: 15(Suppl 1): 15-26.
42. Bridgman SA. Peripheral cold acclimatisation in Antarctic scuba divers. *Aviat Space Environ Med* 1991: 62(8): 733-738.
43. Sullivan P, Vrana A. Trial of in-water oxygen recompression therapy in Antarctica. *South Pacific Underwater Med Soc J* 1992: 22(1): 46-51.
44. Rintamäki H, Hassi J, Smolander J, Louhevaara V, Rissanen S, Oksa J, Laapio H. Responses to whole body and finger cooling before and after an Antarctic expedition. *Eur J Appl Physiol* 1993: 67(4): 380-384.
45. Naidu M., Sachdeva U. Effect of local cooling on skin temperature and blood flow of men in Antarctica. *Int J Biometeorol* 1993: 37(4): 218-221.
46. Reed HL, Silverman ED, Shakir KM, Dons R, Burman KD, O'Brian JT. Changes in serum tri iodothyronine (T3) kinetics after prolonged Antarctic residence: the polar T3 syndrome. *J Clin Endocrinol Metab* 1990: 70(4): 965-974.
47. Reed JL. Circannual changes in thyroid hormone physiology: the role of cold environmental temperature. *Arctic Med Res* 1995: 54 (Suppl 2): 9-15.
48. Savourey G, Barnavol B, Caravel JP, Barbe C, Bittel J. Induction of a "tri iodothyronine polar syndrome " in man under laboratory conditions. *C R Acad Sci III* 1993: 316 (6): 607-610.
49. Savourey G, Barnavol B, Caravel JP, Feuerstein C, Bittel JH. Hypothermic general cold adaptation induced by local cold acclimation. *Eur J Appl Physiol* 1996: 73(3-4): 237-244.
50. Granberg P-O, Hassi J, Holmér I, Larsen T, Refsum H, Yttrehus K, Knip M, eds. *Cold physiology and cold injuries*. *Arctic Med Res* 1991: 50 (Suppl 6): 160 pp.
51. Holmér I, ed. *Work in cold environments*. *Investigation Rep* 1994: 31: 118 pp.

Power requirements during skiing with sledges and backpack

U. Bergh, U. Danielsson

Department of Human Sciences, Defence Research Establishment, S - 172 90, Stockholm, Sweden

Introduction

Information on the metabolic power requirements is very important when estimating the level of maximal aerobic power a person needs to perform different activities. Actual measurements of metabolic power requirements of skiing have most often been made during level skiing on tracks of standardised distance and at given speeds (1, 2, 3). Studies of skiing where the skiers chose speed and terrain, e.g. during ski touring, have relied on heart rate measurements from which oxygen uptake has been calculated; a procedure that frequently is much less accurate than direct measurements of oxygen uptake (4). The present study was conducted to elucidate the metabolic power requirements of rangers during skiing using direct measurements of oxygen uptake.

Subjects, procedures, and methods

Sixteen soldiers 20 years (19-23), 78 kg (66-87), and 1,85 m (1,72-1,96). The rangers skied a distance of 35 km, starting at 800 m over the sea level and finishing at 500 m with the highest point at 1000 m over the sea level. Half of the trail was above the tree limit. The temperature was -25 °C at the start and -9 °C at the finish. The weather was sunny with very little wind and the snow conditions were favourable. A shooting event and a lunch break were included. The speed was chosen by the squad leader who was instructed to keep the group together and to divide the distance into 8 bouts. All soldiers carried a backpack and a rifle (24 kg). In addition, three 50 kg sledges were included, each of them being pulled by 2 soldiers. Heart rate was recorded every minute (Polar). Metabolic power was measured by portable devices every minute in four subjects at a time. Subjective ratings of exertion, temperature and thermal comfort were made after each bout (8 times).

Results

Total time was 8 h 46 min out of which 5 h and 15 min was actual skiing, divided into 8 bouts ranging from 19 min to 58 min in duration. The rest of the time comprised of a shooting event (51 min), a lunch break (80 min), and 5 breaks for changing measuring devices, and haulers of sledges. The average metabolic rate (MR) while skiing was 849 W. With the sledge, MR was 969 W and without the sledge 783 W. The energy cost per kg of transported mass for the corresponding situations were 4.1, 4.5 and 3.9 J•m⁻¹•kg⁻¹,

respectively. HR was 145 beats/min in average, 157 while pulling a sledge, and 138 without the sledge. The estimated requirement on maximal oxygen uptake was $4.5 \text{ l}\cdot\text{min}^{-1}$ ($58 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). Ratings of perception exertion, temperature and comfort covaried with power output and heart rate.

Discussion

The energy cost per unit of mass and distance was lower than reported by most investigators. Values between 5 and $6 \text{ J}\cdot\text{m}^{-1}\cdot\text{kg}^{-1}$ are commonly found. There are a number of factors which influence the energy cost, e. g. type of terrain and snow conditions, skiing equipment, skiing skills. The starting point was higher than the finish, and the snow was hard and coarse-grained. Such conditions will usually reduce the resistance that the skier has to overcome. The skiing equipment was not sophisticated, skis had a wooden sole and were waxed with tar, probably giving equal or higher resistance compared with the equipment used in some of the other studies (3). The subjects had more than average skiing experience without being expert skiers. Hence, favourable terrain and snow conditions were the most probable explanations for the comparatively low energy cost per unit of mass and distance.

Table 1. Average and extreme values for metabolic power, energy cost per unit of transported mass and distance, and heart rate.

	Metabolic rate W	Energy cost $\text{J}\cdot\text{m}^{-1}\cdot\text{kg}^{-1}$	Heart rate* beats $\cdot\text{min}^{-1}$
Backpack	783	3,9	138
	539-991	2,3-8,1	120-179
Sledge+backpack	969	4,5	157
	659-1270	2,7-9,3	143-175
Average	849	4,1	145
	539-1270	2,3-9,3	120-179

*during bouts where power was measured

The aerobic power during skiing was relatively high, and it was in the same order of magnitude as reported by Schantz (4) who calculated aerobic power during skiing from measured heart rate, and its relationship to oxygen uptake. Schantz's subjects were ranger officers who skied a distance of approximately 1500 km in the Swedish mountains in 60 days. Hence, there are similarities between that study and the present one. For example, all subjects were rangers meaning that they were recruited with similar fitness requirements and they were highly motivated. Furthermore, skiing speed was chosen by the subjects and not by the investigator. Judging from the ratings of exertion and the heart rate, the tempo was probably adjusted so that it was just tolerable to the subjects who were the least fit ones. Therefore, it is likely that in both studies, the aerobic power during skiing was mainly reflecting the aerobic capacity of the subjects.

Adding sledge-hauling increased aerobic power output because the transported mass increased. Also, the energy cost per unit of mass and distance was elevated which may indicate that it is less efficient to transport a given mass in a sledge than in a backpack. Similar results were found by Högberg and Christensen (2), while Ilmarinen et. al.(3) found the opposite. This discrepancy might indicate that in certain situations the sledge is more efficient while in other circumstances, it is preferable to use a backpack. In choosing between backpack and sledge other factors have to be considered. For

example, with the sledge, it is possible to carry more mass. Also, it is easier to help persons who are injured or too tired to carry their own equipment. The backpack is advantageous if sharp turns are required, e.g., in a thick forest and if the mass of the equipment is low.

The present results support the findings of previous investigations that it may be quite costly to travel on skis bringing the necessary equipment for surviving and working in the wilderness. It is, however, evident that the cost per unit of mass and distance as well as per unit of time can vary considerably, and that explains why the time it takes to cover a given distance might vary substantially.

Energy requirements for occupational and recreational activities are often calculated from heart rate and its relationship to oxygen uptake. This relationship is, however, affected by a number of factors, e. g. climate, intensity and mode of exercise, and that may induce errors. In the present study both metabolic power and heart rate were measured making it possible to elucidate this matter. The data obtained during first bout of skiing, before which the subjects (n=4) had been resting, was used to calculate the metabolic power during the 5th bout. It was 4 h, including 2 h of skiing, between bout one and five. This calculation gave an average value of 1036 W, while the measured one was 824 W. Hence, the power was overestimated by approximately 25 %, showing that calculations of metabolic power from heart rate measurements can produce considerable errors.

The power output during self paced skiing seems to reflect mainly the aerobic capacity and motivation of the skier. The energy cost per unit of mass and distance is, on the other hand, mostly affected by external conditions such as snow, terrain, skiing equipment although the personal skiing skills may be of importance.

References

1. Buskirk E.R., Dee T.E., Welch B. E., Levy L. M., and Consolazio C.F. Caloric intake associated with prolonged hard work in the cold. Quartermasters Research and Development Centre, US Army Natic, Mass, USA, 1957.
2. Christensen E. H. and Högberg P. Physiology of skiing.1950; *Arbeitsphysiologie* 14: 292-303.
3. Ilmarinen J., Sarviharju P. and Aarnisalo T. Strain while skiing and hauling a sledge or carrying a backpack. 1986; *Eur J Appl Physiol* 55: 597-603.
4. Schantz P. Långtur. Idrottsfysiologi rapport nr 18 (Ski touring. Sports physiology, Report No 18). TryggHansa, 1982.

Cold stress and performance

A. Enander

Department of Leadership, National Defence College, Järnvägsgatan 6, S-652 25
Karlstad, Sweden

Introduction

In many occupations cold stress forms a part of the daily work environment, potentially affecting productivity, health and safety. The medical and physiological problems associated with cold stress are widely recognised today. Increasing attention is now also being focused on understanding the effects on performance and behaviour. These effects may vary considerably between individuals, as a result of differences both in physiological and psychological reactions. While direct effects of cold stress may impose limits on performance capacity, actual performance in a given situation is further determined by situational and organisational factors, and also by individual effort and motivation. Thus it may sometimes be possible to maintain performance even under severe conditions, but at increased cost in terms of effort or reduced safety margins. Figure 1 provides a simplified schematic model of human performance under cold stress.

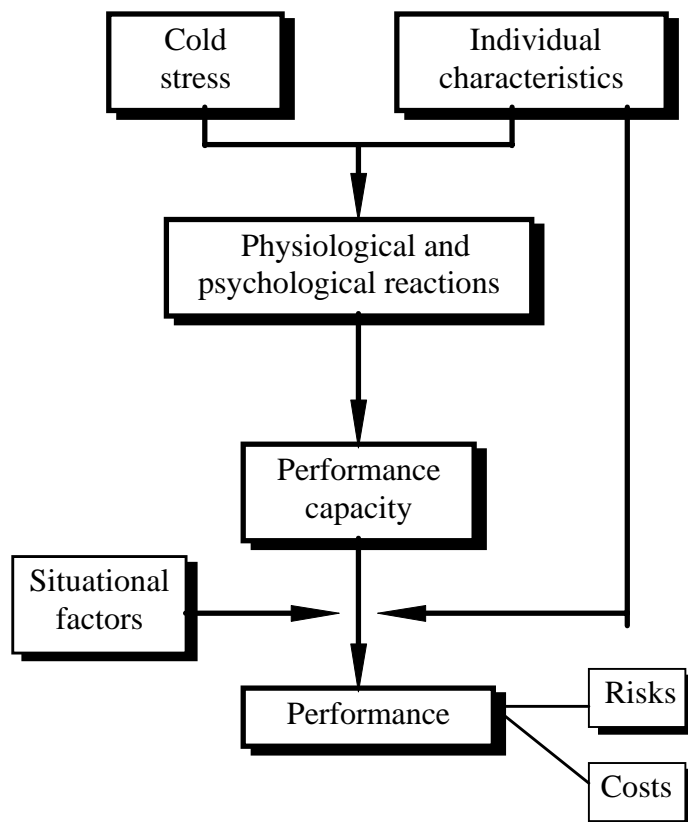


Figure 1. Simplified model of performance under cold stress

In this paper the effects of cold stress on performance are briefly discussed in relation to three areas of functioning: manual performance; cognitive or mental performance and psychological/social adjustment. Broadly these respective areas can be said to reflect a chronological development in the opening up of new fields of research interest.

Manual performance

Research on the effects of cold on hand functioning was established already in the 50's and early 60's. Much of the work in this area has focused on establishing how manual functioning is affected by cold stress, and on identifying possible critical limits. Critical skin temperatures of the hands and fingers have been proposed for unimpaired tactile sensitivity at about 8-10 °C and for manual dexterity at 12- 15 °C (1, 5). On certain tasks an initial drop in performance may occur at finger skin temperatures as high as in the range 20-22 °C (14). Tasks are particularly sensitive to effects of cold when demands on joint flexibility are high, and when rapid and accurate finger movement is required.

The applicability of general skin temperature limit values in the work setting is for several reasons rather limited. Individuals differ considerably in reactions even to controlled experimental hand cooling, and in a normal work group hand and finger temperatures may vary considerably depending on individual, task and climate factors (6). Thus application of limit values implies individual monitoring. Further, the specific negative effects of cold stress depend on the exact nature of the tasks to be performed, and the possibility of for example compensating reduced sensitivity with grosser arm movements.

Current research has come to focus on more closely mapping the relationship between different cold stress conditions and specific tasks, and on evaluating various ways of mitigating the cold stress effects, for example by improving protection. The importance of maintaining the ability to perform manual tasks under extreme survival conditions, as in accidental cold water immersion, has been emphasised. Thus, in view of the strong effect of local arm cooling on performance, special consideration should be given to arm insulation in protective clothing and survival suits (10).

Optimal training of manual tasks may help reduce performance decrements. Some experimental results have indicated the importance of first learning to perform manual tasks under normal temperature conditions, before encountering cold stress. Practice under cold conditions may then be beneficial in further training to higher skill levels (5).

