COLDTECH-- PRELIMINARY STUDY REPORT

THE USE OF PERSONAL PROTECTIVE CLOTHING AND

DEVICES IN THE COLD ENVIRONMENT

JOHN ABEYSEKERA

Division of Industrial Ergonomics

Department of Human Work Sciences

LULEÅ UNIVERSITY, SWEDEN

RAPPORT

Förundersökning ('State of The Art' studie)

angående

PERSONLIG SKYDDSKLÄDSEL OCH UTRUSTNING I KALLT KLIMAT

av

JOHN ABEYSEKERA

(Avdelning för Industriell Ergonomi, Högskolan i Luleå, Sverige)

Då personlig skyddsutrustning (Personal Protective Devices, ppd) används i kallt klimat blir problemen med användarvänlighet mer påtagliga eftersom ppd måste bäras utanpå skyddskläder mot kyla. Forskningen inom området ergonomiska aspekter på ppd i kallt klimat har på senare tid varit bristfällig. Den ppd som idag används i kallt klimat uppfyller inte kraven på användarvänlighet vilket har resulterat i obekväma kläder, skador, oanvändbara kläder samt ett minskat användande av ppd bland utomhusarbetare, speciellt i extremt kalla områden såsom artiska länder. En preliminär studie gjordes angående användningen av ppd i kallt klimat och omfattade de litteraturkartläggning, en enkätundersökning gjord bland utomhusarbetare samt informationssökning genom besök hos relevanta forskningsinstitut, diskussioner med forskare och deltagande i konferenser. Litteratursökningen, som utfördes i sex databaser, gav mycket nyttig information om de speciella områden där det finns problem med användarbarheten hos ppd liksom användbar information om forskningsmetoder. Enkätundersökningen, som utfördes i Luleå regionen, bekräftade att arbetarna ställdes inför många problem vid användande av ppd i kallt klimat. Enligt vad som framkommit i denna studie är de tre

viktigaste typerna av ppd skyddshandskar, skyddsskor och skyddshjälmar vilka diskuteras i denna rapport. Det finns ett stort behov av forskning inom området ergonomiska faktorer på ppd som används i kallt klimat där en förbättring av användarvänligheten hos skyddsutrustningen är ett mål.

Preface

The need for comfort, convenience, fit and good aesthetics of the clothing and other devices which touch the human body or worn by humans, is obvious. Research to improve the user needs of clothing and other devices worn by man is therefore of utmost importance. Unfortunately this area of scientific research has not been given adequate attention in the past. In recent years the need for improvement and wearability of personal protective devices and clothing has been brought into focus at many Conferences and International Symposia. The results of field surveys carried out among users of ppd have confirmed the above view.

COLDTECH as the name implies is an organization that administrates, guides and encourages research and provides funding for research on cold technology. Through its activities it is known that COLDTECH does a yeomen's service to the cold community. An application sent by the author of this report, outlining the need for research in the area of personal protective devices and clothing for cold environments was approved and supported by COLDTECH. This was encouraging and also challenging. Subsequently COLDTECH approved funding for a 'state of the art' study on this topic with a view to spell out the research priorities on the topic. This preliminary study has now been completed and the report is contained in this publication. The resources, encouragement and the guidance given by COLDTECH are much appreciated and acknowledged.

In carrying out this study the author obtained guidance and consultations from Prof. Ingvar Holmér of The National Institute of Occupational Health and Safety, Stockholm. Further, assistance was obtained from Christina Lönnroth (Industrial Ergonomics Division, Luleå University) to search literature, and preparation and distribution of the questionnaire. Their services are acknowledged with thanks.

April, 1992 John Abeysekera

REPORT

Preliminary Study ('State of The Art' Study)

on

THE USE OF PERSONAL PROTECTIVE CLOTHING AND DEVICES IN THE COLD ENVIRONMENT

by

JOHN ABEYSEKERA

(Division of Industrial Ergonomics, Luleå University, Sweden)

Summary

In the use of personal protective devices (ppd) in the cold environment the wearability problems become more aggravated as the ppd must be worn over the cold protective clothing. Research in the area of human factors of ppd in cold environment has been scarce in the past. The lack of adequate user needs in currently used ppd in the cold environment, has resulted in discomfort, injury, non-use, and performance decrement among outdoor workers, particularly in the extreme cold regions, viz. Arctic countries. A preliminary study on the 'state of the art' was carried out on the use of ppd in cold environment which consisted of a literature survey, questionnaire survey among outdoor workers and information search through visits to relevant research institutions, discussions with researchers and participation in Conferences. The literature search carried out in 6 data bases revealed useful information about specific areas where wearability problems exist in ppd as well as some methods to be employed in research. The results of the questionnaire survey carried out in the Luleå region confirm that workers confront many inadequacies in the use of ppd in the cold climate. From the findings of this preliminary study three important kinds of ppd viz. safety gloves, safety shoes and safety helmets are discussed in this report. Human factors research for ppd in the cold environment with a view for improvement of wearability and use seem urgent.

