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Review of Research Studies of Ergonomic Aspects of Selected Personal Protective Equipment

Katarzyna Szczecińska
Krzysztof Łężak

Department of Personal Protective Equipment, Central Institute for Labour Protection, Lódź, Poland

This article is a review of research studies conducted in the Central Institute for Labour Protection (CIOP) on ergonomic aspects of personal protective equipment (PPE) design and use. Research was related to, among other things, a comparison of body strain and work time limitation for users wearing gas-tight and drill suits. Some other studies were connected with the biophysical properties of clothing materials for medical use. On the basis of the measurement results, a proposal of clothing construction with an optimum combination of protection and comfort was created.

Research leading to the development of test methodology concerning automatic welding filters with switchable luminous transmittance is also conducted n CIOP.

The article also brings up the subject of designing new PPE assuring a high level of comfort. A modei of material to be used under tight protective clothing, an inflammable harness for working at a height, and a model of intelligent clothing that will assist human thermoregulation processes during physical effort are examples of new PPE.

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ergonomics personal protective equipment design
tests methods protective clothing automatic welding filters
protective respiratory system electro-acoustic ear protectors
equipment against falls from height feel of comfort

Correspondence and requests for reprints should be sent to Katarzyna Szczecińska, Central Institute for Labour Protection, ul. Wierzbowa 48, 90-133 Lódź, Poland. E-mail: < kaszc@dop.lodz.pl >.

1. INTRODUCTION

One of the problems connected with the use of personal protective equipment (PPE) at the workplace is frequent lack of its acceptance by its users. This is usually because this equipment causes various kinds of problems. With regard to PPE against falls from a height, these are dynamic spine loads during fall arresting, with regard to eyes and face protectors and respiratory system protection—a reduction of the visual field and perception of visual signals while using spectacles, goggles, and full-face masks. It is vital for protective clothing, shoes, and gloves to eliminate difficulties connected with sweat evaporation and heat abstraction, movement restriction, and dexterity. Acceptance of all protectors by their users mainly depends on the weight, shape, and size of the protectors, which should be carefully chosen; elasticity of fabrics, their flexibility, and comfort experienced by the users. That is why when designing PPE, it is so important consider not only properties determining optimal protection level against selected factors, but also ergonomic aspects ensuring comfort when this equipment is used (Koradecka, 1998).

2. RESEARCH STUDIES CONDUCTED IN CIOP

In the Central Institute for Labour Protection (CIOP) research studies have been conducted on the ergonomic aspects of existing PPE as well as on designing new equipment that guarantees both a high level of comfort and protection.

2.1. Gas-Tight Suits With Air Breathing Apparatus

Research studies on the ergonomics of PPE were conducted using gas-tight suits with air breathing apparatus. Their use causes high strain for the body, connected mainly with cardiovascular and thermoregulation systems, which reduces the time clothing can be worn.

The strain is a result of the extra weight of the suit and breathing apparatus (about 25 kg). Research on the expenditure of energy during a wide range of tasks performed in a gas-tight suit showed that it is approximately 25-40% higher than in light clothing, in field and laboratory tests alike.

Research conducted in CIOP concerned, among other things, a comparison of the amount of sweat absorbed in the layers of clothing under a gas-tight suit and under a drill suit during an effort with an assumed load and at two different values of ambient temperature: room (22 °C) and higher temperature (40 °C, Figure 1). As the results show, a gas-tight suit reduces the efficiency of sweat evaporation—as a thermoregulation mechanism—by 60% at 22 °C and by 25% at 40 °C, compared to drill clothing. This is the cause of a sudden increase of the inner temperature of the human body and of skin temperature—the time of reaching the maximum body temperature in given conditions is shorter by more than 50% in a gas-tight suit than in drill clothing (Figure 2). It is characteristic that in a hot environment an increase of inner body temperature is still observed after the end of the effort. This may prove that thermal stress causes heat accumulation in the body, even when the strain factor is not active any more. The results of research showed that effort in a gas-tight suit can be much shorter than in a drill one. Instead, the break-time after such an effort, defined as a period of time during which physiological parameters return to their common values (inner body temperature and pulse), is approximately 2.5-3 times longer than the time of the effort (Bugajska, Szmauz-Dybko, & Sołtyński, 1998).