Cognitive functioning

The negative effects of severe hypothermia on mental capacity are well-known. With accentuated shivering and then progressive lowering of body temperature, cognitive functioning is gradually impaired, judgement is affected and the individual becomes fatigued and disoriented. A relationship between mental performance decrements and lowering of core body temperature has also been demonstrated in several experimental studies. Negative effects on memory registration (2) and on complex mental performance (9) have been demonstrated during immersion in cold water with lowering of core temperature by around 2-4 °C. There has, however, been some doubt as to the

effects of less extreme cold stress with little or no lowering of core temperature (8), and research in this area has been sporadic and unsystematic.

During the late 70's and 80's a number of experimental studies on cognitive effects of cold stress were conducted in several laboratories in different countries (3, 4, 7, 16). A common pattern of effects began to be revealed in the results of this work, showing an increase in the number of errors, and in particular an increase in rapid errors, on tasks requiring rapid correct responses. This decrement in performance is related to the complexity of the task and to increased demands on speed.

Taken together these experimental findings indicate that decrements in performance can be expected particularly on tasks requiring vigilance, memory capacity and rapid accurate judgements under time pressure. Demands of this kind can be found among cold-exposed divers, military personnel, expedition personnel and other occupational categories. A recent study of military personnel performing a complex simulated command and control task under cold stress revealed significant changes in behavioural response patterns during the most demanding part of the task (17). One such change was a greater tendency in the cold-stressed group to engage in unprompted missile fire activity. The effects could be attributed partly to decrements in short-term memory capacity, but the possibility of changes in affective state (e.g. anger, fear) has also been suggested.

Explanatory models

Three main models have been proposed to explain the effects of cold stress on performance. According to the first model, effects can be attributed to direct changes in core body and peripheral temperatures. For manual tasks such a relationship between physiological changes and performance is well-established, even if the exact contribution of central and peripheral processes needs to be examined further and may vary with the tasks used and the specific conditions. For mental tasks application of body temperature models is less straightforward, since negative effects of cold stress can be found without concomitant core cooling.

A second explanatory model proposes that such effects, in particular those occurring immediately upon entering into a cold environment, may be attributable to distraction and discomfort arising from the cold stimulus.

A third model is based on arousal theory, attributing effects of cold stress to arousal-based shifts in attention and behavioural strategy. Certainly the pattern of effects of cold on cognitive performance shows similarities to effects attributed to elevation of arousal levels by other types of stressors (11).

Taken together, the experimental evidence suggests that effects of cold stress on performance may be mediated via both direct and indirect mechanisms (see also figure 1). Most studies have focused on individual performance and have employed healthy and highly motivated young men as subjects. It is therefore likely that the effects demonstrated in laboratory studies underestimate the potential negative influence of cold stress on occupational groups generally.

Psychological and social adjustment

Stressful environments can have negative effects on people's mood, motivation and social attitudes. Anecdotal evidence and case reports from many polar expeditions seem

to indicate affective changes and problems of co-operation and communication among groups exposed to prolonged cold stress. Considerable problems in these areas were for example described in the documentation (15) of the international biomedical expedition to the Antarctic (IBEA). Cold is of course generally only one of several stressors in extreme climate zones, other factors include social isolation, confinement, high altitude, changes in circadian rhythm and light/darkness ratios. Studies of winter-over personnel have demonstrated a number of social and psychological symptoms and problems, although long-term negative effects on health do not appear to be indicated (12). The significance of the sociocultural environment in promoting successful psychological adjustment has been emphasised. However, there has to date been very little research on the issues of group co-operation and leadership requirements in cold working environments.

One significant aspect of psychological and social adjustment concerns risk-taking during cold stress. As early as in the 1920s a relationship between increased number of injuries and low working temperatures was noted in mining work. Accident and injury statistics are, however, difficult to interpret, not least since statistically accidents are comparatively rare events. On the premise that for every serious injury there are a larger number of minor near-accidents and unsafe acts, Ramsey (13) conducted a study of observed unsafe behaviour under different thermal conditions. The results indicated a U-shaped relationship with an increased frequency of unsafe behaviour as temperature conditions deviated from the normal range. The study does not however provide data on clothing or tasks.

Several studies have shown that subjective awareness of the effects of cold stress can be poor. One effect of habitual exposure to cold may be a psychological adaptation, which can diminish the attention paid to normal warning mechanisms signalling physiological thermal stress (6). If individuals accustomed to working under cold conditions learn to ignore signals of cold stress this may improve subjective comfort and possibly also performance due to less distraction. This could however also increase risks, in reducing awareness of safety limits.

Conclusions

The research on effects of cold stress on performance clearly indicates that performance may be affected, not only under extreme hypothermic conditions but also under conditions which can be encountered in many everyday occupational environments. The practical implications of these, primarily laboratory and experimental, findings in real-life situations may depend on factors such as work organisation, equipment and on the individuals exposed. The improvement of protective clothing and other equipment for use in the cold is currently an area of considerable research and development. Similar interest needs to be paid to examining more closely the factors determining how individuals react and adapt psychologically to cold stress, and the implications for training, organisation, safety routines and leadership.

References

1. Clark RE. The limiting hand skin temperature for unaffected manual performance in the cold. *J Appl Psychol* 1961;45:193-194.

2. Coleshaw SRK, Van Someren RNM, Wolff AH, Davis HM, Keatinge WR. Impaired memory registration and speed of reasoning caused by low body temperature. *J Appl Physiol* 1983; 55:27-31.
3. Ellis HD. The effects of cold on the performance of serial choice reaction time and various discrete tasks. *Hum Factors* 1982;24:589-598.
4. Ellis HD, Wilcock SE, Zaman SA. Cold and performance: The effects of information load, analgesics and the rate of cooling. *Aviat Space Environ Med* 1985; 56:233-237.
5. Enander A. Performance and sensory aspects of work in cold environments: a review, *Ergonomics* 1984;27:365-78.
6. Enander A, Sköldström B, Holmér I. Reactions to hand cooling in workers occupationally exposed to cold. *Scand J Work Environ Health* 1980;6:58-65.
7. Enander A. Effects of moderate cold on performance of psychomotor and cognitive tasks. *Ergonomics* 1987; 30:1431-45.
8. Enander A, Hygge S. Thermal stress and human performance. *Scand J Work Environ Health* 1990;16:44-50.
9. Giesbrecht GG, Arnett JL, Vela E, Bristow GK. Effect of task complexity on mental performance during immersion hypothermia. *Aviat Space Environ Med* 1993; 64: 206-211.
10. Giesbrecht GG, Wu MP, White MD, Johnston CE, Bristow, GK. Isolated effects of peripheral arm and central body cooling on arm performance. *Aviat Space Environ Med* 1995;66(10): 968-975.
11. Hancock PA. Sustained attention under thermal stress. *Psychol Bull* 1986;99:263-281.
12. Palinkas LA. Health and performance of Antarctic winter-over personnel: a follow-up study. *Aviat Space Environ Med* 1986; 57: 954-959.
13. Ramsey JD, Burford CL, Beshir MY, and Jensen RC. Effects of the workplace thermal conditions on safe work behaviour. *J Safety Res* 1983;14:105-114.
14. Schiefer RE, Kok R, Lewis MI, Meese GB. Finger skin temperature and manual dexterity - some inter-group differences. *Appl Ergonomics* 1984;15(2): 135-141.
15. Rivolier J, Goldsmith R, Lugg DJ, Taylor AJW. *Man in the Antarctic*. Taylor & Francis, Hampshire, UK, 1988.
16. Thomas JR, Ahlers ST, House JF, Schrot J. Repeated exposure to moderate cold impairs matching-to-sample performance. *Aviat Space Environ Med* 1989; 60:1063-1067.
17. Van Orden KF, Benoit SL. Effects of cold air stress on the performance of a command and control task. *Hum Factors* 1996; 38(1):130-141.

Subjective sensation during local cold exposure

F. Chen¹, I. Holmér

Department of Occupational Medicine, National Institute for Working Life,
S - 171 84 Solna, Sweden

Introduction

The relationship between physiological thermal state and subjective sensation under the influence of cold stress has been the subject of a limited number of studies (see review by (4)). In particular, local thermal sensation and pain in response to local cooling is not much reported. This paper summarises results of two different studies on local hand cooling and thermal sensation.

Methods and material

The details of the experiments have been published (1, 2)

Study I: Bare hand contact on a cold metal surface (1)

25 subjects (13 males and 12 females, 37 ± 7 years for males and 34 ± 7 for females) touched with their middle finger pad an aluminium surface kept at -14, -5 and -1 °C. Hand and metal were kept in a small cold climatic chamber, while the rest of the body was at room temperature. The contact skin temperature (T_{sk}) was measured at the centre of the middle finger pad of the right hand. The contact T_{sk} was continuously monitored with a small and fast-responding copper-constantan thermocouple. Thermal sensation and pain were rated immediately after the cessation of contact. The thermal scale covered 5 points from “neither warm or cold” (0) to “very, very cold” (-4). The pain scale covered 9 points from “no pain” (1) to “intolerable pain” (9).

Study II: Convective cooling of the hand(2)

Eight volunteers (4 male and 4 female, mean 38 years (23-48)) put their left hand for 60 min into the small climatic chamber. The chamber temperature was controlled at 0, 4, 10 and 16 °C. Right hand and the rest of the body were at room temperature (20 to 22 °C). Skin temperatures were measured at nine points of the left hand. All T_{sk} were monitored simultaneously every minute. The T_{sk} from hand and fingers during the last 10 minutes of recording for each subject were used for the analysis. Every 10 minutes of cold exposure, the subjects were asked to rate the sensation of temperature and pain.

¹ F. Chen, Ph.D., is an assistant professor in the Department of Industrial Ergonomics, Linköping University, S - 581 83 Linköping, Sweden.

The thermal scale covered 9 points from “very, very warm” (+4) to “very, very cold” (-4). The pain scale covered 5 points from “no pain” (1) to “intolerable pain” (5).

Results and discussion

In conductive cooling the ratings of thermal sensation and pain did not correlate significantly with T_{sk} under -1, -5 and -14 °C aluminium surface temperature conditions ($r^2 < 0.04$) (Figure 1). Elapsed time before subjects felt very cold or considerable pain averaged 17 seconds (7 to 43 seconds) on -14 °C metal surface, 23 seconds (6 to 85 seconds) in -5 °C metal surface and 126 seconds (32 to 202 seconds) on -1 °C metal surface. Individual variation was considerable. Since the exposure time was so short (most of the subjects stopped the cold exposure within 4 minutes), the subjects sometimes could not accurately describe their feelings. In some cases the subjects complained that they could not distinguish slight pain from very cold sensation. The confusion between cold and pain sensation could be a reason for the poor correlation. Also, the rapid decrease of T_{sk} complicated detailed comparisons of discrete values of temperature and sensation. The study concluded that subjective sensation of temperature or pain is a poor predictor of the actual cooling under cold metal surface contact and cannot be relied upon in practical situations.

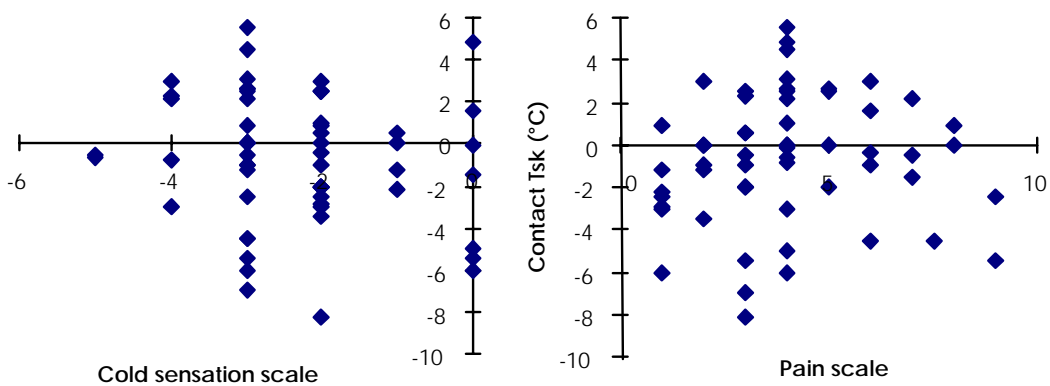


Figure 1. Relation of thermal and pain sensation to contact skin temperature during bare hand contact with a cold metal surface.

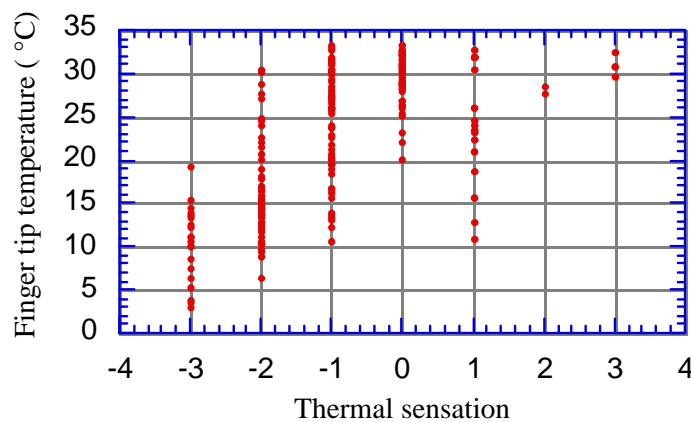


Figure 2. Relation of thermal sensation and skin temperature of the index finger tip during convective cooling.