HUMAN FACTORS OF PERSONAL PROTECTIVE DEVICES AND CLOTHING USED IN THE COLD ENVIRONMENT

1. INTRODUCTION

Personal protective clothing and devices (ppd) are recommended to be used as the last line of defence against injury and illness at work . This is because of the inherent limitations in the control or prevention of hazards using ppd such as efficiency, period of use, discomfort in use, maintainability, availability and interference to work in use. Inspite of these limitations ppd are widely used as they are comparatively cheaper than engineering control methods, can be provided quickly, easier to satisfy the legal requirements to provide safe conditions of work, so much so in some countries and establishments ppd use is the only method of defence against occupational hazards. Much of the Swedish workforce wears some type of ppd, as many as 7 out of 10 workers, (Working Environment, 1982).

Cold protective clothing is a form of ppd worn by people to protect them from the cold or extreme cold environment. The outdoor workers in Sweden most of the year round often have to use two types of ppd, viz. cold protectuve clothing for cold protection and other ppd to protect them from other types of work hazards.

Considerable amount of research work has been carried out on protection performance of ppd and standards have been adopted specifying these characteristics. Research on human needs of ppd such as comfort, acceptability, wearability, good fit, minimum obstructions and interferences for work, ease of putting on, off and adjust, style and economy, has been few, and no proper standards are in place on these characteristics. Unfortunately these wearability problems seem to cause the non-use or inadequate use of the ppd provided, thus rendering this important method of protection from work hazards almost worthless.

Important Ergonomics or Human Factors Needs in Ppd

Control of additional physiological loads

In the use of ppd it is important that the additional physiological loads from the environment, the extra weight that has to be carried by the wearer, the strains from the ill-fitting designs and additional physical work of wearing ppd are controlled to the minimum. These additional physiological loads contribute to extra energy expenditure.

Thermal comfort

Clothing and other materials used as protective wear which are worn over the normal clothing have a major influence on the thermal comfort of the wearer. The properties of clothing or materials of ppd, viz. porosity, permeability, flexibility, elasticity, design and fit, thickness, number of layers, colours, surface charateristics, texture and weight and properties of fibre such as size, insulation, stiffness, behaviour towards water, etc., can influence the radiative, convective, and evaporative heat exchanges (Reische and Strausky, 1980).

The need for well-fitting equipment and adjustability

When a ppd fits well it provides more comfort than one that is ill-fitting. Correct fitting of ppd is also essential to derive the protection offered by such wears. For example there can be considerable leakage through face seals of a respirator if proper fit and seal are not maintained (Hounam et al, 1963; Luxon, 1968; White and Beal, 1966). Helmet fit contributes heavily towards retention, vision, communication, noise attenuation and reduction of hotness according to Kamin and Scalone (1974).

Adjustability in ppd is especially important considering the great variability in physical body dimensions of the users. When a facility can be adjusted, for example the circumference of a head harness in a helmet, it can be designed to accommodate a reasonable range of individuals, say from 5th to 95th percentile. Another important factor is the increment available for adjustment.

Tightness and poor fit in ppd can impart pressure on the skin resulting in pains and aches. Injury, trauma or swelling could occur with poor fit when shoes are too tight and cuts behind heels caused by friction even when the shoes are too loose. Other important factors of fitting and comfort, for example in helmets are correct location of center of gravity and distribution of impact forces over wide an area of head as possible.

Minimum interference to to the use of senses

In the use of ppd any obstacles to the use of senses, e.g. vision, hearing, feeling, etc., must be checked to the minimum. The wearer is more comfortable and efficient if the use of senses are not interfered. Bulky respirators can restrict binocular vision. Goggles or spectacles can become misty due to high breathing rates or humidity changes of the external air, which can interfere vision. Ear plugs or defenders can restrict the hearing capacity to normal speech or audible warning signals. Face masks interfere with speech intelligibility. Safety gloves (depending on their thickness) reduce the sense of feeling which affects hand dexterity which is a problem in precision jobs.

Mobility

Freedom of movements of the whole body or body parts is an important requirement in ppd. A two-piece garment can be better than a one-piece suit for ease of movement. If any garment be subject to undue tensile stress as a result of wearer crouching, climbing or reaching up, then the garment has not met the specification of ease of movement.

Work performance

One of the important wearer problems in the use of protective clothing is that it takes a long period to perform a certain job with the protective clothing on. Loosely fitting gloves can slip easily on control surfaces and thus can increase the operation times.

Wearing more than one ppd

Special provision must be made to accommodate the second ppd when two ppds have to be worn at the same time, e.g. helmet with brackets to fix ear-muffs.

Ease of putting on and off

The inclination to wear ppd is less if it is difficult to put on and off or to adjust, If a ppd needs a conscious effort to put on or fit properly, it is indeed a major weakness in design.

Other User Needs

Out of the other user needs that are important in ppd, good aesthetics and economy must be mentioned. Style and good appearance make ppd acceptable and popular. Unless the use of ppd is cost beneficial in terms of injury costs and when compared with other protection methods, employers will be reluctant to provide ppd to the workers.