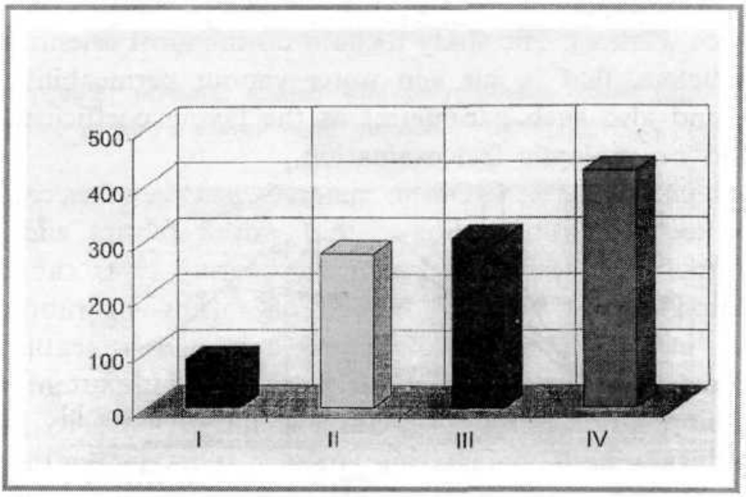

Figure 1. Comparison of absorbed sweat (g) in the layer of clothing in different temperatures: (I—22 °C, drill; II—gas-tight suit, 22 °C; III—drill, 40 °C; IV—gas-tight suit, 40 °C).

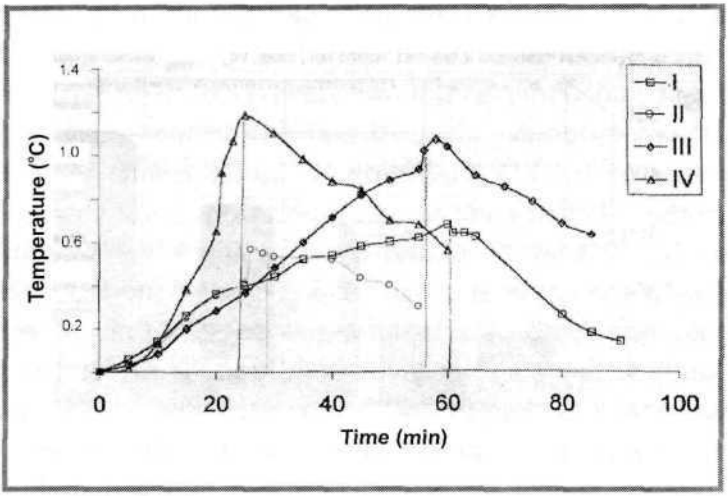

Figure 2. Comparison of inner body temperature during effort with assumed load for different conditions (I—22 °C, drill; II—gas-tight suit, 22 °C; III—drill, 40 °C; IV—gas-tight suit, 40 °C).

2.2. Protective Clothing for Medical Use

Another research study conducted in CIOP concerned the biophysical properties of available materials used for manufacturing clothing for health service workers. The study focused on the most essential—for the user—parameters, that is, air and water vapour permeability, thermal resistance, and also such parameters as the laying coefficient, bending rigidity, and organoleptic feel evaluation.