With convective cooling both thermal and pain sensation were significantly correlated with skin temperature, even though, the correlation coefficient in this study was not as high as Enander's ($r=0.9$) (3) Coefficients varied between 0.64-0.73 for thermal sensation and 0.66-0.81 for pain. The individual differences were large. Figures 2 and 3 show the thermal and pain sensation in relation to skin temperature of the index finger tip.

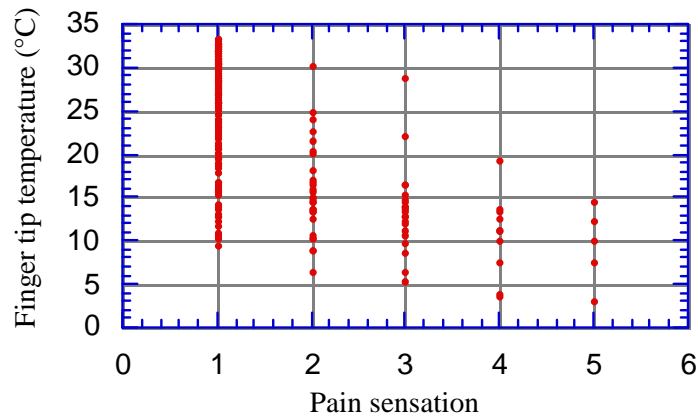


Figure 3. Relation of pain with skin temperature of the index finger tip during convective cooling.

Conclusions

- In convective cooling both thermal and pain sensation strongly correlated to the skin temperatures on the hand and fingers, best so for palm, thumb and index finger base.
- In contact cooling no correlation was found for thermal and pain sensation and contact skin temperature.
- The size of the cooled area appears to be important for the perception stimulus.
- During rapid changes, as with contact cooling from metals, skin numbness may develop before a clear sensation has developed.

References

1. Chen F, Nilsson H, Holmér I. Cooling responses of finger in contact with an aluminium surface. *Am Ind Hyg Ass J* 1994;55:3:218-222.
2. Chen F, Liu ZY, Holmér I. Hand and finger skin temperatures in convective and contact cold exposure. *J Appl Physiol* 1996;69:1:55-60.
3. Enander A. Perception of hand cooling during local air exposure at three different temperatures. *Ergonomics* 1982;25:351-361.
4. Enander A. Sensory reactions and performance in moderate cold. *Arbete och Hälsa* 1986;32.

Effects of low temperature on operation efficiency of tree-felling by chain-saw in North China

L. Wang

Northeast Forestry University, Harbin 150040, China

Introduction

The test site, 46° 50' 9" north latitude and 128° 37' 47" east longitude, is located in the district of Dailing Forest Bureau, Heilongjiang Province, China. It is inland climate. Annual precipitation there is around 600 mm and elevation is 620-650 meters above sea level. The slope at test site is 10.8 degrees in average. Forest covering about 95 % of the piece land of mountain is a mixture of conifer and broadleaf trees. Selective cutting was the prevailing cutting method.

Survey method

Two group of skilled operators using the 051 type of chainsaw which was domestically manufactured, were surveyed during the test time span, from September to March next year. Two video-tape recorders were used for recording the performances of these operators. And diameter ruler and 100 meter-ruler were employed for measuring the diameters of trees as well as the distances between trees to be cut respectively. The air temperature and humidity were read from the Centigrade thermometer and humidometer. The depth of ground top snow was taken by the simple ruler. The precipitation data were obtained from the local meteorological observation station. A day with moderate weather during the test period was chosen as the test day in order to reduce the influence from other weather factors, such as strong wind and heavy rainfall. The weather data were measured twice a day before and after recording operations.

Results and discussions

The data concerning the working environment of tree-felling at testing site from September to March were shown in Table 1. The operators travelled more slowly during the cold time period (see Table 2), from November to March, than that in September mainly due to: (1) operators put on more clothing which made operators more difficult to move from one tree to another; (2) more snow on the ground of operation site during cold period, which also produced more moving resistance to operators, than in September.

Table 1. Working micro-environment of tree-felling operations during testing time span

	Average Temperature(°C)	Lowest Temperature(°C)	Precipitation (mm)	Depth of Snow(cm)	Humidity (%)
September	11.7	-2	86.5	0	77
October	2.9	-11	32.2	0	73
November	-10.0	-25	10.7	10	71
December	-20.9	-36	7.9	25	70
January	-24.0	-39	5.2	45	71
February	-19.1	-28	4.2	40	69
March	-8.6	-26	10.3	35	64

The operations of tree cross-cutting were consisted of preparation, starting, moving chainsaw aiming at the cut, cutting, and operator moving around the tree. Although the efficiency of cutting the standing trees in frozen state is 10 % higher than that in normal state, the total operation efficiency of cross-cutting decreased (see Table 2). The reasons were: (1) It was too cold for the operators to perform the operations. Low temperature made operator's arms and legs and even fingers more stiff than that under normal temperature (approximately 10 °C). Operator's limbs and faces were exposed to cold weather too long during operations. The chainsaw was not as easy to handle by the operator as in September; (2) Preparation time increased significantly due to more snow around the trees and this made the cleaning work cost more time; (3) The frequency of chainsaw breakdown was higher in the cold weather than in normal weather (see Table 2).

According to the observations from the survey of testing site, proportion between cutting time and other time including preparation, travelling and breakdown, was approximately 64 % : 36 %. So the deduction of tree-felling operation efficiency at this site could be estimated through the Tree-Felling Efficiency Model [1] as shown in Table 2.

Table 2. Results of test survey and data analysis

	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Velocity(percentage) (m/h)	2890 (100)	2540 (88)	1950 (67)	1800 (62)	1820 (63)	1880 (65)	1920 (66)
Deduction of cross-cutting efficiency (%)	0	2.2	6.5	15.9	18.6	16.2	8.1
Frequency of chainsaw's breakdown (times/h)	0.3	1.2	2.5	4.7	5.4	5.0	3.4
Deduction of tree-felling efficiency (%)	0	5.7	16.0	23.9	25.2	23.0	17.4

Conclusions

The results of test survey and data analysis showed that the tree-felling operation efficiency was influenced by cold weather, properly decreased 18.5 % in average in this case study. The lower the temperature (below -20 °C), the more quickly the operation efficiency decreased. It was approved by multi-variable regression model ($R^2=0.98$) of

$$\text{Tree-felling Efficiency} = -0.14(\text{Average temperat.})^{1.5} - 0.01(\text{Precip.}) - 0.62(\text{Humidity}) + 53.86$$

The correlation analysis showed that tree-felling efficiency had a high correlation with temperature (0.97) and precipitation(0.90), but less with humidity (0.65) during the testing period.

References

1. Wang L.. *Planning and operations research of timber procurement* (Chinese Edition). Beijing: China Forestry Publishing House, 1997.
2. Wang L.. Effects of micro-climate on tree-felling operation efficiency. *J. of Forest Engineering* (Chinese Edition) 1995:11:32-36.

Hand dexterity with different gloving in the cold

Q. Geng¹, I. Holmér

Department of Ergonomics, National Institute for Working Life, Solna, Sweden

Introduction

Gloves are used in various occupations in the cold. However, the use of protective gloves against the cold can impair manual functions such as hand dexterity. Some studies have indicated that finger and/or manual dexterity is deleteriously affected by wearing gloves in the cold (1, 4). Moreover, there is an interaction between the restrictive and thermal properties of glove designs. All manual performances decrease in the cold (2, 3). However, there has been little research on hand performance with different gloving in the cold environment. In order to both maintain local thermal comfort and permit the retention of enough manual precision for safe and efficient work, it is necessary to investigate hand performance relative to different gloving during cold exposure. Therefore, the aim of this study is to investigate the effect of three different gloving (double, outer and inner) on manual dexterity in the cold operation for searching a suitable way to use the protective gloves against the cold.

Methods

In this study, hand dexterity with different gloving has been studied by two designed tasks (bolt-nut and pick-up). The details of these tasks were described in a test program for working gloves (5). In the bolt-nuts task, a board with 4 sizes of bolt-nut (12, 10, 8 and 6 mm) was used. In the pick-up task, 5 sizes of steel balls (20, 15, 10, 7 and 5 mm) were used. The experiment was carried out on 6 male subjects (age: 27 to 43 years) seated in a cold climate chamber (-10 °C) and performing the tasks with gloved hands, respectively. Each subject was asked to unscrew/screw the bolt-nut and pick up the balls from a bowl to a box with different gloving, respectively. The time required to complete the tasks was recorded. The finger skin temperature of each subject was also measured every minute. Four gloves (B, C, D and E), which are often used for the cold operations in Nordic countries, were used as outer gloves in this study. A thin glove (Glove A) was utilised as an inner glove in the test. The configurations and properties of these gloves were described in our previous work (1).

¹ Doctoral student at Department of Human Work Sciences, Luleå University of Technology, Luleå, Sweden

Results and discussion

Figure 1 shows the results of the 95 % Tukey HSD Intervals for mean time to perform the two tasks using double, inner or outer gloving, respectively. In Figure 1 (a), no significant difference between double gloving and outer gloving exists in the bolt-nut task. In the pick-up task, the results in Figure 1 (b) show that a difference between double and outer gloving is statistically significant. It is interesting to see that double gloving gives even a better task performance. However, intuitively, wearing more gloves against cold should reduce hand dexterity. It is difficult to explain why hand dexterity could be improved with one more inner glove in addition to the outer glove. One explanation for this may be that some gloves (glove B and E) were too big to fit subject's fingers. Wearing double gloves might meet the fitting requirement for the fingers through adding an inner glove due to their increased internal friction. Thus, double gloving may be recommended to be used in the cold operations. This combination of using gloves may both maintain local hand thermal comfort and permit the retention of manual work capacity. Furthermore, in some cases where people in the cold operation need to perform some precision tasks such as pick-up small objects with an inner glove, the way of double gloving can make the process more easy and convenient, and then enhance work efficiency. In addition, Figure 2 shows the mean time required to complete the tasks using outer or double gloving with four gloves in some detail. Figure 2 (a) shows that the hand dexterity with the gloves C and D used as outer gloving are better than that used as double gloving in the bolt-nut task. However, double gloving with glove B or glove E needs a short time to perform the bolt-nut task at -10 °C. In Figure 2 (b), double gloving with four gloves gives a superior performance than their outer gloving in the pick-up task.

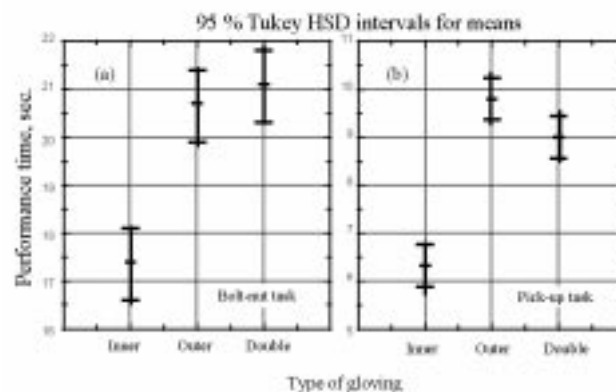


Figure 1. Comparison of mean performance time with different gloving (inner, outer and double) at -10 °C

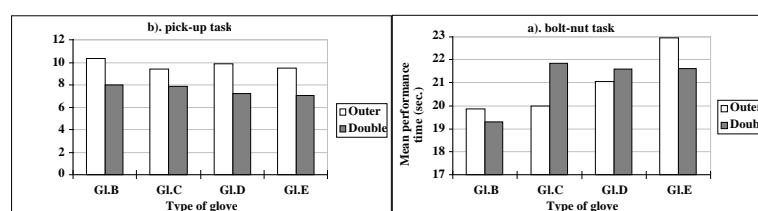


Figure 2. Mean performance time between outer and double gloving with 4 gloves in a). Bolt-nut task; and b). Pick-up task at -10 °C.

Also, there are significant differences between inner and outer gloving as well as between inner and double gloving in the two tasks (Figure 1). The inner gloving gave a

better hand dexterity compared with the others. This may be mainly contributed to the thickness of glove material. The thickness of glove can affect the manual dexterity at -10 °C. However, it is important to note that due to the effect of hand cooling, the inner glove can not be used alone for a long duration in the cold, as shown in Figure 3. Thumb/Little finger skin temperature with the inner glove A at -10 °C was below the critical limit (13 °C) after 40/25 minutes, Also, it is easy to see from these curves that the finger skin temperature with the combination of inner glove A and outer glove B is higher than that with inner glove A. This combination shows a better thermal performance at -10 °C, since double gloving could increase the thermal insulation of gloves against cold. Further studies in this field are suggested.

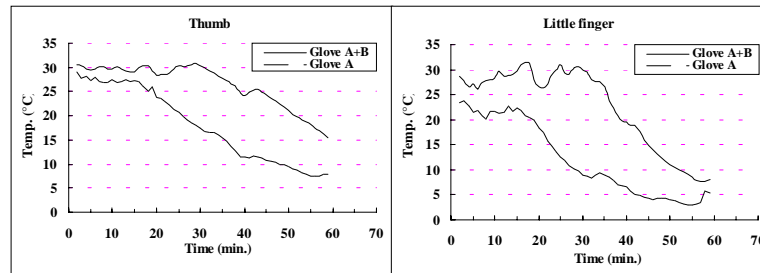


Figure 3. Finger skin temperature during cold exposure of 60 minutes at -10 °C with inner glove A and double gloving (glove A+B).