2. PERSONAL PROTECTIVE DEVICES IN COLD ENVIRONMENT

For protection from occupational hazards in the cold environment workers have to wear both ppd for work hazard protection as well as cold protective clothing. Ppd (used for work hazard protection) often help to increase the insulation of the clothing to protect the wearer from the cold environment or to promote thermal comfort. While thin, ventilated, light and least insulated ppd are preferred to be worn in hot environments, thick and insulated ppd are preferred in the cold environments.

From the physiological point of view the most important characteristics of cold protective wear are the thermal insulation and resistance to water vapour. An important function of cold protective clothing is protection of extremities, viz. head, hands and feet. The face is most difficult to protect. In hands sufficient thermal insulation cannot be achieved without losing the dexterity with low activity and also in hands the thermal insulation must be ensured and the suppleness of moving maintained. The extremities are the very parts of the body which have to be protected from other occupational hazards for which various types of ppd are used. When wearing ppd in the cold climate the wearability or user problems can be even more aggravated.

For example in the cold environment the expired air within a respirator can condense in the respirator valves or even icing of the valves can occur, leading to discomfort and annoyance. Misting can occur on the lenses of the safety goggles which can block the vision to a great extent. Conflicting requirements of the hands for cold protection as well as manipulative performance are problems in glove design. Equal frequencies of uncomfortably warm and cold feet reflect the lack of opportunity to vary the insulation of footwear to match variations in the environment and activity with the result that sweating wets the insulation and increases the risk of cold injury.

It seems that the problem of accommodating protection from work hazards as well as from the cold environment and at the same time considering the wearability of ppd in the cold climate has not been adequately investigated. In order to highlight the wearability problems of ppd in the cold climate and to ascertain the priority areas for research, a 'State of the Art' study was carried out in the first instance. This study consisted of the following surveys and investigations.

(i). A literature survey of published and unpublished work in Sweden, Scandinavian countries and other cold regions in the world.

(ii). A questionnaire survey among users of protective wear in Luleå, who are engaged in outdoor work in the cold climate. (See Annex. 1, Questionnaire used).

(iii). Visits to research institutions carrying out similar research and to relevant scientific libraries.

(iv). Participation in International Conferences and meetings on relevant topics.

3. METHODS

3.1 Literature Survey

The sources of the literature survey included the following:

CISILO: International Occupational Safety and Health Centre of ILO.

NIOSHTIC: National Institute for Occupational Safety and Health.

Information Centre

ARBLINE: Arbetsmiljöinstitutet

MEDLINE: Medlars on Line

BYGGDOC: Institutet för Byggdokumentation (Databas BODIL)

CCOHS: Canadian Centre for Occupational Health and Safety, Information Services

LUH: Luleå University library

3.2 Questionnaire Survey

300 questionnaires were mailed or handed over to approximately 15 companies in Luleå, to be distributed among workers engaged in outdoor work using protective wear in the cold. A researcher visited some companies to explain the questionnaire to the workers. Majority of the questionnaires were filled in by the respondents on their own.

(Copy of Questionnaire see Annexure 1)

3.3 Information from other Research Institutions

Information from other universities and research institutions carrying out similar research work was obtained by either visiting such institutions or by post. Information was received from the following institutions.

-Technical University of Denmark (visit)

-National Board of Occupational Safety and Health, Solna (visit)

-Chalmers Tekniska Högskolan, Göteborg (visit)

-Oulu Regional Institute of Occupational Health, Oulu, Finland

-Finnish Institute of Occupational Health, Helsinki, Finland

3.4 Conference Participation

Conferences and Symposia which had a theme or a session on development and wearability needs of ppd in the cold climate, were attended and papers presented by one researcher as follows:

(i). 'Nordic Conference on Cold, Tromsö, Norway, Jan 30-Feb.2, 1991. A poster presentation was made which was entitled 'A field study of cold effects among cold store workers in China'.

(ii). 'Fourth International Symposium on the Performance of Protective Clothing: (ASTM Symposium), June 18-20, 1991, Montreal, Canada. A paper entitled 'Ergonomics contribution to personal protective devices design' was presented at the Conference.

(iii). Symposium on 'Quality and Usage of Protective Clothing' NOKOBETEF IV, February 5-7, 1992, Kitilä, Finland. A paper entitled 'New trends in research to improve wearability of personal protective devices' was presented at the Symposium.

4. RESULTS AND DISCUSSION

4.1 Literature

The literature search on 'Ergonomics or wearability aspects of ppd and clothing in cold climate' indicated that the research carried out in this specific field has been rather little. Most of the studies carried out on ppd and clothing in the cold climate had been to improve insulation and protection of the user from the cold. From the published literature the 164 articles and papers classified in Fig. 1, provide information about studies already carried out of which many dealt more on insulation and cold protection.

