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Improving Conditions for Personnel Performing Condition-Based Maintenance on Infrastructure by Measuring/Monitoring Their Winter Performance Ability

Anders LINNÉ[1] and Ulla JUNTTI[1,2]

1. Performance in Cold AB, Storgatan 11, SE-972 38 Luleå, Sweden, anders.linne@minus8.nu

2. Luleå Railway Research Center, Luleå University of Technology, SE-971 87 Luleå, Sweden, ulla.juntti@minus8.nu, ulla.juntti@ltu.se

ABSTRACT

An available, reliable and well-maintained infrastructure is the foundation for competition and market growth. Infrastructure is often synonymous with technical assets operating in outdoor conditions, e.g. railway and road infrastructure. The harsh winter of 2009-2010 caused several railway assets to fail, resulting in cancelled and delayed trains. The costs were estimated to 3 billion SEK, according to the Swedish Transport Administration. Half of the delays could have been avoided by improvements in the railway infrastructure maintenance process, such as winter adjustments of assets, better information and communication, and preparedness and emergency plans. Moreover, little attention was paid to how the maintenance personnel are affected by a harsh working environment.

It is well known that a cold climate reduces the functional capacity not only of technical systems, but also of humans, although there are no clear limitations for humans performing work in a harsh climate. Low temperature affects human performance by reducing the blood circulation, by burdening the heart, and by affecting other body parts like the skin, hands and feet. The impaired functional capacity and powers of concentration increase the risk of accidents and injuries. Human error due to reduced functional capacity caused by a cold climate may be one root cause of those failures which occur after maintenance has been conducted.

A new method has been developed, called the “Performance-in-Cold Method of Linné”, which makes it possible to measure and monitor each individual’s own winter performance ability and the effects of cold weather, cold surfaces and vibrating tools. The measurements are made using an infrared camera that detects the surface temperature of the skin. The temperature of the skin can then be translated, according to previous research, into functional ability.

The method has been fully or partially tested on different groups, i.e. maintenance personnel, cadets, biathlon skiers, office workers, physiotherapy students and schoolchildren. The aim has been to identify, analyze and improve the environment for each individual to enable her/him to perform in the best possible way in the cold. The goal is to create a health profile that allows individuals to achieve maximum performance without risk.

The results show differences between individuals (men, women, people of different age), the extent of cold-related problems, and development areas for improvement of the working environment and work aids.

Keywords: Maintenance, IR Camera, Human Error

1. INTRODUCTION

A cold climate is defined as a climate where the temperature range is from +10°C to -10°C (SAN, 1994) and the duration of the prevailing cold climate in Sweden is 6-8 months in a year.

Most of the systems working in a cold climate need specific maintenance actions and more maintenance to achieve reliability, availability, dependability, stable productivity and safety. Vehicles, machines and assets need additional supervision. Safety is affected by low temperatures, ice, snow, humidity and poor light. Available statistics from 2005 show that 16.4% of all employees in Sweden suffered from body cooling during outdoor or indoor work for at least a quarter of the working time (Arbetsmiljöverket, 2005). In Sweden it is estimated that over 300,000 individuals are exposed to the cold in their profession during 50% of the working time, because of the climate (Arbetslivsinstitutet, 2002, Hassi et al., 2002).

The operation and maintenance of railways are in many respects outdoor activities where high demands are made on the performance of trains, with stringent requirements for maintenance of the safety of electrical installations and railway traffic. Some areas, such as signalling technology, require personnel with many years of education and annual certification, which means personnel with key skills. A cold climate also puts higher demands on the competence and experience of the personnel and, in particular, their knowledge of how environmental factors affect the assets/vehicles, the logistics and their own performance. The maintenance work is also affected by the assets' design and construction (near ground level, cold surfaces etc.) and the design of the equipment and tools.

The harsh winter of 2009-2010 caused several railway assets to fail, resulting in cancelled and delayed trains, and the costs were estimated to 3 billion SEK (SOU, 2010:69). Half of the delays could have been avoided by improvements in the railway infrastructure maintenance process, such as winter adjustments of assets, better information and communication, and preparedness and emergency plans. Moreover, little attention was paid to how the maintenance personnel are affected by a harsh working environment and how great a contribution maintenance and skilled personnel can make to the achievement of better quality, if they are aware of what affects their performance in different conditions and if they know the right action to initiate, which can result in more efficient work, less downtime, a more secure work environment and improved health.

