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Manual work in cold environments and its impact on selection of materials for protective gloves based on workplace observations

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ABSTRACT

This article presents a workplace observations on manual work in cold environments and its impact on the selection of materials for protective gloves. The workplace observations was conducted on 107 workers in 7 companies and involved measurements of the temperature of air and objects in the workplaces; in addition the type of surface and shape of the objects was determined.

Laboratory tests were also carried out on 11 materials for protective gloves to be used in cold environments. Protective characteristics, including mechanical properties (wear, cut, tear, and puncture resistance), insulation properties (thermal resistance), functional parameters, and hygienic properties (resistance to surface wetting, material stiffness) were evaluated. Appropriate levels of performance and quality, corresponding to the protective and functional properties of the materials, were determined. Based on the results of manual work and laboratory tests, directions for the selection of materials for the construction of protective gloves were formulated with a view to improving work ergonomics.

1. Introduction

Cold environments are defined as places with a temperature equal to or less than 10 °C (Holmer, 1993). They may affect the entire human body causing hypothermia and a subjective feeling of being cold (Virgílio, et at., 2014), or distal body parts only, e.g. hands, through contact with cold surfaces.

The effect of low temperatures on humans, and in particular the problem of hand and finger cooling, as well as the influence of various factors on this process, is the object of interest of many research centers in different countries. Special attention has been given to situations in which human exposure to cold concerns not only occupational activity, but also everyday life (Rintamäki el al., 2016). The main objective of scientific research has been primarily to understand the impact of various factors on the process of hand cooling, and also the influence of low temperatures on manual dexterity. Some data concerning determination of the limits of exposure to cold environments are also available in the literature (Zander and Morrison, 2008). Hand skin temperature is an important predictor of manual performance (Gaydos and Dusek, 1958; Enander, 1998; Schiefer et al., 1984; Giesbrecht et al., 1995). Fox (1967) suggested that manual dexterity deteriorates below a critical hand skin temperature of 8 °C, and that tactile sensitivity is impaired below 12–16 °C. Further studies have documented a decrease in finger dexterity starting below a skin temperature of 20–22 °C, and becoming significant below 15–16 °C (Vincent and Tipton, 1988). Daanen (1993) documented decreased finger dexterity below 14 °C.

It is known that gloves used for protection from heat loss in workers exposed to cold should be characterized by adequate insulation properties, which in turn depend on glove design and are primarily associated with the type of materials used. Most frequently, such gloves are produced from textiles, possibly with the addition of waterproof leathers or materials coated with polyvinyl chloride, nitrile rubber, or polyurethane. Higher thermal insulation is achieved by applying additional inserts or linings with insulating properties. Sari et al. (2004) found that protective gloves reduced hand heat losses in a cold air environment by 60–90% and that heat losses were 50–100% greater from the fingers than the palm and the back of the hand. Finger skin temperature is also affected by manipulation of objects or tools. The rate of change in skin temperature has been shown to depend on the pressure exerted on the fingers, the weight of the objects handled, material type, and glove thickness (Havenith et al., 1992; Lotens, 1992; Chen et al., 1994), with gloves greatly reducing sensitivity to different materials (Havenith et al., 1992).

Currently, the main standard defining the technical requirements and test methods for gloves designed for cold protection is EN 511:2006, which concerns gloves protecting the user from heat loss through convection and contact with cold the effects of which are comparable to those of air temperature equal to −50 °C. Based on the

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results of material laboratory tests, the protective properties of gloves are classified into four performance levels for each of the parameters tested. However, it is difficult to correlate glove properties assessed in the laboratory with the actual protection they afford workers, taking into account different work conditions and exposure to cold (Voelcker, 2014).

The type of glove material has a significant impact on glove fit and ergonomics. This fact affects manual dexterity and the feasibility of performing a variety of manual tasks (Wang et al., 2007; Geng et al., 1997a,b). Manual dexterity is also affected by the kind of occupational tasks and the shape and surface of objects handled by workers (Holmer, 1993). Surface type has a significant effect on hand cooling and dexterity of the worker (Jussila et al., 2017). A direct contact of fingers with a cold surface causes a greater thermal trauma than exposing the fingers to a cold atmosphere (Geng et al., 2006). Moreover, heat loss is greater upon hand contact with a metal surface than, for example, with a wooden one, all other things being equal. Hand cooling dangerously reduces the precision and speed of occupational task performance (Havenith et al., 1992). Thus, to fulfil their basic function in cold environments, gloves should be characterized not only by appropriate protective properties, but also by ergonomic features suitable for manual work under such conditions. The aim of this study was to **develop** design options for improving the construction of protective gloves used in cold environments taking into account the ergonomic factors linked to occupational exposure and the shape and surface type of objects handled.