Recommendations and conclusions

1. The experimental results showed that replacing single outer gloving with double gloving in the cold may be recommended. Double gloving may not only give a better thermal performance but also solve the problems of performing some precision manual tasks when inner glove is used in the cold. It was found that the inner glove A may be used in the calm cold operation at -10 °C for about 30 minutes. Further studies at very cold climate (below -10 °C) in actual work sites are necessary.
2. The thermal performance, thickness and fitness of gloves should be considered when using gloves for safe and efficient work in the cold climate.

References

1. Geng Q, Chen F, Holmér I. The effect of protective gloves on manual dexterity in the cold environments. *Intern J of Occupational Safety and Ergonomics*, 1997;3, 1-2: 16-30
2. Holmér I. *Work in the cold Environments*. Solna: National Institute of Occupational Health, 1994: 49 pp.
3. Parsons KC, Egerton DW The effect of glove design on manual dexterity in neutral and cold conditions In: Oboine D ed. *Contemporary Ergonomics*. Taylor & Francis, London, 1984: 203-209.
4. Rogers WH, Noddin EM. Manual performance in the cold with gloves and bare hands, *Perceptual and Motor Skill*, 1984: 59: 3-13.
5. Sperling L, Jonsson B, Holmér I, Lewin T. *Testprogram för arbetshandskar*. Solna: Arbetskyddsstyrelsen, 1980:18

Cold - its interaction with other physical stressors

B. Griefahn

Institute for Occupational Physiology at the University of Dortmund, Ardeystr. 67,
D-44139 Dortmund, Fed. Rep. Germany

Introduction - Research on multiple stress

Real-life situations are determined by the presence of numerous environmental stressors which occur with varying combinations and concentrations (intensities). They are categorised into biological, chemical, physical, and psychosocial stressors which affect well-being, performance and physiological functions and eventually cause or contribute to the genesis of health disorders. Where the nonoccupational environment is generally determined by a great number and variety of stressors of rather low intensities, the environment at the workplace is often determined by a limited number of stressors of rather high intensities, thus causing a monotonous situation.

Studies in the past concerned mainly the effects of isolated stress, the clarification of underlying mechanisms, the detection of individual vulnerability, the determination of dose-response relations and the definition of upper limits to prevent health disorders. These limits are debatable as they apply for single stress only. Almost nothing is known about the interaction with other stressors which can enhance, reduce, or even extinguish the effects of the primary stress. Research on the effects of multiple stress is therefore strongly recommended, in particular the identification of critical situations arising from a particular combination of stressors and of the quantitative share the single stressors have on the overall effects.

The need for research on multiple stress was repeatedly stated by scientists working in different areas but only a few valuable studies have been executed so far. This is true for the effects of cold and other physical stress as well. It is therefore advisable to scrutinise first the reasons for the large gap between the recognised need for research in this field and the absolutely insufficient solutions.

Basic requirements for research on multiple stress

Apart from a few excellent studies research on multiple stress was executed as if studying the effects of single agents, but the difficulties which arise during evaluation and interpretation reveal that research on multiple stress requires special designs, particular procedures, and sophisticated statistical methods.

Figure 1 presents the four basic designs which clearly distinguish between single and multiple stress (agents, stimuli) on the one hand and single and multiple strain (effects, reactions) on the other hand. An unequivocal terminology is a basic requirement to describe the goal and the design of a study. This concerns even the term 'combined effects' which is used for multiple stress and multiple strain as well.

There is scarcely any stressor, which causes only a single effect. Instead, most stressors evoke specific and unspecific reactions, in case of noise e.g. decreased hearing acuity and an increased sympathetic tone. So, the overall strain caused by the simultaneous influence of several stressors can be evaluated rather qualitatively by describing the variety and strengths of specific effects (e.g. frostbites and hearing loss due to cold and noise) or rather quantitatively by integrating measures provided by non-specific responses which are e.g. caused by any physical stressor concerned (i.e. excitation of the sympathetic nervous system). At this point it has to be stated that even research on multiple stress scarcely concerns the entire complexity of real-life situations. It is for example possible that non-specific responses to a defined stressor (cold-induced vasoconstriction) might also enhance specific responses to another stressor (noise-induced hearing loss).

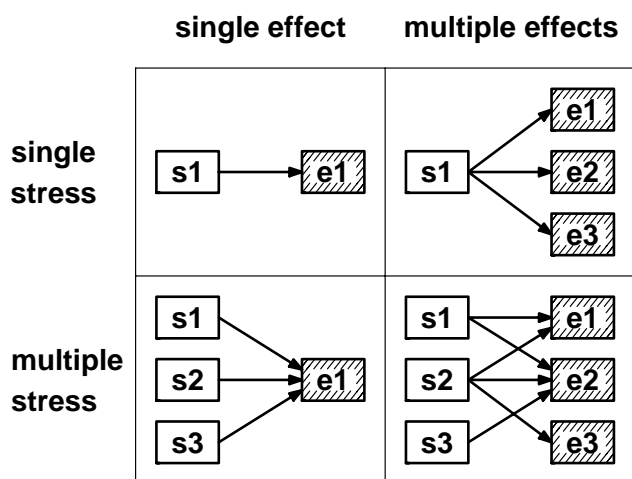


Figure 1. Relationship between stress and effect.

Regarding single stressors it might be acceptable to some degree ‘just to look what happens’ in case of exposure. This is no longer acceptable for studies on multiple stress. Instead, well specified hypotheses based on literature reviews, the knowledge of mechanisms, and a clear concept of expected interactions between various stressors are essential for the development of directed and economic studies. This presupposes again the application of an unequivocal terminology. The controversial usage of the terms additivity, independency, synergism, antagonism, coalism, inertism etc. caused several scientists with widely differing viewpoints to agree on a common terminology, but for only 2 agents where each of them is effective alone, both following monotonic dose effect functions which increase or decrease in the same direction [10]. Table 1 summarises the ‘Saariselkä-Agreement’.

Table 1. The Saariselkä Agreement on the terminology of 2 simultaneously acting agents

Overall effect	Individually effective are		
	both agents	only one agent	neither agent
greater than predicted	Loewe/Bliss synergism	synergism	coalism
as predicted from reference model	Loewe additivity Bliss independence	inertism	inertism
less than predicted	Loewe/Bliss antagonism	antagonism	

Procedure for studies on multiple stress

Due to the large number of possible combinations and variations studies on multiple stress and strain presuppose particular strategies for the execution and evaluation of respective studies in the laboratory and in the field. It is reasonable, first, to identify critical situations in the field, second, to study and to quantify the effects in the controlled situation in the laboratory, and third to apply and evaluate preventive measures in the field.

The application of multiple stress and the registration and evaluation of qualitatively different effects on well-being, performance, and physiologic functions requires the cooperation of scientists of various disciplines and an adequate (rather expensive) equipment. So, research on multiple stress is costly and time-consuming and it is therefore reasonable to record not only one but several effects, which, of course, ought to be carefully selected.

One of the most wide-spread erroneous believes is that work on multiple stress is the domain of pharmacologists and toxicologists. But most work has been done to elaborate models to predict the effects of climate on man. Yet, more than 100 thermal indices were developed. Their validity is, insufficient resp. restricted to a more or less limited range of climates and to defined effects. At present, 3 analytical models for the evaluation of heat, of comfort climate and cold are suggested in International Standards (Ereq, ISO 7933; PMV, ISO 7730, IREQ, ISO/TR 11079). They are most complex as they include the 4 physical and the 2 personal variables which determine heat exchange of the body with its environment. Though it is of course advisable to use already established thermal indices for research on multiple stress it has to be admitted that these indices which consist of so many variables are most delicate instruments which might fail to work well when simultaneously acting stressors are concerned.

The increasing interest in the effects of multiple stress is evidenced e.g. by the biannual International Conference on Combined Effects of Environmental Factors where the fundamental problems of complex environmental exposures are discussed with respect to health and physiological effects including terminology, dose determination, risk assessment, and identification of mechanisms. Additionally, there are several congresses where special sessions concern multiple stress (e.g. International Congress on Biological Effects of Noise).

Cold and other physical stress

The present paper concerns combined actions of cold and other physical stress. Respective constellations are quite common in many industrial sectors. Cold is an essential condition for the prevention of premature spoiling of food, of many chemical products and drugs and thus a permanent stress in the respective industrial sectors. It is then frequently combined with shift work, often with noise, vibrations and poor light. In other sectors such as construction work, forestry, agriculture, horticulture, and navigation cold is a seasonal stressor, often combined with noise, whole-body vibrations, hand-arm vibrations, poor light, and electromagnetic fields.

Despite their rather frequent occurrence these combinations were scarcely studied. But again these few papers point out the need of an unequivocal terminology which concerns here in particular the differently understood term 'cold'. Some authors defined cold as low air temperatures and treated humidity and velocity as additional stressors [1]. Others apply a physiologically based definition where cold is a risk of excessive

local or general heat dissipation. This is strongly recommended if it is not the intention to develop a very special model for very special situations.

The additional physical stressors concerned here are those which do not primarily influence heat exchange of the body with its environment. The rather specific effects of these stressors are in short:

Noise impairs hearing acuity temporarily and even permanently. Acute extraaural effects are disturbances of communication, rest and sleep. Complex mental performance decreases due to distraction or masked acoustic information.

Vibrations reduce performance due to impaired sensor and/or motor functions. Communication might be degraded due to altered speech. In the long run wears of joints and destruction of bones are possible (due to vibration source hands, elbows and shoulders, or the spine).

Poor *light* (dim or flickering light) degrades visual and thereby sensomotor performance. *Electromagnetic fields* might reduce the production of melatonin which is significant in the control of the circadian rhythm. *Time* i.e. the alteration of the circadian rhythm during night- and shiftwork is another physical stress though not generally accepted as that. Respective effects are sleep disturbances and consecutively decreased performances.

Non-specific effects i.e. elevations of the sympathetic tone and after-effects on well-being e.g. via disturbed performance and communication are evoked by most physical stressors as well.

Combined actions of cold and other physical stressors were mostly studied with respect to long-term effects that are health disorders. Only a few experimental studies concerned acute effects on physiological functions and performance.

Health disorders related to cold and other physical stress

As already stated, health disorders solely caused by cold are rather accidents such as frostnips, frostbites and hypothermia, whereas even long-term exposure to cold does not cause specific diseases. But epidemiological studies revealed significant statistical associations between frequently repeated and prolonged exposure to cold and the prevalence of several multifactorial diseases. Causative contributions are plausible particularly for musculoskeletal disorders, hearing problems and cardiovascular diseases [14]. As these health disorders concern also persons never exposed to cold, low temperatures are obviously not essential in their genesis but they aggravate and accelerate this process.

Musculoskeletal disorders (MSD) is a collective term for several diseases subdivided into:

- Clinically well-defined disorders (e.g. tendinitis, vibration induced white fingers)
- Less clinically well-defined conditions (e.g. tendon neck syndrome)
- Non-specific disorders (e.g. cumulative trauma disorders or repetitive strain injuries)

Most important in the genesis of these disorders are repetitiveness, forceful and/or sustained exertions, extreme postures, and static muscle loads, less frequent causes are local or segmental vibrations [6]. Cold accelerates the clinical manifestation which is concluded from epidemiological studies [14] and the reports of the US Bureau of Labor Statistics: the highest rates of MSD concern the red meat packing plants and poultry processors rank in the 4th position. The workers in both these industrial sectors are permanently exposed to low air temperatures which are essential to prevent premature spoiling of the products.

Within this group of diseases, non-specific **cumulative trauma disorders (CTD)** which concern muscles, tendons, and nerves of the upper extremities became a significant occupational problem within the last decade [6] and needs more attention in the future.

Regarding musculoskeletal disorders **vibration-induced white fingers** resp. the secondary Raynaud phenomenon is the most frequently and carefully studied disease. The most significant symptoms are excessive vasoconstrictions evoked by cold or by emotional stress. It is highly prevalent in workers who operate hand-held vibrating tools and acknowledged as an occupational disease. According to a complex yet provisional model [9] the multifactorial genesis involves sympathetic hyperactivity, damages of vaso-regulatory structures and functions, changes in the alpha adrenergic receptor mechanisms, reduced vessel lumen, and increased blood viscosity. Frequently repeated decreases of oxygen supply in the fingers are characteristic in its pathogenesis where several factors at the workplace contribute to, either permanently or repeatedly.

Initially, vibrations were regarded as most decisive. But without static load, vibrations evoke both, a local vasodilation and a sympathetic constrictory reflex [4]. Sound pressure levels usually emitted by vibrating tools as well as low air temperatures cause significant vasoconstrictions again mediated by sympathetic excitation [4, 12]. When gripforces are exerted, peripheral circulation is reduced due to mechanical compressions of the vessels. Combined influences of gripforces and cold cause larger reactions which are once more enhanced due to the tendency to exert greater gripforces if the material is cold (e.g. the grip [7]). Cold apparently decreases the workers' ability to assess the right force to be adjusted. Though cold acts at many workplaces only seasonally, its significance as a contributor to the VWF is undoubted as the prevalences increase with the extent and the duration of cold exposures.

Noise and/or vibration are not effective if additionally applied to gripforces and cold [12]. Vibrations may nevertheless contribute indirectly to the overall effect due to the tendency to exert greater gripforces if a tool starts to vibrate [6, 7, 12]. This leads to the assumption that the secondary Raynaud phenomenon is primarily related to frequent and forceful exertions of gripforces and to cold rather than to vibrations.