(Note: Only the literature on safety gloves, safety shoes and safety helmets used in the cold climate is discussed in this report)

4.1.1. Safety Gloves and Mittens

There is a heirarachy of design needs for a safety glove in the cold. While some needs rank high, others rank low depending on the conditions of use. A study had been carried out on fishermens' gloves in Sweden where the workers ranked their preferences in glove design. According to this study protection from the cold was ranked highest followed by durability, good fit, flexibility, protection from wetness, protection from abrasions or cut injuries, good strength against damage or durability, easiness to put on and off, protection from cold wind, airy and ventilation, protection of the hand, and lastly protection against oils (Arbetarskyddsfonden, 1984). Perhaps the preferences in the design needs of building workers gloves or forest workers gloves may be different. The fact remains that wearability needs such as good fit, flexibility, etc., usually seem to receive high rank order and therefore seem important in glove design.

Insulation and Activity

The most important needs of a glove used in the cold climate are to keep the hands warm and comfortable. It is not only the materials used for glove construction that can influence the total insulation of a glove but several other factors such as the glove design, looseness or tightness of fit and the surface area available for heat loss, (Nilsson et al, 1992). A draft proposal for a standard within CEN (prEN, Comite European de Normalisation, 1991) has been proposed regarding the performance of handwear in terms of protecting the hand against cold.

Finger and hand temperature in the cold are influenced by other factors in addition to the insulation provided in the glove and the ambient temperature. They are, exercise, use and non-use of the hands and wind chill (Steegmann, 1977). Lack of continous exercise, handling cold material or removal of the gloves from the hands can reduce hand temperature. A study conducted by Whydham and Dickson (1951), has shown that during rest periods at ambient temperature of -12°C with varying wind, there is rapid and marked cooling of the hands and feet. With the body heavily clad and body temperature raised by vigorous work even bare hands were prevented from cooling. This principle can be used in performing extra precision work using bare hands for short periods in the cold climate.

Performance

A review on performance and sensory aspects of gloves, for work in the cold environment reveals the following subjective needs, viz. tactile sensitivity, manual performance, complex performance, subjective reactions, individual differences and maintaining performance in the cold (Enander, 1984). They are therefore important considerations in glove design. Further, the temperature has been found to be affecting performance independent of the glove effect or in other words the reduction of performance has been task specific (Rogers and Noddin, 1984). For motor functions and cognitive tasks, dry gloves have performed best when compared to wet or no gloves (Vaernes et al, 1988). It has been also shown that manual performance is influenced not only by the temperature of the local parts but also by the general thermal conditions of the whole body (Tanaka et al, 1983).

Another important aspect of performance with gloves is the decrement in grip strength. Though muscle activity (EMG) had no significant difference between a gloved hand and a bare hand, the grip strength had been significantly less in the two types of gloved conditions (rubber and leather) than in a bare handed condition (Sudhakar et al, 1988). Certain amount of muscle force seems to have lost in the hand-glove interface.

Hand Dexterity

Dexterity decrement seems to be the major problem in working with gloves. In a study on dexterity impairment while working with gloves, it has been shown that the threshold of hand skin temperature below which the dexterity is affected is 23° to 24°C (Aptel, 1987). Inactivity in the cold environment requires that the gloves have high insulation. While performance and manual dexterity are degraded (Haisman, 1988., Riley, 1982) when hands are cold, thick gloves to improve insulation can have a negative effect on dexterity. Significant difference in dexterity has occurred between males and females (Riley, 1982) perhaps due to males having a thicker palm skin which provides natural insulation to a certain degree. If it is assumed that dexterity does not decline until the hand skin temperature reaches 12° to 16°C, over clothing the torso can be a feasible strategy for cold environments (Sundheim and Konz, 1990).

The effect of glove configuration on dexterity has shown that mittens are worst performers (Persons and Egerton, 1985., Lyon, 1985) both in neutral and cold environments. From 9 glove configurations (Fig. 2) the gloves 1 and 3 performed best and gloves 7, 8 and 9 performed worst in neutral environment. In the cold all performance scores decreased and while glove 1 which initially had high performance finished lowest (Persons and Egerton, 1985). This study concludes that both the thermal effects and glove effects on manual performance should be considered in glove design.

Glove Sizes

Safety gloves are usually available in either two (large and small) or three (small, medium, large) sizes. Correctly fitting hand gloves are important for good performance and better dexterity. The hand length, hand breadth, hand circumference and finger lengths and circumferences are useful in designing correctly fitting gloves. There could hardly be any difference between internal glove size specifications between safety gloves used in the cold and those that are used in warm or other climates, but the external sizes for cold gloves can differ due to the thickness required for insulation. Larger the glove area, larger will be the space provided for heat transfer from the hand. In this respect mittens provide better insulation than gloves of the same material as mittens have lesser area for heat transfer than gloves. While larger and thicker gloves may seem to provide extra insulation the heat lost from large gloves would be also more. With the additional disadvantage of being clumsy, large and thick gloves cannot be recommended for use by outdoor workers in the cold. Loosely fitting gloves can slip easily on the surfaces on controls and can increase the operation times (Bradley, 1969). For precision work a snug fit may be important to get the feel of the hand. A compromise has to be reached between the thickness, material, micro environment within the gloves, insulation, correct fitness and hand measurements before appropriate glove sizes are determined.