The study adopted a two-pronged approach. First, workplace observations was conducted in workplaces in order to obtain objective data about manual work. Second, materials for protective gloves were subjected to instrumental tests. Both aspects are important and should be considered in parallel when designing protective gloves for cold work environments with a view to improving manual ergonomics.

2. Methods

2.1. Workplace observations

The study involved 107 workers performing tasks in refrigerated environments in 7 companies (A-G). Companies A, B, and C specialized in processing meat, manual sorting of frozen products, and meat cutting and boning. Companies D and E dealt with manual product handling and loading. Companies F and G were mainly engaged in weighing intermediate products, multi-packaging, as well as product labelling.

The companies were divided by type of predominant worker activity into production, warehouse, and packaging sectors (see Table 5). Workplace temperature as well as the surface type, weight, temperature, and shape of objects handled by workers during routine manual work were assessed for each sector.

- An integrated moisture and temperature sensor (iButton, USA) made of acid-proof steel and equipped with a temperature measuring and recording system, was used to measure workplace temperature parameters. Readings were made every 10 min with a resolution of 0.5 °C.
- The surface temperature of objects was determined by means of an infrared thermometer with a built-in hygrometer (Laserliner CondenseSpot Pro, Germany). The device enables contactless measurement of surface temperature in the range of −40°C–600 °C (with an accuracy of ± 1 °C in the range of −10°C–60° C and ± 1.5 °C in the range of < 10 °C and > 60 °C).
- The weight of objects was determined by means of non-automatic electronic scales (Radwag, Poland).
- Surface type and shape of objects were assessed visually in a descriptive manner without quantitative data.

Table 1
Characteristics of tested materials for protective gloves.

Symbol of material	Composition	Thickness [mm]	Type of material, weave/construction
A	60% polyamide, 40% polyurethane	0.77	Synthetic leather
B	100% polyester	1.98	Bilayer composite: - Knitted jacquard, double-knitted cast-on - Knitted plush fabric (weft-knitted)
C	84% polyester, 16% elastomer	1.62	Bilayer composite - Single jersey plated with elastomer thread
	94% polyester, 6% elastomer		- Double weft-knitted after scratch treatment
D	50% polyamide, 50% polyurethane	2.65	Weft-knitted plush fabric
E	50% polyester, 50% wool	8.46	Fur knitted fabric
F	100% polyacrylonitrile	1.90	Plated single-jersey fabric
G	External coat: 100% polyester Membrane: 100% PTFE Lining: 100% polyester	3.01	Triple-layer composite External coat: knitted fabric, Middle layer: membrane, Lining: knitted fabric
H	Polyester	6.44	Nonwoven fabric
I	50% wool, 50% polyester	3.49	Weft-knitted plush fabric
J	100% polyester	5.24	Weft-knitted plush fabric
K	100% natural leather	0.76	Lambskin

2.2. Materials

This section gives the results of laboratory tests performed on commercially available materials most commonly used in the production of cold protective gloves (Table 1). Materials were selected based on years of experience of a company producing such gloves. The company is one of Europe's leading manufacturers of a wide range of gloves for both occupational and non-occupational use which holds ISO 9001:2008 and ISO 14001:2004 management certificates and whose high-quality products are EC-certified by European Notified Bodies. The highest quality raw materials, supplied for many years by the same manufacturer, guarantee reproducibility of the protective and functional parameters of the gloves produced. The company operates its own quality control laboratory.

It was assumed that each of the studied materials should be characterized by good protective properties over a range of parameters such as hygiene, mechanical properties, insulation, and ergonomics.

2.3. Laboratory tests

The suitability of the selected materials for the construction of protective gloves was assessed in terms of mechanical, hygienic, and ergonomic properties in cold environments using combined methods for evaluation of personal protective equipment and glove materials. The test methods were developed using European standards (EN 14058:2004, EN 24920:1992, EN 31092:1993/A1:2012, EN 388:2003, EN 511:2006). Moreover, the method for evaluating bending stiffness, which is directly linked to the ergonomics of grip and manual dexterity, is proprietary and has been described detail in another paper (Irzmańska and Stefko, 2015).

Laboratory tests of the following protective and functional parameters were performed for the studied materials (Table 1):

- Mechanical parameters according to the standard EN 388:2003 with samples acclimatized prior to tests for at least 24 h at (23 ± 2)°C