Personnel working in a cold climate are exposed to:

- Body cooling due to low temperatures, wind and body contact with cold surfaces. Touching cold surfaces can lead to rapid local cooling and touching cold surfaces with one's bare hands should therefore be avoided. Different surfaces/media dissipate cold differently; e.g. plastic/synthetic materials divert cold with a ratio of 1:10, moisture and water with a ratio of 1:10, ice with a ratio of 1:80 and steel with a ratio of 1:9600 (Holmér et al., 2003). The cooling effect of wind at low air temperatures increases the risk of hypothermia. The wind chill index (WCI) is used to estimate and measure the wind's cooling effect; e.g., if the wind speed is 5 m/s and the temperature -10°C, the cooling effect is -21°C. Cooling reduces one's discretion and work capacity and results in lower sustainability.
- Work wear/protective clothing can be heavy, bulky and thick and therefore difficult to move in.
- Greater psychological stress. In addition to the actual maintenance task, the personnel must also focus on their own personal thermal protection. This means that their concentration, attention and decision making are shared by these tasks.
- Snow, ice, moisture and wind.
- Cold, ice and snow can result in poor performance and safety for vehicles.
- Maintenance work in a cold climate coincides largely with short dark days.

Badly performed maintenance has been a common trigger of some of the major accidents in history. Kang (1999) found that 34% of industrial accidents in Korea were caused by incorrect maintenance, and Holmgren (2003) found that about 80% of the maintenance-related accidents in the Swedish railway system during 1988-2000 happened during the execution phase. The dominant cause of incidents and accidents was human error.

The performance of complex tasks is affected more by cold than the performance of simpler tasks. Chill has a negative impact on aspects of muscular performance such as endurance, strength, power, speed, coordination and concentration. Manual performance is determined by the range of motion in the arms, hands and fingers, and the ability to manipulate objects with the hands and fingers. The important factors are the reaction time, sensation, grip strength, endurance and mobility (Arbetslivsinstitutet, 2002, Enander, 1984, Lehmuskallio et al., 2002).

The main risk associated with work in cold climates is the cooling of the body's tissues due to imbalance between the body's heat and the body's release of heat. Heat from the body is delivered through the respiratory organs, radiation, clothing (depending on the insulation, vapour resistivity, and absorption of wind and water), convection (depending on the air temperature and wind speed), and evaporation (Arbetslivsinstitutet, 2002, Försvarsmakten, 1997).

The body can also be injured by chilling. The reaction which is initiated by chilling aims to limit the heat loss and maintain the normal body temperature in the body's core vital organs – the brain, spinal cord, heart, lungs, liver and kidneys. The main reaction is that the blood flow is controlled and diverted to other courses than before, by reducing the blood circulation in the hands and feet. A vasoconstriction of the extremities occurs, one's temperature drops and one's performance decreases (Gavhed and Holmér, 2006, Lloyd, 1994, Sallis and Chassay, 1999).

A cold-induced injury is an injury incurred in a surrounding temperature less than 0°C (Castellani et al., 2006). The most vulnerable areas are the nose, ears, cheeks, and exposed wrists, but injuries can also occur in the hands and feet (Castellani et al., 2006). The limit for when the temperature receptors in the skin proceed to react with pain has been reported to be a body temperature of around 13°C (Enander, 1984, Rintamäki et al., 2004). The hands begin to lose their functional capacity already at 32°C as the ability to sense differences in a surface's density and structure decreases. When the temperature falls below 27°C, precision and accuracy are reduced (you can move your hand, but you cannot direct it) and between 12 and 16°C, the mobility is reduced. If the temperature drops below 8°C, permanent injury can be caused.

Cooling also affects the cognitive ability by deteriorating the short-term and working memory, as well as the long-term memory and the consciousness. You become a danger to yourself and others, without knowing it.
The employer is legally obliged to take all the measures necessary to prevent the worker from exposure to illness or injury (the Swedish Work Environment Act – AML – Chapter 3, §2), and there are guidelines issued by the Swedish Work Environment Authority (the Authority's Statute Book – AFS) for risk assessment for personnel working in the cold, but the specifications are very vague. There are also no significant temperature limits for work in cold climates.