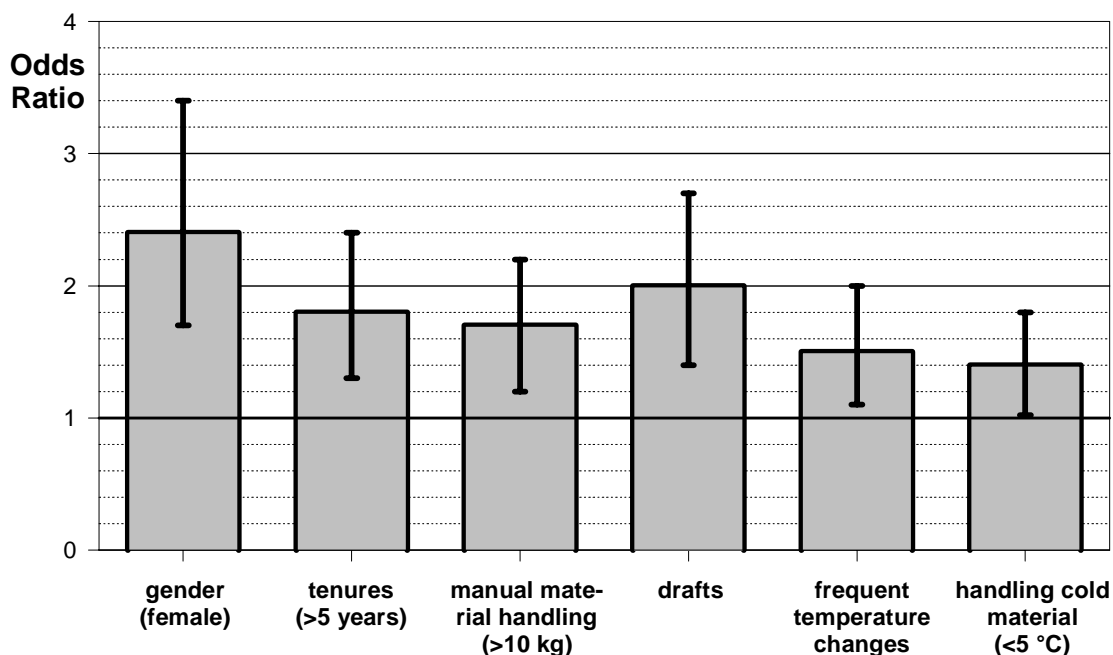


Figure 2. Factors that determine the prevalence of the secondary Raynaud-phenomenon in workers exposed to moderate cold in the food industry (193 cases).

Accordingly, a cross sectional study revealed that the prevalence of suddenly occurring white fingers was almost twice as high in workers exposed to moderate cold (-5 to +15 °C, 18 %) than in the general population in Germany, though only a very few of them used hand-held vibrating tools [14]. The prevalence increased with tenures, in persons who handle cold material of less than 5 °C, who lift and carry weights of more than 10 kg, who are exposed to drafts or experience frequent changes in temperature. Due to their well-known higher prevalence of the primary Raynaud disease these symptoms appeared more often in women, but the attributable risk was the same as in men (12-14 %, high gripforces are exerted while lifting and carrying heavy weights and while treating manually cold material).

A field study has shown that finger skin temperatures decreased at moderately cold workplaces, the more the lower the air temperature and more in women than in men (7.8 vs. 4.4 °C). Rewarming time after exposure was inversely related to air temperatures at the workplaces and for those working in 10 °C or less this time was even longer than required for the cold water test which is used to identify persons with a secondary Raynaud phenomenon.

Lumbago is e.g. highly prevalent in carriers exposed to cold. Whether cold is a causative factor is, however, debatable as lumbago is frequently provoked by more or less vehement motions which again are characteristic for carriers who exert strenuous movements such as bending and stretching, often abruptly, particularly if working under time pressure.

Hearing problems: Noise-induced hearing loss (NIHL), an irreversible destruction of the haircells is caused by occupational exposure to sound pressure levels of 85 dBA and more. Additional exposure to cold and/or to vibrations is associated with higher prevalences, greater hearing loss, and earlier manifestation [14].

The pathogenesis of NIHL is not yet fully understood but reduced oxygen supply during noise exposure plays a significant role. Cold-induced vasoconstrictions enhance this long-term effect. The acute effect is a temporary threshold shift (TTS), which is completely reversible. After a sufficient stay in a quiet environment (< 70 dBA) hearing acuity is fully regained. If the pauses are too short, microlesions accumulate in the long run and result eventually to an irreversible hearing loss.

Contrary to NIHL, which becomes more frequent in the cold, TTS decreases with air temperatures and with body temperatures. The assumption that low temperatures protect the ears [18], however, does not hold. If oxygen supply is already at a low level due to cold-induced vasoconstriction, any additional stress causes smaller effects than if acting alone. But the critical limit for sufficient blood supply is then of course earlier surpassed. There are some indications that whole body vibrations cause a further decrement of TTS.

Cardiovascular diseases: Additionally, a common effect evoked by most physical stressors is an excitation of the sympathetic nervous system [17]. As this is a typical non-specific response to stress which is known to play a significant role in the genesis of several multifactorial, in particular of cardiovascular diseases, repeated and prolonged exposure to either of the physical agents and the more to their simultaneous action contributes likely to the genesis of cardiovascular diseases, particularly of hypertension [13].

This is supported by an observation of 75 younger (25 - 44 yrs) and 71 older workers (46 - 65 yrs) during a normal workday while recording blood pressure [11]. In the younger group blood pressure was inversely associated with ambient temperatures and positively with noise levels.

Acute effects on physiologic functions, performance and well-being

Only a few experiments were executed to study the acute effects of cold and simultaneously acting other physical stressors on physiological functions, performance, and well-being.

Whole-body vibrations in cold environments: In several countries injuries of the spine are acknowledged as an occupational disease for workers exposed to whole-body vibrations. It was assumed that these injuries are more likely if the workers are additionally exposed to cold as this provokes larger tensions of the back muscles and thereby a stiffness of the spine which again enhances the transmission from the buttocks to the head and thereby the likelihood of injuries [8]. The authors proofed this hypothesis experimentally with 12 lightly clad subjects who participated in 9 one-hour sessions. During these sessions they were exposed to the 9 combinations which result from 3 levels of whole-body vibrations and 3 levels of air temperatures ($a_{zw} = 0, 0.6, 1.2 \text{ m}\cdot\text{s}^{-2}$ r.m.s., $t_a = 18, 24, 30 \text{ }^\circ\text{C}$). Though the subjects felt cold in $18 \text{ }^\circ\text{C}$, transmission did not increase, possibly as the cold stress was not strong enough.

The same study revealed that annoyance due to vibrations increases gradually during the sessions and this increase was steeper in the cold.

Performances: Degraded performances due to cold concern manual dexterity and tactile sensitivity when hands and fingers are cooled down to $20 \text{ }^\circ\text{C}$ or to $15 \text{ }^\circ\text{C}$ or less. Where it is rather trivial to expect further decrements in case of poor light due to decreased visual control, manual performance is specifically affected when the person is simultaneously exposed to vibrations. This interaction was studied in our institute (Broede) where a tracking test was executed in air temperatures of $5 \text{ }^\circ\text{C}$ under the simultaneous influence of whole-body vibrations (1.6 and 4.1 Hz, up to $2 \text{ m}\cdot\text{s}^{-2}$). Performance was the same as in $23 \text{ }^\circ\text{C}$ but achieved with a greater subjective effort, which was evidenced by higher heart rates.

Cold and light: Directed studies on the interaction between cold and light were not yet done. 3 studies concerning the interaction between climate and light revealed that rectal temperatures were slightly lower during sleep, during immersion in a hot bath, or during exercise after previous exposure to bright light than after exposure to dim light [15, 16, 21]. Though these results are consistent, an extrapolation to the interaction with cold would be rather speculative. A suitable explanation might be that the turn off of bright light which suppresses the production of melatonin, causes a rebound of melatonin production which is known to be reversely related to core temperatures. Concerning colour, the assumption that colours influence general thermal sensation or even rectal temperature was not verified [3, 5].

Effects on the circadian rhythm: Cyclic alterations of temperatures, even with amplitudes of not more than $2 \text{ }^\circ\text{C}$ can entrain the circadian rhythm as it is well known for the light-dark-cycle [2]. The underlying mechanism is probably the same, namely the influence on the production of melatonin and on the activity of N-acetyltransferase in the pineal gland, where cold corresponds to darkness. Assuming an interaction, some directed studies with animals were executed.

The respective results are controversial. Reductions of melatonin as well as of the activity of the pineal NAT, no alterations, and even increases were found when cold temperatures were applied during dark [19, 20]. On the basis of these results merely speculations are possible.

Overall, apart from some epidemiological investigations on long-term exposure to cold and to other physical stress, research on combined stressors is still at its very beginning. Enforced activities are strongly recommended in the future.

References

1. Anttonen H, Anttonen L, Virokannas H. Combined effects of cold and other physical factors. In: Seppälä P, Luopajarvi T, Nygård CH, Mattila M, eds. From experience to innovation. IEA '97. Proceedings of the 13th International Congress of the International Ergonomics Association. Helsinki: Finnish Institute of Occupational Health, 1997: 2: 491-494
2. Aschoff J; Tokura H. Circadian activity rhythms in squirrel monkeys: entrainment by temperature cycles. *J Biol Rhythms* 1986;1:91-99
3. Bennet CA, Rey P. What's so hot about red? *Human Factors* 1972;14:149-154
4. Bovenzi M, Griffin MJ, Ruffel CM. Acute effects of vibration on digital circulatory function on healthy men. *Occup Environ Med* 1995;52:834-841
5. Fanger PO, Breum NO, Jerking E.: Can colour and noise influence man's thermal comfort? *Ergonomics* 1977;20:11-18
6. Frederick LJ.: Cumulative trauma disorders - an overview. *AAOHN J* 1992;40:113-116
7. Fritz M. Ermittlung von Beanspruchungen des Hand-Arm-Systems bei Schwingungsbelastungen mit Hilfe von biomechanischen und physiologischen Methoden. Forschungsbericht. VDI Reihe 17 Nr. 71, Düsseldorf: VDI-Verlag, 1991
8. Fritz M, Bröde P, Drisch-Jaspert B, Griefahn B. Ermittlung der Reaktionen des Menschen bei Kombination aus thermischer Belastung und Ganz-Körper-Schwingungen mit Hilfe von EMG, Herzschlagfrequenz und Hauttemperaturen. *Zbl Arbeitsmed* 1996;46:138-145
9. Gemne G. Pathophysiology of white fingers in workers using hand-held vibrating tools. *Nagoya J Med Sci* 1994;57 Suppl: 87-97
10. Greco W, Unkelbach HD, Pösch G, Sühnel J, Kundi M, Bödeker W. Consensus on concepts and terminology for combined-action assessment: The Saariselkä agreement. *ACES* 1992;4:65-69
11. Green MS, Harari G. Combined effects of exposure to industrial noise and ambient temperature on ambulatory blood pressure in normotensive males. *ACES* 1992;4:18
12. Griefahn B, Bröde P, Fritz M. Der Einfluß von Hand-Arm-Schwingungen auf die ausgeübten Greifkräfte. *Z Arb wiss* 1995;49:48-53
13. Griefahn B, Bröde P, Fritz M, Schwarzenau P. Noise-induced vascular responses - Interference with skin temperature. *Archives of Complex Environmental Studies* 1994;6:7-11
14. Griefahn B, Mehnert P, Bröde P, Forsthoff A. Working in moderate cold - a possible risk to health. *Journal of Occupational Health* 1997;39:36-44
15. Ishimoto A, Kim HE, Rutkowska D, Tanaka S, Tokura H. Influence of bright and dim light intensities prior to taking a bath on core temperature, heart rate and thermal comfort during 1 hr bathtub immersion of 38.5 °C. In: Nielsen Johannsen B, Nielsen R. *Thermal Physiology 1997, Book of Abstracts*, Copenhagen: The August Krogh Institute 1997: 131p
16. Kim HE, Tokura H. Influence of different light intensities during the daytime on evening dressing behaviour in the cold. *Physiol Behav* 1995;58:779-783
17. Kristensen TS. Cardiovascular diseases and the work environment. A critical review of the epidemiologic literature on nonchemical factors. *Scand J Work Environ Health* 1989;15: 165-179
18. Rentzsch M, Minks B. Combined effects of sound, climate and air pollutants on noise-induced hearing loss. *ACES* 1989;1:41-44

19. Stokkan KA, Nonaka KO, Lerchl A, Vaughan MK, Reiter RJ. Low temperature stimulates pineal activity in Syrian hamsters. *J Pineal Res* 1991;10:43-48
20. Tannenbaum MG, Reiter RJ, Vaughan MK, Troiani ME, Gonzalez-Brito A. Effects of short-term cold exposure on pineal biosynthetic function in rats. *Cryobiology* 1988;25: 227-232
21. Zhang P, Tokura H. Effects of two different light intensities during the forenoon on thermoregulatory responses during afternoon exercise. In: Nielsen Johannsen B, Nielsen R. *Thermal Physiology 1997, Book of Abstracts*. Copenhagen: The August Krogh Institute, 1997:131p

Combined effects of cold and other physical factors

*H. Anttonen, L. Anttonen, H. Virokannas**

Oulu Regional Institute of Occupational Health, Aapistie 1, 90220 Oulu, Finland
* Department of Public Health Science and General Practice, University of Oulu, Aapistie 1, 90220 Oulu, Finland

Introduction

The combined effects of physical factors have often been studied in laboratory conditions. In the present study the combined effect of cold and other physical factors have been analysed mainly in outdoor work. The methods used were a questionnaire evaluating health risks of work conditions (N=2780) and a clinical examination of reindeer herders living in arctic regions (N=650). The risk level of symptoms and illnesses caused by cold, noise and vibration was 15-25 %.