Glove Material

Since the body releases 20% of the heat through the hands (Day, 1949), the material (and/or insulation) used for safety gloves would have to differ for cold and hot environments. In deciding the glove material it has been shown that leather meets most of the military needs in moderate climates, but in cold and wet climates leather alone had been inadequate (Herman et al, 1992). In the same study glove materials recommended were: shells - animal skin (cow, deer, goat), water barrier insert - Goretex, insulation - micro and macro fiber, lining - polyester. Field tests in Alaska have indicated that adequate insulation provided by a glove system consisted of Scotchguard TM treated cowhide shell, Goretex TM insert, Thermolite TM insulation and worn over Hightrek knit liner (Little, 1991).

Subjective Impressions and Participative Approach

Considerable research has already been conducted on protection characteristics and cold protection and much information is available on wearability. But the fact remains that acceptable gloves have yet to be developed. It is presumed that using subjective impressions and participative approach the problems in the use of gloves can be solved. In a study carried out in Sweden to develop better winter gloves, a pooled knowledge of civil servants, suppliers and members of the safety and health committee, have taken a

more practical view to this problem. The best available gloves have been improved according to the suggestions put forward by this group of experts. The improved gloves have been tested and further improvements made which have resulted in much better winter gloves. Important improvements suggested and implemented were, strengthening the thumb grip, using flexible leather with special impregnation against wetness, polyester backs to protect against cold and wetness and providing long elastic loose cuffs which are strong (Arbetsmiljö, 1987). Thermally how a subject feels on the hand has correlated well with the objective measures on the skin. For example the thermal sensitivity and the pain felt on the hand have been consistent with the hand skin temperature (Enander, 1982).

4.1.2 Helmets and Head Gear

Protection of the head becomes most important, as the part of the body that is most susceptible and vulnerable to disabling injury is said to be the head or more specially, the brain. The head protection required, varies from hard head impacts, chemical splashes, electrical shocks, radiation, severe cold and heat, and even protection from mild hazards such as rain, sun, dust, etc. Hundreds of miscellaneous head gear or devices are used today to protect, cover or adorn the head (Fig. 3). Helmets are categorized as industrial, crash, firemens, welders, sports, diving, miners, cycle, etc. Hard hats, bump caps, straw hats, woolen hats, scarves and caps, head covers, etc., are other types of head gear used for protection apart from the stylish and ceremonial hats and scarves used to adorn the head or for special occasions. With regard to safety helmets though wearability problems exist, research in this area has been scarce.

A comprehensive literature search on ergonomics or wearability aspects of safety helmets for hot environments has been carried out by Abeysekera (1989) as a part of his Ph.D. research. But the literature search carried out on ergonomics of safety helmets in the cold environment in the current study has shown that such studies had been extremely rare. What is discussed below contains some areas of investigations from the few studies conducted in the past.

Swedish Helmets

Swedish scientists and manufacturers have incorporated both protection adequacy and wearability / comfort improvements into the design of new head gear for sports activities, but have not extended these improvements to industrial helmets. Sweden has developed some of the best helmets from a human factor (comfort, wearability) and from safety (impact resistance) viewpoints for cycling and ice-hockey. Very recently a

F ig 3. Helmets and Head Gearresearcher has developed a special childrens' helmet to be used in sports or playing, which is a little different to bicycle helmets. This new childrens' helmet has special facility to unlock (or remove) the helmet in emergencies when the helmet can get hooked or caught in climbers nets, etc., or while playing (Fig. 4). The lack of this facility had been responsible to several fatal accidents among children when they used normal cycle helmets while playing (News report from NSD, 15 April, 1992). Unfortunately this same standard of excellence which explicitly incorporates human factors into design in sports helmets has not been extended to industrial safety helmets.

Helmet Use in Cold Climates

Previous studies on industrial helmets have established that thermal discomfort is considered a major problem by wearers of industrial helmets. Researchers have pointed out a number of strategies to improve the thermal comfort of safety helmets for cold and

for warm weather. Harness modifications for either insulation or ventilation have been suggested (Roszkowski, 1977; Fonseca, 1974; Vangraan and Strydom, 1968; Kamin and Scalone, 1974). Improved industrial helmet designs that incorporate better thermal characteristics for hot environments have been prepared at the Department of Human Work Sciences, Luleå University (Abeysekera, 1989). But no research had been carried out to extend similar designs to accommodate helmets for cold climate.

A study in the United Kingdom established that temperatures as low as 16°C are uncomfortably hot for helmet wearers (Stroud and Rennie, 1982). Studies of forestry work have noted that industrial safety helmets lack warmth in winter (Väyrynen, 1983). Forestry workers have also complained that sweating occurs when they wear the same helmets both in winter and summer. Therefore in helmet design the ability to allow sweat evaporation is important even during winter as sweating in the head area can occur during hard work.

Plastic material which is usually used in the construction of the helmet shell can have an advantage in the cold climate as it helps to retain the heat within the head which provides a protection from the cold. Shells of different colours or of different plastics can have different heat transfer properties (Abeysekera, 1989). On the other hand due to the lack of ventilation in plastic helmets sweat evaporation during hard work in the cold or in warm environments, is hindered. Therefore a head gear system to accomodate these conditions have to be developed to provide both protection and comfort in the cold and warm environments.