The lack of knowledge in this field has led to the statistics for cold-induced injuries not being reported, except for those in a few professional areas, such as the Swedish military defence and kindergartens. This lack of knowledge is also reflected in the statistics for occupational injuries, where there is a lack of codes/classifications for cold-induced injuries (Arbetsmiljöverket, 2005 and 2008).

Due to the lack of statistics, cold-induced injury is not perceived as a problem area. Moreover, there are no simple methods for the measurement and evaluation of cold-induced injury which make it possible to detect the damage caused by hypothermia and cold-induced injuries.

The ”Performance in Cold Method of Linné” has been developed in order to detect cold-induced injuries and reduced circulatory capacity.

The objectives of the present study have been to identify, analyze and improve the environment for each individual, to enable her/him to perform in the best possible way in the cold. The study aims to create a health profile that allows individuals to achieve maximum performance without risk.

2. THE ”PERFORMANCE IN COLD METHOD OF LINNÉ”

The patented methodology being developed by Performance in Cold AB is composed of:

- A questionnaire for finding out the individual root causes of each individual's problems.
- Measurement of the hand and finger temperature in a warm initial state and after a rapid cold provocation, followed by continuous measurement during the temperature recovery phase. The temperature of the skin is measured by a thermograph camera. The surface temperature of the skin can then be translated, according to previous research, into functional ability.
- Analysis and identification of problem areas.
- Suggestions for prevention, mitigation and restoration measures.

By measuring the surface temperature of a body part, it is possible to see how the blood circulation is affected by cold-provocation. The method shows in a pedagogical manner the extent of any circulation problems. The method also makes it possible to measure and monitor each individual's own winter performance ability and the effects of cold weather, cold surfaces and vibrating tools. Another purpose of the method is to provide a simple, standardized, fast, clear, reliable, precise and repeatable means of examining the surface temperature of a body part and, at the same time, provide a portable device for such examinations which is easy to use, can be easily and quickly installed, and quickly presents the results.

The method is executed as follows (see FIGURE 1):

- The company's new employees are introduced to the topic of working in a cold climate, at a workplace meeting. The introduction provides the new employees with greater knowledge of what happens to the body when exposed to cold and the hazards and risks that they face.
- The new employees must answer a questionnaire in order to determine any root causes of possible circulation problems in their hands, feet or head/face.
- The date of testing is booked. The test can be performed on the new employees in their own work area, and the only requirement is a 220 V power supply. The new employees must have had at least a 30 minute long break with rest in an indoor climate, and must not have smoked or used snuff during the four hours before the test.
- The new employees receive immediate feedback after the measurements through an MMS showing the circulation in their own hands. A few days later, they will receive a written report with their own status as compared to the group's health profile.
- The analysis of the questionnaire and measurement will also result in an individual recommendation and testing of protective clothing/gloves and/or equipment; e.g. gloves can be extra insulated in order to provide protection from cold surfaces in the workplace or on the tools used daily.
- Subsequent measurements are made in order to evaluate if the implemented recommendations are sufficient or whether further measures must be taken.

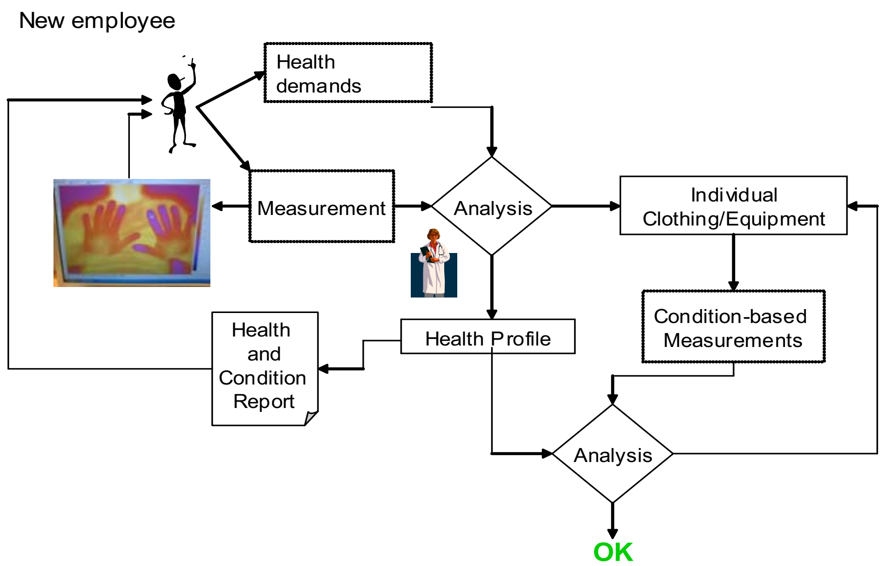

FIGURE 1. The procedure in the ”Performance in Cold Method of Linné”