Risk analysis of physical factors was made by traditional methods mostly by ISO standards (ISO 1999, ISO 5349) according to the exposure data evaluated. The risk for frostbite were evaluated by Windchill index.

Voluntary test persons were exposed to four different conditions which varied in temperature (+20 °C...-10 °C, 1 m/s) and whole body vibration (2.5 m/s², 5 Hz) in sitting position. Before and after the exposure persons made mock-up-, VIENNA-two-hand coordination- and maximum force test. EMG-signal was measured from erector spinae and trapezius-muscles. Subjective feeling of vibration and cold was asked. Transmissibility was also measured.

Results

Air conduction hearing acuity was examined and about 18 % of the whole material had over 20 dB threshold shifts. During active work days the daily noise exposure was from 93 to 104 dB(A).

90 % of the analysed subjects had used some kind of vibrating tools, the median total life use of a chainsaw was 3510±5660 hours and that of a snowmobile 2840±4670 hours. The frequency weighted acceleration of hand vibration on the snowmobile was 3.2 - 4.9 m/s² and on the chainsaw 4.1 m/s². The prevalence of vibration - induced white finger calculated from the exposure data was 17 - 21 % and 19 % respondents reported white finger symptoms.

22 % of the respondents reported frostbite during the last 12 months. With longer exposure the incidence increased up to 68 %. The age adjusted prevalence of white finger was over three times higher in the snowmobile and chainsaws user groups than in the controls (6 % and 28 %).

In the VWF group significantly more frostbite on the extremities had occurred than in the non-VWF group, but the differences for frostbite on the head (face and ear lobes) were negligible (Table 1).

In the group of non-NIHL (hearing threshold < 30 dB, 4 kHz) the incidence rate of frostbite was 16 % when in the NIHL-group it was (hearing threshold < 30 dB, 4 kHz) 17 %.

In the VWF group (N=76) there were no higher hearing thresholds at 4 kHz than in the non-VWF group (N=366) either in the right or left ear in the whole material and in any age group analysed in the mild and heavy exposure groups. In the pair-matched groups there were no significant differences between the VWF cases and non-VWF controls groups at any frequencies.

Table 1. Cumulative incidence rate of frostbite in two years (CIR2) on the different areas in the body in the VWF group (N=243) and non-VWF group (N=852).

Frostbite area	VWF group		Non-VWF-group	
	CIR2 (%)	95 % C.I.	CIR2 (%)	95 % C.I.
Face	20.2	15.1-25.2	21.6	18.8-24.4
Ear lobe	8.6	5.1-12.2	7.7	6.0- 9.5
Finger	12.8	8.6-17.0	2.7	1.6- 3.8
Toe	7.4	4.1-10.7	1.5	0.7- 2.4
All	62.1	56.0-68.2	34.3	31.1-37.1

Table 2. Age-adjusted hearing thresholds in the group of frostbite and non-frostbite drivers.

		Frostbite group (N=52)	Non-frostbite group (N=267)	p
3 kHz	right	12.9 (18.5)	9.5 (15.8)	NS
4 kHz	right	14.1 (19.5)	11.6 (18.3)	NS
3 kHz	left	15.7 (18.9)	13.7 (17.8)	NS
4 kHz	left	19.1 (21.9)	19.8 (21.2)	NS

In EMG-measurements the clear reflex output was observed, also muscle activity increase was clear. In the end of the cold and cold/vibration exposures muscle activity was greater than in the warm situation because muscle tonus increased in cold. In the two-hand coordination test the ability to correct errors was worse in the cold and cold/vibration than in warm situations. The mock-up simulation test showed an additive combined effect in hands performance, which was slower. In transmissibility the resonance frequency was smaller and over 10 Hz frequencies was attenuate for the cold body. The combined effects between whole-body vibration and cold were found, which effected significantly on human performance in cold.

Discussion

In conclusion, it is not clear if the VWF is a risk factor for frostbite but more studies are needed to solve this relation between VWF and NIHL. At least the VWF cases with the heavy noise and vibrating exposure didn't have lower hearing thresholds than the others. It is possible that the workers who have a sensitive reaction of the sympathetic nervous system may first get VWF and then NIHL, although this was not found in this study. In the same way an association between frostbite and NIHL wasn't very evident.

References

1. Pyykkö, I., Pekkarinen, J., Starck, J., 1987, Sensory-neural hearing loss during combined noise and vibration exposure. *Int Arc Occ Env Health* 59, 439-454.

Convection cooling from wind and body motion

U. Danielsson

Defence Research Establishment, Department of Human Sciences, S - 172 90
Stockholm, Sweden

Introduction

Normally, the major resistance to the heat transfer between a body and the ambient air refers to the apparent still air layer surrounding the body. The still air layer also impedes the transportation of water vapour so a good protection against heat loss can not be combined with a low resistance to evaporation of sweat. A thick layer impedes the transportation more than a thin air layer. However, body motion and external wind reduce the air layer thickness with increased rate of transfer as a result. Covering the surface with e.g. textile layers produces air layers less influenced by the forced air flow than at unprotected surfaces. Nevertheless, wind and body motion affect the thermal properties of garment layers, an effect that is enhanced if clothing ventilation occurs. The convection coefficient is normally used as a measure of the still air layer thickness. The aim of this presentation is to display convection coefficient relationships valid for the nude and clothed human performing various physical activities in calm air and in the wind.

Materials and Methods

Comprehensive series of experiments were performed on human subjects to survey natural and forced convection coefficients during standing, walking and running (1). The coefficients were measured both at uncovered and clothed surfaces in calm air and in the wind. Large series were also carried out to obtain the convection coefficients in single and multi-layer ensembles to establish the combined convection effects of wind, body motion and ventilation (2). The experiments were run both on a treadmill in a wind tunnel and on an indoor running track. The convection coefficient was measured with heat flux sensors with aluminium surface to eliminate the influence of heat radiation. The temperature was measured with thin thermocouples and the air speed between the clothing layers and at the outer surface was measured with heated thermistors.

Results and Discussion

The air motion around bodies in external wind has been studied in technical applications for decades. Hence, the knowledge about the governing mechanisms in respect of convection heat and mass transfer is good. So, if it can be shown that the

human body acts as one or combinations of simple bodies in respect of convection, general conclusions can be drawn from a limited studies of the human body in wind.

Natural convection is always prevalent as long as there is a temperature and partial pressure difference. These air streams may transport a considerable amount of heat, vapour and particles from the lower part of the body (if erected) upwards. It has been shown that the human body works similar to a vertical wall and roughly the same correlation equations can be used. The magnitude of the thermal convection coefficient depends on the thermal characteristics of the surface. If the surface is isothermal which corresponds to a situation when the skin is warm the convection coefficient is governed by the distance from the leading edges (l), normally the feet and the finger tips, and the temperature difference to the ambient air (ΔT), both variables raised to -0.25. If the skin is cool or the body is clothed the natural convection heat flux is constant and the h_c -value depends roughly on $l^{-0.20}$ but not on ΔT .

When a standing human is exposed to an external wind the body acts as a vertical cylinder of slightly different shapes depending on body part, ranging from a hexagon-, square to a circular shaped cylinder. However, uncovered body parts can, approximately, be considered as circular cylinders where $h_c = 3.8 \cdot d^{-0.36} \cdot v^{0.61}$ [W/(m²K)] where d [m] is the body part diameter at right angle to the wind and v [m/s] is the air speed. This expression gives the average value for the body part but local values differ considerably depending on angle to the wind and body shape. The h_c -relation shows that the convection coefficient is inversely proportional to the body part diameter indicating the potential risk for frostbite at slim parts in ambient temperatures. The interference from other parts can be considerable. General, local h_c -expressions are difficult to derive but the effect can easily be shown experimentally by using simple bodies. The blockage from other body parts changes the h_c -relation more often when the body is dressed than when nude. The expected effect of blockage is a reduced h_c -value due to greater diameter but because of air flow disturbances from the textile structure and folds, the whole-body h_c -relation is changed from $h_c = 7.4 \cdot v^{0.61}$ to $h_c = 10.2 \cdot v^{0.64}$. These effects can be studied in detail when using fabric covered cylinders of various shapes. If the nude h_c -relations are used up to 15-20 % over- or underestimation may occur, depending on body part. During walking, with or without external wind, the blocking effect is reduced. Walking in still air gives $h_c = 7.6 \cdot v^{0.49}$ (nude) and $h_c = 7.2 \cdot v^{0.40}$ (clothed). The whole body h_c -equation when running nude is $h_c = 7.6 \cdot v^{0.65}$. Walking and running produce different local values, especially at and adjacent to the swinging limbs. When the air streams over the body originate both from external wind and body motion the convection coefficient becomes greater than if there is only one source, resulting in $h_c = 12.9 \cdot v^{0.55}$ (walking, nude) and $h_c = 11.7 \cdot v^{0.57}$ (walking, clothed) where v [m/s] is the walking and wind speed. Running nude, $h_c = 12.7 \cdot v^{0.59}$, gives a similar relation as when walking. The local air speed is both a result of the external wind and the induced air stream from the moving body parts. The resulting air speed, measured close to the skin, can be obtained at most body parts by adding the speeds from when walking without external wind and standing in the wind. However, the resulting h_c -value can not be obtained as simple as that because the air speed exponent differs from unity. The resulting h_c -value can be derived from $h_c = (h_{c,wind}^x + h_{c,walk}^x)^{1/x}$ where the exponent ranges from 1 (nude trunk) to 2.7 (clothed leg).

If the clothing apertures are closed the internal air layer convection is an effect entirely from compression of the fabric layers. External wind and open apertures increase the internal air speed. Internal air speed and intrinsic convection coefficient were measured for various combinations of walking speed, wind speed and aperture shape. It was found that the lowest internal air speed was obtained at no external wind

and closed clothing apertures. The greatest air speed was produced at the opposite conditions, i.e. wind and open apertures. The other combinations gave air speeds between these extremes which differed, averaged over the whole body, from 0.1 m/s at the lowest walking/wind speed to about 0.15 m/s at the greatest speeds. These differences raise the internal air speed by 30-40 %. It could be expected that this effect should influence the internal h_c -value considerably. However, this was only the case close to the openings whereas the whole body value differed very little. This is partly because the internal air-layer h_c -relation depends on the air speed raised to 1/3 which reduces the ventilation effect considerably. The ventilation effect at wide air layers (e.g. skirt, coat) is somewhat greater as the h_c -value is related to air speed raised to 0.5. Closing an aperture causes the internal air layer thickness to decrease because folds are developed. This makes the h_c -value increase which partly masks the effects of ventilation.

References

1. Danielsson, U. Activity and wind-induced convection coefficients, In: *Climate and Buildings*. Stockholm: Royal Institute of Technology, 1990, vol. 3.
2. Danielsson, U. *Convection coefficients in clothing air layers*. (PhD thesis). Stockholm: Royal Institute of Technology, 1993.

Thermal effects of respiration heat-exchanger devices

D. Gavhed, W.-F. Zheng, G. Ohlsson, I. Holmér*

Department of Occupational Medicine, National Institute for Working Life, Solna, Sweden

*Department of Human Work Sciences, Luleå University of Technology, Luleå, Sweden

Introduction

Breathing of cold subfreezing air feels uncomfortable for many healthy individuals, especially at physical work. In certain asthmatic patients cold is known to induce bronchoconstriction (BC) at exercise (1). Also in normal seated subjects reflex-mediated BC is suggested to be induced by nasal inhalation of cold air (2) and by cooling the face (3). BC results in discomfort and reduced physical capacity. Respiratory heat exchangers (RHE), have been shown to reduce discomfort due to cold air breathing and to reduce airway obstruction in cold climate (4) by heating the air before inhalation.

In most respiratory heat exchangers (RHE), the expired air cools as it passes through the filter structure, thus transferring heat to the filter walls. As the air cools, water condenses and is retained in a mesh made out of metal or cellulose. At inspiration, the heat and moisture is transferred to the colder and drier air before inhalation into the airways. Thus, the heat exchanger mask minimises the total loss of respiratory heat and moisture (5).

A study was designed with healthy subjects at three activity levels exposed to $-25\text{ }^{\circ}\text{C}$ to test the ability of four commercially available RHE devices to heat the air before inhalation.

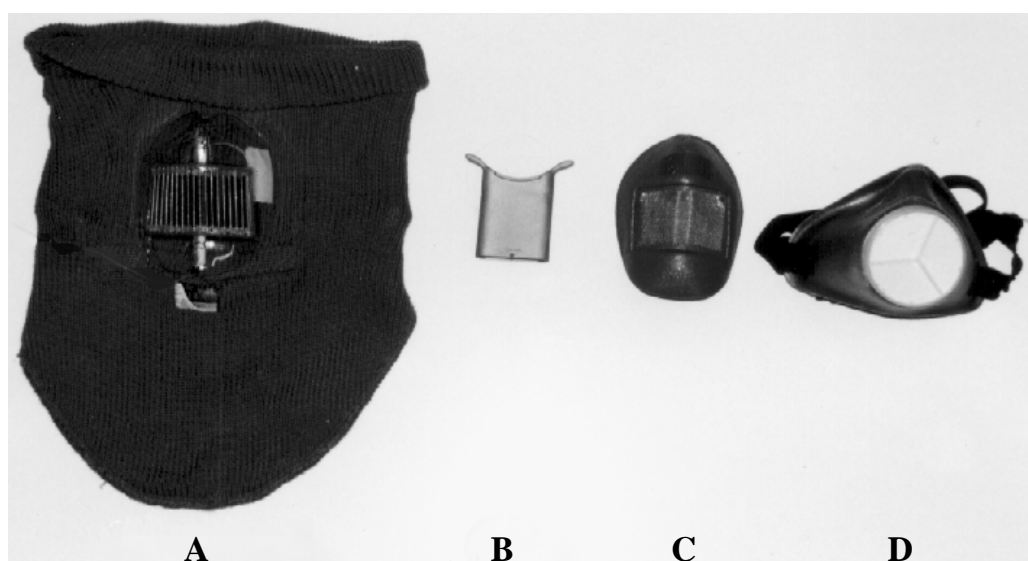


Figure 1. The respiratory heat exchanger devices tested in the study.