In the extreme cold conditions the insulation provided even by plastic helmets may be insufficient. It is known that 30% of the body heat escapes through the head (Proctor, 1982). Therefore in extreme cold conditions like in the winter season in the North of Sweden the outdoor workers may use woolen caps under the safety helmet. From the safety point of view against head impacts the helmet fit over a woolen cap would be unsatisfactory. Safety helmets are not designed to be used with woolen hats. Therefore this is another area where research should be concentrated when developing safety helmets for the cold.

Regarding the other human factors of safety helmets a comprehensive coverage has been made by Abeysekera (1989) during his Ph.D. research and therefore not discussed here.

4.1.3 Safety Shoes and Boots

Factors that influence the design of optimum safety shoes are more or less similar to other types of protective wear. Total foot comfort is determined by the interaction between socks, soles and shoes (Nielsen, 1990). Some important considerations in new designs of boots have been lightness, softness, flexibility and durability (Rasenblad - Wallin). With regard to the cold weather footwear, precautions are needed in terms of (a) insulation, (b) ventilation, (c) bulk, (d) poor support, (e) traction and (f) sweat accumulation and wetness sensation.

Insulation

Properly insulated safety shoes or boots provide thermal comfort in cold climates, but in warm climates sweat disposal from shoes may be more important (Stokes, 1972). In cold environments to avoid heat loss through conduction from the foot to the ground, the shoes must be constructed by inserting insulating material which traps air. Experiments on a heated model have revealed that compression of the socks by a 20 kg weight applied to the foot model reduced insulation values by 60-80 % compared to the uncompressed socks (Elnäs et al, 1985). This explains that the air trapped within fabric enhances insulation. By keeping the outer surface dry and close to ambient temperature, the other heat losses due to convection, evaporation and radiation can be controlled. However heat losses which is essentially determined by the surface area and air temperature, could not be directly controlled by the designer (Montieth, 1973). Most of the incident radiation is absorbed if dark coloured boots are used.

The use of layer principle for feet insulation has not been found very useful in boot design. Worsley et al, (1974) found that overboots hinder mobility and their insulation effect becomes very small. When boots fit only one sock, several socks cannot be used. But still socks have been found to provide the best insulation (Oakley, 1984). Wear resistant compounds which provide good grip are generally poor insulators. Metal shanks inserted to impart stiffness are actually good conductors.

It is known that pumping effects caused by body movements or exercise, increase the convective heat loss inside clothing and ppds worn on the body extremities. This is an advantage in hot environments and during vigorous activity in cold environments as it helps to release the built up body heat to the environment. But the pumping effect also diminishes the thermal insulation of the ppd which is a disadvantage in extreme cold environments. The results of the studies on thermal insulation of boots have indicated that upper and lower body exercise had different kinds of effect on boot thermal insulation with the greatest decrease of insulation occuring inside the boots (Rintamäki et al).

Another cause of reduction of insulation in winter boots is the water accumulation inside the boot, either due to sweating or external moisture. The warm wet feet can rapidly become cold wet feet. Therefore in cold climate, boots should be waterproof and water penetration has to be reduced.

In a study on prediction of foot temperature and foot comfort Wouter and others (1988) have found that sole insulation and gaiters improve foot comfort in the cold but thicker soles can cause more discomfort in the heat. In the cold semi-permeable gaiters accumulated slightly less sweat than impermeable gaiters. They have also found that the key factor for the foot temperature or for the foot to be warm or cold is the core temperature.

Performance

Literature on performance of the foot with footwear has revealed the following (Rosenblad - Wallin).

- Footwear shall be soft and articulated as the foot.

- Footwear must have extra volume in front to allow bending and spreading of the toes.

- Footwear must have a firm grip around the heel.

- Footwear shall be light as possible.

- Outer sole shall be steady under the heel but soft and flexible under the fore foot.

- Heels must have a good shock absorption properties.

- Sole pattern and material shall give a good unslippery grasp to the ground.

Materials

Different kinds of material are used in shoe and boot manufacture for purposes such as insulation, flexibility, softness, durability, anti-slip properties of sole, moisture absorption properties of upper materials, sweat disposal, lightness, economy, etc. The following advantages for each material have been highlighted in the past studies.

- New materials like thinsulate and ensolite combined with the shearling wool insert help to produce the warmth without bulk in the polar environments (Wendt, 1985)

- Leather has been preferred over other materials for its breathability and strength

- Rubber water proof bottoms were the most effective for boot construction for retaining insulation levels during water exposure (Santee and Endrusick, 1988; Rintamäki and Massi, 1989a)

- Navy boots developed using a double moisture barrier principle, two layers of rubber sealing in wool insulation were extremely effective and could eliminate trench foot (Wojtaszek, 1988)

Foot temperature and shoe design

Typically the foot tends to be either warm or cold. The key factor in foot temperature is the core temperature (Wouter et al, 1988). The foot skin temperature depends also on the insulation of the rest of the body (Rintamäki and Massi, 1989a). Foot temperature and thermal sensation in the foot studied in the naked and clothed men has revealed that close correlation exists between skin temperature of the extremities (foot and hand) (Rintamäk and Massi, 1989b). In the same study it has been shown that whereas the foot temperature depends primarily on the thermal state of the body as a whole, the thermal sensation depended mostly on the temperature of the coldest part of the leg (usually the toes). At rest the thermal sensation depended on leg temperature and at work on toe temperature.