The results are presented in a pedagogical way in which the test persons immediately receive a receipt of their own performance; e.g. they will be informed if they have poor circulation in any of their limbs (see FIGURE 2, which shows a person with impaired circulation in the right middle finger).

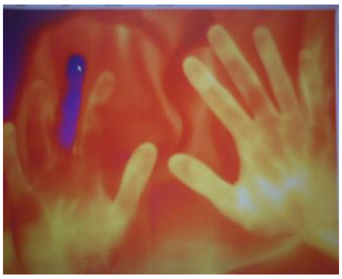

FIGURE 2. Impaired circulation in the right middle finger

3. RESULTS

3.1 Questionnaire

The questionnaire has been refined and verified with regard to the interpretation, in order to enhance the possibility of improving the subsequent analysis and to ensure that the data can be used as input data for new research.

A total of 179 people submitted answers to the questions and, in some cases, commented on the questionnaire's structure and identified issues that were unclear. The response rate was high in that, on average, 77% of those who had access to the questionnaire responded. The response rate has not been assessed for schoolchildren, because the questionnaires were distributed by school staff whose knowledge of the number of questionnaires distributed varied, see TABLE 1.

Those (of the test individuals) who were introduced to the background of the questionnaire before answering it recognized the issues and problem areas. Few of the respondents had knowledge of the wind chill factor and the effects of cold and cold surfaces, for example, and many of them wanted to know more and obtain advice on measures that could reduce the cooling effects. The results from the questionnaire show that:

- 42% feel that they have impaired blood circulation in their hands,
- only 21% claim to have warm hands,
- 59% believe that the existing protective clothing against cooling is inadequate or very inadequate,
- 74% believe that protective gloves, head coverings and shoes are inadequate or very inadequate against the cold, and
- gloves are too bulky, and must be taken off in order to conduct maintenance work in the cold.

Another interesting result from the assessment of the survey targeting the Swedish Armed Forces (the Norrbotten Regiment –I19) is that the left half of the body sustained 60% more cold-induced injuries, meaning that the clothing on the left side of the body might need some more insulation.

TABLE 1. Results from questionnaire

Group	**Date (YearMonthDay)**	**Number of responses**	**% of females**	**Total response rate**
Schoolchildren in the 9-year compulsory school, Boden Municipality	20090217-19	119	47%	-
Swedish biathlon team	20090515	12	42%	92%
Office personnel, Department of Health Sciences, Luleå University of Technology	20090622	14	86%	100%
Trainee train drivers	20091012	11	18%	48%
Banverket Production Boden	20091023	8	0%	67%
Physiotherapy students, Department of Health Sciences, Luleå University of Technology	20091116-26 20100301-04	15	80%	79%

3.2 Measurements

The method has now been validated by the Department of Health Sciences at Luleå University of Technology. Moreover, an application for permission to test humans has been approved by the Ethical Review Board.

The method has been fully or partially tested on different groups, i.e. maintenance personnel, cadets, biathlon skiers, office and workshop workers, physiotherapy students and schoolchildren. If the method proves to be valid, it can be used in a wider context consisting of different professions and health care providers and, in the latter case, may replace older methods that are being scrapped.

The results show differences between individuals (men, women, people of different age), the extent of cold-related problems, and areas of development for improvement of the working environment and work aids.

4. DISCUSSION

Researchers around the world are endeavouring to gain increased knowledge of and better preparedness for the "extreme climate change". In Sweden, the climate change (towards a warmer climate) has meant that we instead have lost our unique expertise in handling cold-climate conditions. We rely on the garment industry and are driven by fashion. Reliance on the materials provided by that industry has led to clothing sewn up out of such materials as Goretex, which stops breathing at 10 degrees below zero. Contact with cold surfaces cools the fingers and increases the risk of accidents, especially in the stressful environment that Banverket Production's personnel face when they must perform work between trains, to fulfil the requirement of maintaining the safety of electrical installations and railroad traffic.