Methods

Four RHE devices were tested in a randomised design: A: metal mesh for the mouth in a knitted face cover, approx. volume (V) = 13 cm³, B: a mouthpiece with a metal mesh, V = 21 cm³, C: metal mesh for nose and mouth, V = 5 cm³, D: cellulose honeycomb in a nose and mouth-mask, V = 28 cm³. Eight healthy subjects were exposed to -25 °C. They were standing, walking and running for 10 min at each activity with warm breaks between the sessions. The temperature of the air before inhalation and the expired air near the heat exchanger mesh was measured at an interval of 50 ms with a small thermistor during the exposure.

Results and discussion

The inspired air temperature was 31.2 to 43.4 °C higher than the ambient air in the tested RHE devices at standing. (Figure 2). In three of the four heat exchangers, the heating of the inspired air was slightly less efficient at running. Device C had a significantly lower performance than the other three at walking and running. The cold ambient air in C was heated by 14 °C, while the increase was more than 25 °C in the other devices. This difference may partly be due to the smaller heat exchanging surface area of C (estimated by the mesh volume), compared to the surface area of the others, and partly due to differences in design and the way they were used.

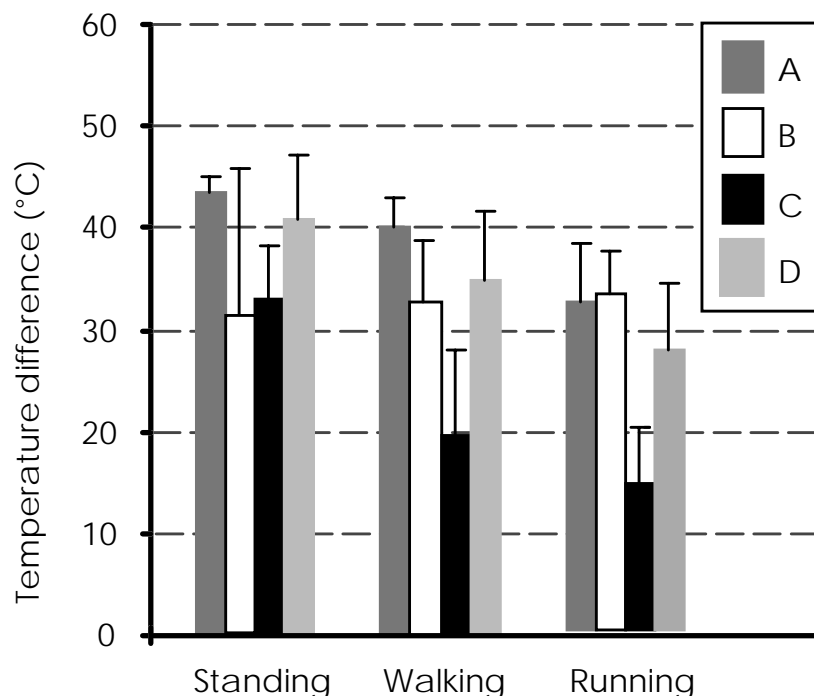


Figure 2. Average temperature differences between inspired and ambient air in four RHE in eight healthy subjects at different activities. The more efficient was the heat exchanger, the higher was the temperature difference.

At rest the air is inspired and expired mainly through the nose, but at higher minute ventilation, the air is respired mainly through the mouth. The differences in design may explain why B did not show the same pattern at the three activities as the other devices, i.e. lower efficiency at more intensive physical work. Device B covered only the mouth,

while the others covered both the nose and the mouth. Consequently, mouth-breathing was predominant in B at all activities.

The temperature of the air measured by the outside sensor was higher than the ambient temperature at inspiration. This was most likely due to the heat loss by convection and radiation from the subject's body.

Conclusions

Any of the tested RHE devices most probably reduces cold discomfort and prevents bronchoconstriction at standing and at exercise in cold climate. However, the performance of different respiratory heat exchangers seemed to be related to the volume (and surface area) of the heat exchanger, but also to varying design.

References

1. Deal ECJ, McFadden ERJ, Ingram RHJ, Strauss RH, Jaeger JJ. Role of respiratory heat exchange in production of exercise-induced asthma. *J Appl Physiol* 1979;46:467-475.
2. Fontanari P, Burnet H, Zattarahartmann MC, Jammes Y. Changes in airway resistance induced by nasal inhalation of cold dry, dry, or moist air in normal individuals. *J Appl Physiol* 1996;81(4):1739-1743.
3. Koskela H, Tukiainen H. Facial cooling, but not nasal breathing of cold air, induces bronchoconstriction: A study in asthmatic and healthy subjects. *Eur Resp J* 1995;8(12):2088-2093.
4. Millqvist E, Bake B, Bengtsson U, Löwhagen O. Prevention of asthma induced by cold air by cellulose-fabric face mask. *Allergy* 1995;50:221-225.
5. Mekjavic, I.B., and Eiken, O., 1996. Thermodynamic characteristics of a prototype respiratory heat and moisture exchanger. *Environment Ergonomics. Recent progress and new frontiers*. Editors: Shapiro, Y., Moran, D.S., Epstein, Y. Freund Publishing House Ltd. London and Tel Aviv.

Wind effects on head heat loss

G. Ohlsson, E. Hiltunen, H. Anttonen*, I. Holmér*

Department of Occupational Medicine, National Institute for Working Life,
S - 171 84, Solna, Sweden

* Oulu Regional Institute of Occupational Health, FIN-902 20 Oulu, Finland

Introduction

It is well known that increased wind speed enhances heat transfer from the body. The cooling effect of wind on the human head is complicated. The reason for the susceptibility of the head to cold temperatures and wind are both physiological and physical in nature (3)

At an air temperature of -4 °C and a wind speed of 2.2 m/s Froese & Burton (2) show that head heat loss will amount to about half of the resting heat production.

When reaching dangerously low temperatures, as shown by Tochihara et al. (7) cold-induced vasodilatation (CIVD) may occur in facial regions leading to higher levels of heat loss from the head.

This study was conducted to measure head heat loss in different wind speeds using a heated thermal manikin head (4). By using the manikin head the geometry fits well with the head of a human. This makes it possible to calculate local convective heat transfer coefficients for different zones of the head that corresponds well with the human head. Using these results makes it possible to predict dangerous combinations of wind speed and air temperature concerning head heat loss and local risks of frostbite.

Materials and Methods

The thermal manikin head

In this study a thermal manikin head was used (4) A computerised control unit regulated the heated manikin head surface temperature. Surface temperature and heat flux was monitored and controlled six times per minute by a computer program. In order to simulate the skin temperature of a human being the surface temperature was controlled within the range of 34 ± 0.1 °C.

The wind tunnel

A wind tunnel (height 200 cm, width 100 cm) was used for creating wind speeds from 0.44 m/s up to 15.49 m/s. The manikin head was placed in the centre of the wind tunnel at a distance of 480 cm from the fans. Wind speeds and air temperatures were monitored during all experiments with sensors placed 50 cm upwind from the head at three levels (jaw, nose and forehead level). Tunnel data for the different experiments are shown in Table 1.

Procedure

Before the experiments begun, the thermal manikin head was calibrated at 34.0°C. This is the surface temperature that the computerised control unit regulates towards. After this the head was placed inside the wind tunnel facing the wind. The power supply was put on and the climate chamber temperature was set to wanted value. When the chamber temperature and the head heat loss was stable the experiment could begin. The experimental conditions comprised a series of air velocities from 0.14 to 15.5 m/s. Turbulence intensity was less than 4 % from 0.4 m/s (SD divided by mean air velocity).

Calculations

All calculations were based on the last 20 minutes average data. Heat loss was directly determined as the power required to maintain the surface temperature at 34.0°C during the last 20 minutes of each test. The heat transfer coefficients were calculated as:

$$h_{tot} = \frac{H}{(T_s - T_a)}$$

$$h_c = \frac{(H - R)}{(T_s - T_a)}$$

$$R = \sigma \varepsilon (T_s^4 - T_a^4)$$

where h_{tot} is the heat transfer coefficient (radiation and convection; W/m²,K), h_c is the local convective heat transfer coefficient (W/m²,K), H is the heat loss from the manikin head (W/m²), R is the radiation heat loss from the manikin head (W/m²), σ is Stefan-Boltzmanns constant ($5.6705 * 10^{-8}$ W/m²,K⁴), ε is the emissivity factor for the surface of the head (0.95), T_s is the surface temperature and T_a is the air temperature (K).

Results and discussion

The total heat loss (convection and radiation) is shown in Figure 1. Heat loss is highest from forehead and top of head followed by face, ears and neck. The wind effects are greatest at wind speeds between 0.2 m/s up to 6 m/s. The results show that forehead heat loss is 100% higher at a wind speed between 1.5 - 2 m/s compared to the lowest wind speed of 0.2 m/s. The total heat loss from the head compared with heat loss at 0.2 m/s is doubled at less than 4 m/s and ends at a level of 5.2 times higher at a wind speed of 15.5 m/s.

The measured heat losses from different parts of the head are given in Table 1.

Values provided figures in the range observed by previous investigators. Apparently the present physical method allows relevant, accurate, and repeatable measurements for detailed analysis of head heat exchange.

Table 1. Comparison of head heat loss reported from various sources.

	Forehead	Top of head	Face	Whole head
(2)				419
(1)	557±17	481±22	596±18	
(5)				318
(6)				579
This study	451	439	429	436

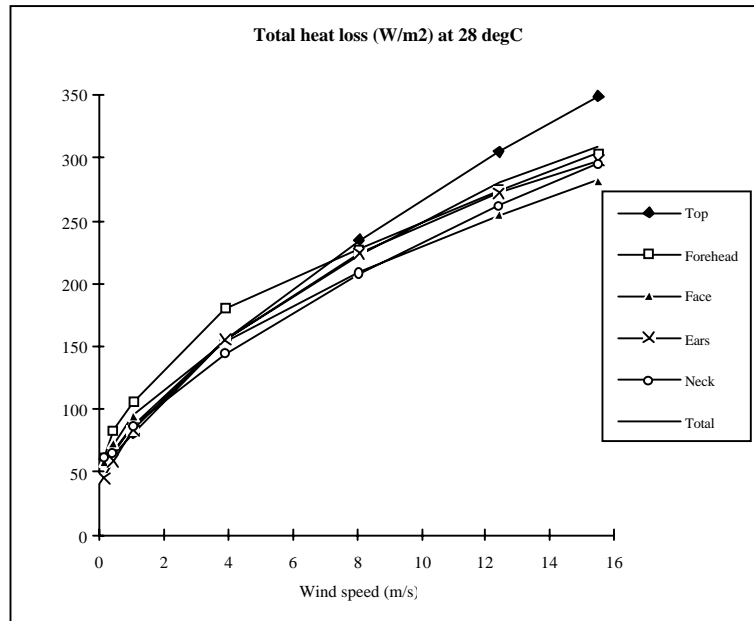


Figure 1. Wind effects on total heat loss (convection and radiation) measured at different zones of the manikin head. The average total heat loss from the head is also shown.

Acknowledgement

Supported by grants from the Swedish Council for Work Life Research and the Finnish Work Environment Fund.

References

1. Afanasieva R. In: Personal communication, 1997.
2. Froese G, Burton AC. Heat loss from the human head. *J Appl Physiol.* 1957;10:2:235-241.
3. Kaufman WC, Laatsch WG, Rhyner CR. A different approach to wind chill. *Aviat. Space Environ. Med.* 1987;58:1188-1191.
4. Liu X, Holmér I. Evaporative heat transfer characteristics of industrial safety helmets. *Applied Ergonomics* 1995;26:135-140.
5. Mochida T. Convective and radiative heat transfer coefficients for the human body. *Bulletin of the Faculty of Engineering. Hokkaido University* 1977;(84):1-11.
6. Siple PA, Passel CF. Measurements of dry atmospheric cooling in subfreezing temperatures. *Proc American Philosophical Society* 1945;89(1):177-199.
7. Tochihara Y, Ohlsson G, Karlsson E, Gavhed D, Holmér I. Effects of Facial Cooling on Thermal Responses of Humans. In: Shapiro Y, Moran DS, Epstein Y, ed. *The Seventh International Conference on Environmental Ergonomics.* Sheba Medical Centre, Israel: , 1996: 127-130.

Medical and biological support of Antarctic expedition

E. Zhilyaev, V. Klyuzhev, V. Ardashev, V. Kostritsa, V. Varfolomeev, A. Antonov

Institute of Extreme Medicine, Moscow, Russia

We consider the experience of the medical and biological support for the female sport team, that covered 250 km distance during 13-day ski race from Antarctic seashore up to the pole. Before and after the expedition clinical and physiological examination of sportswomen was carried out in order to estimate their physical and psychological state, hormonal and immunity systems, albumen/protein-, carbohydrate- and fat-metabolism, characteristics of white and red blood cells, the heart and vascular systems, central nervous system, psychological status of the race.