Equal frequencies of uncomfortably warm and cold feet reflect the lack of opportunity to vary the insulation of footwear to match variations in environment and activity with the result that sweating wets the insulation and increases the risk of cold injury. Since activity involving the leg movement can increase the foot temperature in variable cold environment, footwear that provides insulation to extreme cold conditions can become uncomfortably warm when the temperatures increase. Shoes with high insulation properties that provides thermal comfort to the foot in outdoor cold conditions can become uncomfortably warm within a few minutes in indoor climate. Therefore insulation properties of material used for shoe construction should be optimised with the ambient temperatures and activity levels of the wearers depending on the pumping effect or ventilation of the shoe.

Shoe sizes and Fit

A shoe should fit well on the foot. It should be large enough for socks and allow toes to move. Correct fit of shoes or boots determines foot comfort and ease of mobility. Shoes and boots are manufactured in different standard sizes. Depending on the lengths and breadths of feet, shoes are produced either in 1/2 sizes or full sizes with the appropriate width depending sometimes on the length. Apart from the basic measurements such as the length and the width of foot, circumferences of ball of foot,

instep sole and heel instep, have to be considered in the correct designing of safety shoes and boots. In UK certain safety boots are produced in 1/2 sizes with only one width and military boots in full sizes with three widths (Oakley, 1984). Large amount of fitting research has been carried out by major shoemakers including SATRA (Shoe and Allied Trades Research Association) to ensure that one range of shoes will fit the highest possible number of feet on which they are tried (Audemars, 1978). But no one range of shoes will fit 100% of the feet on which they are tried on.

Another anthropomatric feature observed by researchers is that with advancing age the big toe tends to incline inwards, and women take the lead from the tender age of 11 years (Helmerssen, 1986). The Swedish Shoe Institute had demonstrated that the feet kept in a moulding machine for eight hours a day, the big toe will finally move to the middle which can be an advantage for ladies wearing pointed fashion shoes, (Helmersson, 1986).

Boots should not fit only one sock because several socks (with different insulation properties) cannot be used. A study by Påscle et al (1988) has shown that the fit of the footwear was equally important for feet temperature as was the built-in insulative material of the boots. Any tight fit would cause an effect on blood circulation for the feet and the consequent feet temperature and thermal comfort. Injury, trauma or swelling could occur with poor fit when shoes are too tight and cuts behind heels caused by friction even when the shoes are too loose.

Slipping, Walking and Running

In the Nordic countries slipping has caused 16% of all accidents at work, at home and at leisure activities. Two-thirds of these slips occur on ice or snow (Raoul and Mikko, 1992). The primary cause of slippery accidents is said to be the unsatisfactory friction between the foot/footwear and the underfoot surface. Secondary causes are reported to be for instance poor control of man's balance, ageing and use of drugs or alcohol (Honkanen, 1983, Pyykkö, 1988). In a field evaluation of work clothing for use in arctic climate, Påsche and others (1988) have found that several of the cold climate footwear were found to have a sole totally inadequate for ice and snow surfaces and represented in itself a safety hazard.

The properties of footwear soling materials and their design also seem to be important for safe walking. From their studies Raoul and Mikko, (1992) recommend soft heel and sole materials of thermoplastic rubber for winter shoes on dry ice. They also

recommend that footwear with studded heels and soles to be used on icy surfaces when the ambient temperature is close to 0°C or on wet ice.

Large bulky boots such as blucher type may be warm but can present difficulty in walking. Under some precautions given on footwear in the Handbook for Surface Slips (U.S.Navy, 1989) it is stated not to allow feet to become numb and to make every effort to remove the ice prior to travelling on decks and ladders and to avoid walking on ice whenever possible.

Cardiorespiratory strain during walking on snow with boots of different weights has been studied by Smolander and others (1989). There had been no significant difference in ratings of perceived exertion during walking tests on snow wearing winter boots, viz: Winter Jogging Boots (WJB, 0.9 Kg), Rubber

Boots (RB, 1.9 kg) and Rubber Safety Boots (RSB, 2.5 kg). The author recommends RSB (2.5 kg) for jogging work in snow, since they are known to provide greater protection than lighter boots and the increase in physiological strain had not been significantly higher than lighter boots.

In a study by Lees and Thonley (1990) of the effect of a running shoe, air circulation system on the temperature and sweat accumulation of the foot they concluded that the shoe promoted the buildup of heat in the foot, and this was not ameliorated by the air circulation system under investigation.

4.2 Questionnaire Survey Results

Eighty-six workers from building, fire-fighting, forest, postal, police, electrical and cleaning companies and who were engaged in outdoor work responded to the questionnaire. The respondents classified according to their age and type of work are shown in Table 1. (Three questionnaires were discarded due to insufficient or unreliable information). It is seen that nearly 100% of the respondents are men and majority of them are in the age group 30-40 years and 20% of them are over 50 years .