Today in Sweden it is only the Armed Forces that must have knowledge of sub-arctic operations and the requirements for performing and exercising their professional knowledge in sub-arctic conditions.

Education is needed to increase awareness of the effects of winter conditions on the railway system, i.e. what happens to the machinery, materials, lubricants, etc. in cold weather, how the logistics are affected when the accessibility deteriorates, and how people are affected by the cold (i.e. impaired mobility/concentration results in less security awareness and an increased risk of accidents and injuries). Such training could have prevented two accidents, including one fatal accident, and reduced the 37 reported incidents, of which 13 were near-accidents (SOU, 2010:69).

Early results from the measurements also indicate that women have colder hands than men. In a study by Jay and Havenith (2004), the conclusion was drawn that women during slow body-cooling show a more rapid cooling in contact with cold materials in comparison with men. It may be tentatively suggested that this is due to the differences found in the size, texture and pattern of women's hands/fingers, but we need to conduct more experiments with men and women with equal hand dimensions finally to prove this. There are also studies that contradict the existence of a gender difference (Isii et al., 2007). Nevertheless, it is remarkable that working cloths for women were introduced on the market just two year ago (Ny teknik, 2009, NSD, 2009).

If we can identify and measure the extent to which cold affects humans, we can also restrict, prevent and mitigate the effects of cold, and find new innovations to counteract these effects. Some improvement areas discussed are:

- Personal protective equipment/clothing is perceived as inadequate, especially for the hands, feet and face. Protective gear/clothing has evolved with man as the norm and it was not until 2009 that work equipment for women was introduced. Women also need more insulation/reinforced insulation on their hands, arms and feet, compared to men.
- Cold surfaces deflect and absorb heat from your hands. Frostbite can occur after only a few seconds of contact with such surfaces (Holmér et al., 2003). Specifications for equipment to be used outdoors need to be changed so that the surfaces to be touched/handled by the human skin are provided with an insulating layer.
- Knowledge of the impact of the wind chill factor, i.e. the combination of cold and wind that increases the heat transfer factor and the cooling effect (Arbetslivsinstitutet, 2002).

Concerning the working environment in a cold climate, one can note that working environment managers, unions, human resource managers and others are seeking measures to improve workers' safety. To quote the personnel manager in the Swedish Post Office, who is responsible for 16,400 postmen:

"*LET SLEEPING DOGS LIE. Naturally, we are willing to train our personnel in the requirements, for example, from the Work Environment Authority. We value our personnel and want them to get the best means of coping with their work without injury."*

A related problem is vibration-induced injuries (related to circulatory capacity, e.g. white finger). A newly presented research report shows that the occurrence of cardiovascular disease is 30% higher for miners who work with vibrating tools and machines in a cold environment (8°C).

If training is not upgraded in terms of the knowledge and skills required to work in diverse environments, the problems will increase in the future.

5. CONCLUSION

The aim of the "Performance-in-Cold Method of Linné" is to measure and identify the unique cold-sensitivity profile of each individual. Seeing with one's own eyes what one's own ability looks like spurs one to increase one's knowledge and awareness of what can cause hypothermia or cold-induced injuries, and the following questions will arise:

- What can I do about this now?
- Can I influence my work situation/environment to make it better and can I give suggestions as to how my future work situation/environment should best be designed?
- Where can I learn more?

Training and practical exercises often fail to increase knowledge. It is not until you as an individual can receive feedback on yourself and your own circumstances that you can "waken up the sleeping dog that lies". Reviewing the questionnaires has resulted in numerous suggestions for improvement, and has also demonstrated that there is a desire for more education and improvement of equipment, as well as a big interest among respondents in obtaining a measurement and confirmation of their performance/health profile.

A natural extension of this project is to study the maintenance work in the railway environment that is carried out on vehicles and facilities etc., with respect to the cold climate conditions which railway personnel are exposed to. Different ergonomic methods and maintenance techniques will be studied and solutions will be proposed, such as using the infrared camera to identify and quantify the cold surfaces to which maintenance personnel are exposed. This will result in new methods, policies, products and tools which, when implemented, will lead to increased security, a reduced need for maintenance time, increased productivity, and better health and safety.

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