The analysis of the data has shown that two processes were present during the race: adaptation to the expedition conditions and increase of fatigue. Signs of mountain disease, decrease of subjective appraisal of their state, disappearance of appetite, increase of anxiety level were noted during beginning days of the race. The sportswomen's state was characterised as transitional from optimum level of psychical adaptation towards its disturbance as dysfunction of anxiety level, the instability of blood-circulation regulating mechanisms.

The signs of mountain-disease disappeared gradually after 4-5 days of the race. On the day of the expedition the phase of "final effort" was registered as the improvement of feelings - activity - mood factors.

After the expedition there were no essential change in the state of heart-vascular system. At the same time the blood features had some dynamic changes. Showing adaptation to intensive and prolonged physical loading in conditions of oxygen shortage: the quantity of erythrocyte and haemoglobin level increased, clotting system activated. The index of albumen metabolism was characterised by predominance of the albumen division process, not of albumen reconstruction. Usually it takes place when protein consumption is insufficient.

The analysis of the expedition results made possible to elaborate recommendations to improve preparedness of sportswomen to carry out such races, to perfect their technical equipment, clothes, feed and optimum regime of loading.

Authors in alphabetical order

A

Abdel-Rahman, T. A. 190
Abeysekera, J. 201
Afanasieva, R. F. 19; 92
Alyukhin, Yu. S. 140
Andersson, J. 178
Antonov, A. 269
Anttonen, H. 29; 63; 75; 77; 94; 108; 114;
..... 258; 266
Anttonen, L. 258
Ardashev, V. 269
Arjamaa, O. 118
Arokina, N. K. 140
Azhaev, A. 145

B

Bergh, U. 232
Berzin, I. 145
Bittel, J. H. M. 147
Blazejczyk, K. 111
Brändström, H. 136
Burmistrova, O. 92

C

Chen, F. 240
Chernetsov, A. 145
Chuiquin, A. E. 140
Collins, K. J. 166; 190
Conway, G. A. 1

D

Danielsson, U. 133; 232; 260
Divert, V. 195
Donaldson, G. C. 210

E

Easton, J. C. 190
Enander, A. 235
Ervasti, O. 132; 142

G

Gavhed, D. 39; 42; 58; 165; 263
Geng, Q. 246
Gerasimova, L. 192; 205; 216
Giesbrecht, G. 184
Greibenkin, V. 145
Griefahn, B. 45; 249
Gyllerup, S. 197

H

Hamlet, M. 127
Hassi, J. 132; 142
Havenith, G. 82; 89
Heller, J. 152

Herman, H. 26; 69; 86
Heus, R. 82; 89
Hiltunen, E. 75; 77; 94; 108; 266
Hisdal, J. 172
Holm, B. 178
Holmér, I. 31; 39; 42; 77; 79; 96; 114; 165;
..... 240; 246; 263; 266
Hošek, V. 152
Husberg, B. J. 1

I

Ishii, N. 175
Ison, J. 190
Ivanov, K. P. 140; 158; 208

J

Janáková, H. 152
Janský, L. 152
Johansson, B. W. 222
Juopperi, K. 132; 142

K

Keatinge, W. R. 120; 210
Khan, Z. 201
Kistemaker, L. 89
Klyuzhev, V. 269
Kostritsa, V. 269
Kozyreva, T. V. 219
Kuklane, K. 79; 96

L

Laitinen, J. 118
Larsson, K. 165
Legg, S. J. 124
Leppäluoto, J. 118
Lesná, I. 152
Levkovich, Yu. I. 140; 208
Lincoln, J. M. 1
Linna, T. 132; 142
Lugg, D. J. 224
Lundgren, H. 222
Lupandin, Yu. 192; 205

M

Mahar, H. 60
Meigal, A. 192; 205; 216
Meinander, H. 79
Miyai, N. 175
Miyashita, K. 175
Morioka, I. 175
Müller-Suur, C. 165
Mäkinen, T. 39; 42; 58; 118

N	
Nielsen, R.....	16
Nilsson, H.....	114
Niskanen, J.....	63
O	
Ohlsson, G.....	77; 114; 263; 266
Oikarinen, A.....	108
Oksa, J.....	216; 218
P	
Palmberg, L.....	165
Parízková, J.....	152
Parsons, K.....	72
Parsons, K. C.....	48; 66
Pause, B.....	99
Pekkarinen, A.....	63
Pihlajaniemi, R.....	132; 142
R	
Reinertsen, R. E.....	11; 137; 172
Rintamäki, H.....	39; 42; 58; 72; 118; 132; 142; 182; 216; 218
Risikko, T.....	29; 75
Rissanen, S.....	182
S	
Sacco, P.....	190
Sawada, S.....	161
Schagatay, E.....	178
Sergeev, A.....	205
Shevchenko, S. V.....	140; 208
Shustov, E.....	143
Šimecková, M.....	152
Simonova, T. G.....	219
Slepchuk, N. A.....	140
Smirnov, A.....	143
Šrámek, P.....	152
Sullivan, P.....	224
T	
Tikuisis, P.....	101
Tkatchenko, E.....	195
Tochihara, Y.....	13
Tornling, G.....	165
Turunen, L.....	118
U	
Ulicný, B.....	152
W	
Wang, L.....	243
Varfolomeev, V.....	143; 269
Virokannas, H.....	258
Vuolteenaho, O.....	118
Vybiral, S.....	152
Z	
Zeman, V.....	152
Zheng, W.-F.....	263
Zhilyaev, E.....	145; 269

Instructions to authors

Content

Most articles published in *Arbete och Hälsa* are original scientific work, but literature surveys are sometimes published as well. The usual language is Swedish. Doctoral theses, however, are usually written in English.

Manuscript

The manuscript must be submitted in six copies. Detailed instructions can be obtained from the Institute's Department of Information. The manuscript is printed by photo offset in the same form in which it is received. It is introduced by a title page containing the title (in capital letters) in the center. Below the title are the names of the authors. In the upper left-hand corner is *Arbete och Hälsa*, followed by the year and the issue number (e.g. 1994:22). This number is assigned after the manuscript has been approved for publication, and can be obtained from Eric Elgemyr in the Department of Information (telephone: (+46)8/617 03 46).

A brief foreword may be presented on page 3, explaining how and why the work was done. The foreword should also contain the acknowledgements of persons who participated in the work but who are not mentioned as authors. The foreword is signed by the project leader or the division manager. Page 4 should contain the table of contents, unless the manuscript is extremely short.

Summary

Summaries in Swedish and English are placed after the text, preceding the reference list. A summary should be no more than 100 words long. It should begin with complete reference information (see below for format). The texts should be followed by no more than 10 key words, in both Swedish and English.

References

The references are placed after the summaries. They are arranged alphabetically and numbered consecutively. They are referred to in the text by a number in parentheses. Unpublished information is not taken up in the reference list, only in the text: Petterson (unpublished, 1975).

When a work by more than two authors is referred to in the text, only the first name is given: Petterson et al. All the authors are given in the reference list. In other respects, the references should follow the Vancouver system.

Abbreviations for periodicals are those given in the *Index Medicus*.

For articles that are not written in English, German, French or one of the Nordic languages, the English translation of the title is usually given, with a note on the original language.

Examples:

a. Article

1. Axelsson NO, Sundell L. Mining, lung cancer and smoking. *Scand J Work Environ Health* 1978;4:42–52.
2. Borg G. Psychophysical scaling with applications in physical work and the perception of exertion. *Scand J Work Environ Health* 1990;16, Suppl. 1: 55–58.
3. Bergkvist M, Hedberg G, Rahm M. Utvärdering av test för bedömning av styrka, rörlighet och koordination. *Arbete och Hälsa* 1992;5.

b. Chapter in book

1. Birmingham DJ. Occupational dermatoses. In: Clayton GD, Clayton FE, eds. *Patty's industrial hygiene and toxicology Vol.1*. 3rd ed. New York: John Wiley, 1978: 203–235.

c. Book

1. Griffin MJ. *Handbook of human vibration*. London: Academic, 1990.
2. Klaassen CD, Amdur MO, Doull J, eds. *Casarett and Doull's toxicology*. 3rd ed. New York: Macmillan, 1986.

d. Report

1. Landström U, Törnros J, Nilsson L, Morén B, Söderberg L. *Samband mellan vakenhetsmått och prestationsmått erhållna vid körsimulatorstudie avseende effekter av buller och temperatur*. Arbetsmiljöinstitutet, 1988 (Undersökningsrapport 1988:27).

e. Articles written in languages other than English, French, German or one of the Nordic languages

1. Pramatarov A, Balev L. Menstrual anomalies and the influence of motor vehicle vibrations on the conductors from the city transport. *Akushersto Ginekol* 1969;8:31–37 (in Russian, English abstract).

f. Article in conference proceedings

1. Mathiassen SE, Winkel J, Parenmark G, Malmkvist AK. Effects of rest pauses and work pace on shoulder-neck fatigue in assembly work. *Work and Health Conference*. Copenhagen 22–25 February 1993: 62–63 (Abstract).
2. van Dijk F, Souman A, deVries F. Industrial noise, annoyance and blood pressure. In: Rossi G, ed. *Proceedings of the Fourth International Congress on Noise as a Public Health Problem*. Milano: Centro Ricerche e Studi Amplifon, 1983: 615–627.

Figures and tables

Figures are placed in the text and numbered in order of appearance. The figure text is below the figure. The tables are placed in the text and numbered in order of appearance. The table text is placed above the table. Tables are normally placed at the top or bottom of a page, or immediately above a subhead.

ARBETE OCH HÄLSA

1997

- 21 **G Aronsson och L Svensson.** Nedvarvning, återhämtning och hälsa bland lärare i grund- och gymnasieskolan.
- 22 **M Lagerström, T Hansson och M Hagberg.** Arbetslivsinstitutets expertkommitté för ergonomiska frågor. Dokument 2. Ländryggsbesvär i sjukvårdsarbete.
- 23 **Z Wang.** Acute Cytokine Responses to Inhaled Swine Confinement Building Dust.
- 24 **Kriteriegruppen för hygieniska gränsvärden. Ed. P Lundberg.** Vetenskapligt Underlag för Hygieniska Gränsvärden 18.
- 25 **Criteria Group for Occupational Standards. Ed. P Lundberg.** Scientific Basis for Swedish Occupational Standards XVIII.
- 26 **A Renström.** Allergy to Laboratory Animals. Risk Factors for Development of Allergy and Methods for Measuring Airborne Rodent Allergens.
- 27 **C Sconfienza och F Gamberale.** Unga mäns och kvinnors arbetssituation.
- 28 **L Hallsten.** Arbetslöshet och psykisk ohälsa 1980–1996 – en meta-analys.
- 29 **Å Kilbom, P Westerholm, L Hallsten, B Furåker (Eds).** Work after 45? Proceedings from a scientific conference held in Stockholm 22–25 September 1996. Volume 1 and 2.
- 30 **I-L Engkvist.** Events and Factors Involved in Accidents Leading to Over-exertion Back Injuries among Nursing Personnel.

1998

- 1 **J Järnberg.** Toxicokinetics of Inhaled Trimethylbenzenes in Man.
- 2 **A Engqvist.** Mercury exposure from amalgam fillings. Analysis of mercury in different biological matrixes and speciation in the feces.
- 3 **G Aronsson och S Göransson.** Tillfälligt anställda och arbetsmiljödialogen. En empirisk studie.
- 4 **E Elovaara.** The Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals. 122. Dichlorbenzenes.
- 5 **L Laflamme och E Menckel.** Skaderelaterade faktorer i skolmiljön. Utveckling av ett instrument för registrering och analys av elevskador.
- 6 **A Toomingas.** Methods for evaluating work-related musculoskeletal neck and upper-extremity disorders in epidemiological studies.
- 7 **L Hallsten.** Psykiskt välbefinnande och arbetslöshet. Om hälsorelaterad selektion till arbete.
- 8 **E Åhsberg, F Gamberale och K Gustafsson.** Upplevd trötthet efter mentalt arbete. En experimentell utvärdering av ett mätinstrument.
- 9 **S Törnqvist, U Bergqvist, R-M Herlin, T Lindh, B Knave, F Gamberale, Å Kilbom, L-I Andersson, M Hagman och M Tesarz.** Hälsorisker i arbete med elproduktion och eldistribution – slutrapport från en prospektiv studie.
- 10 **J Winkel, M Attebrant och B-O Wikström (red).** Konsensusrapporter rörande kunskapsläget om arbetsmiljön i skogsmaskiner.
- 11 **J-E Berg and K Skyberg.** The Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals. 123. Antimony.
- 12 **A Zitting.** The Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals. 124. Thermal Degradation Products of Polyethylene, Polypropylene, Polystyrene, Polyvinylchloride and Polytetrafluoroethylene in the Processing of Plastics.
- 13 **B Pingel och H Robertsson.** Yrkesidentitet i sjukvård – position, person och kön.
- 14 **E Bejerot.** Dentistry in Sweden – Healthy work or ruthless efficiency?
- 15 **C Bayard.** Purification, Characterization and Immunological Studies of Rat Urinary Proteins Causing Allergy in Humans.
- 16 **L Wilhelmson.** Lärande dialog. Samtalsmönster, perspektivförändring och lärande i gruppsamtal.
- 17 **K Kjellberg.** Methods for description, analysis and assessment of work technique in manual handling tasks.
- 18 **I Holmér and K Kuklane.** Problems with cold work. Proceedings from an international symposium held in Stockholm, Sweden, Grand Hôtel Saltsjöbaden, November 16–20, 1997.