Sixty-two percent of the respondents had specific complaints to make to the question whether they experience any problems in the use of ppd in cold climates. Some common complaints are as follows.

Twenty-five respondents said that their feet became cold due to the cold sensation from the steel toe cap on their boots. 13 said that the gloves they used interferred with the dexterity and 7 complained that the gloves are not properly insulated. Four, complained

that their helmets were heavy, cold and not fitting. 8 complained about the winter clothing and 6 on ear defenders due to miscellaneous reasons.

The specific nature of the complaints and their average ratings are shown in Table 2. The items that are circled in the Table which have an average rating higher than 3.5 (middle rating on the scale is 3.0) indicate that they could be significant factors to be considered in the development of each type of ppd.

For the question which season they find it most difficult to wear ppd, the respondents were divided equally (50% said during winter and 50% said during summer). This explains the fact that wearability problems are experienced both in the cold as well as in the hot seasons.

The respondents were asked to indicate thermal discomfort problems, viz. coldness or hotness in the use of helmets, gloves, shoes, and clothing. Further, whether there were specific complaints such as dexterity with safety gloves and difficulty in walking or trauma of feet using safety shoes. Their responses are shown in Table 3.

Lastly respondents were asked to provide suggestions for improvement of ppd particularly in respect of wearability and use. The users who have long experience in wearing ppd are the best judges regarding where improvements and development are needed. The suggestions of the respondents are listed in Table 4.

4.2.1 Discussion on the Questionnaire

(Only Safety gloves, shoes and helmets are discussed)

4.2.1.1 Safety Gloves

In the use of safety gloves in the cold, special problems mentioned by the respondents were that working with gloves affect their dexterity and generally the gloves lacked adequate insulation to protect their hands from the cold.

The results of the questionnaire revealed that the safety gloves were not very popular among the workers. There was no difficulty in wearing them or removing them, but they found it difficult to adjust the gloves to varying conditions of use. Nearly half of the respondents considered that gloves do not fit properly. Performance decrement was very significant and so was limitation in hand and finger movement. Most considered that weight of the gloves was not a problem as they felt lighter on their hands. 90% of the respondents said that the gloves used by them made their hands cold sometimes and 25% said that gloves made their hands to sweat and 80% admitted that it is difficult to work with a gloved hand. Out of the other problem areas mentioned, difficulty in maintenance of gloves was significant.

4.2.1.2 Safety Helmets and Head Gear

It was surprising to observe that safety helmets used today in the cold climate have been assessed as unpopular and uncomfortable by most respondents. Many users found helmets easy to don and doff but difficult to adjust and to fit properly. More than half the respondents believed that helmets provided sufficient protection to the head, durable and easy to acquire.

57% of the respondents considered that they felt cold inside the helmet. Surprisingly 86% said that they felt hot on their heads sometimes, indicating that even in the cold sufficient helmet ventilation is required. To improve acceptability and popularity of helmets the respondents suggested that the helmets must fit better on the head and sufficient ventilation provided.

4.2.1.3 Safety Shoes and Boots

In the case of safety shoes and boots the major problem was the weight which the users considered heavy and as a result they experienced difficulty in walking. This in turn interfered with their work performance.

As regards the other aspects of rating more respondents considered that shoes were uncomfortable. The fit, interference to senses, popularity and durability had average rating (approx. 50% favourable and 50% unfavourable). It was easier to put on the shoes but more difficult to put off. More respondents admitted that the maintenance and repair problems of safety shoes were difficult.

The feeling of coldness on their feet was high (72%) and the reasons were attributed to the steel toe cap getting cold. It was significant to note that 48% felt the shoes became warm on certain occasions. 54% found it difficult to walk with safety shoes among other reasons due to slippery surfaces during winter. Out of the respondents suggestions for improvement, lighter shoes, replacing the steel toe cap with material of low thermal conductivity and providing anti-slip shoe soles are worth considering.

5. CONCLUSIONS

From the preliminary study on ppd in the cold environment the following brief conclusions are made:

-- The literature is very scarce on ergonomics of personal protective devices in cold climate.

-- The need for ergonomics development in ppd in cold climate is emphasized in recent Conferences and Symposia.

-- The responses to the questionnaire among ppd users in outdoor cold climate have confirmed that they confront wearability problems in ppd use.

-- Many methods of testing and evaluation of ergonomics in ppd that can be used for research are available in literature.

-- Priority research for ppd development should concentrate on ppds used to protect the extremities viz. safety gloves, safety helmets and safety shoes.

-- The research knowhow acquired in the development of improved safety gloves, helmets and shoes can be used and extended to other types of ppd.

-- Computer models and computer aided designs for ppd are useful for ppd evaluation, testing and design development.

6. REFERENCES

(Divided into six pictures)

Abeysekhera JDA (1989) to Elnäs S & Holmer I (1980)

ANNEXURE 1

QUESTIONAIRE SURVEY FORM

The questionaire survey form used in this report can be ordered from the author by e-mail:

John.Abeysekera@arb.luth.se