Research conducted in CIOP on materials used in other countries for medical protective clothing showed that woven fabrics and unwoven fabrics without any additional polymeric coating layer cannot ensure full protection against blood and micro-organism penetration. On the other hand, in most cases coating layers have a detrimental effect on multilayer materials. For barrier materials the most important parameter describing biophysical comfort is water vapour permeability, which can be formed during the manufacturing process. By modifying the structure of the composite, we can obtain complete protection against any contact with blood or micro-organisms ensuring water vapour permeability at a level that guarantees physiological comfort. However, composite materials have a much worse laying coefficient and much bigger bending rigidity. On the basis of organoleptic research it can be concluded that for the majority of products with an extra protective layer, coated or laminated products have been classified as more rigid, harder, rougher, and more unpleasant in contact compared to those without coating.

Negative effects like lack of air permeability, a decrease of water vapour permeability, and excessive rigidity can be counteracted by proper clothing design. It should have a simple cut with a minimal number of stitches and it should be loose in order to ensure freedom of movement. Using a material with significant air and water vapour permeability in places that are not exposed to contact with body fluids and using a barrier material for the front part and for the sleeves makes obtaining a required level of protection and biophysical properties possible (Kowalczyk, 1999; Figure 3, 4).

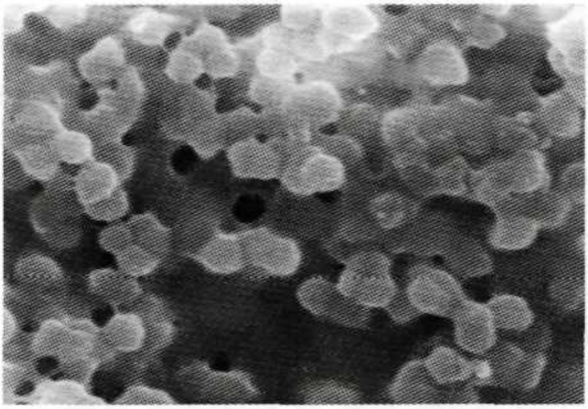

Figure 3. Polyester material coated with polyurethane water vapour permeable layer. Structure of polyurethane layer surface (x 2000).

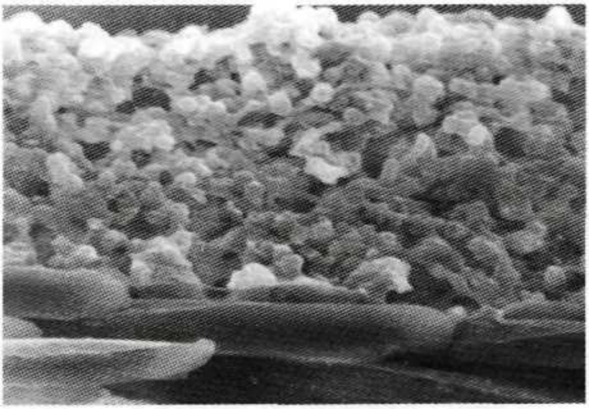

Figure 4. Polyester material coated with polyurethane water vapour permeable layer. A cross-section (x 1000).

2.3. Automatic Welding Filters

In CIOP studies are also carried out on commonly used automatic welding filters. According to standard EN 379:1994 (European Committee for Standardization [CEN], 1994), measurements of spectral transmittance of ultraviolet, infrared, and visible radiation are taken only when radiation is perpendicular to the surface of the optical filter. The aim of the research is to analyse the relation between the transmittance coefficient and the angle of filter placing. The relation between the response time of an automatic welding filter and variable outer lighting is also examined. This will enable a precise determination of the relation between phenomena occurring during the blackout of automatic welding filters and actual conditions in which these filters are used.

The research results will make it possible to formulate the Polish opinion during work on the revision of standard EN 379 (CEN, 1994) in the WG4 Working Group of the Technical Committee CEN/TC 85. The work concerns defining angular dependence of the transmittance coefficient for automatic welding filters.

2.4. Protective Respiratory System

Research conducted in the field of protective respiratory system concerns modelling the shape of filter mediums and forming an effective visual field of face parts of respirators, helmets, and protective hoods. As a result of these studies a procedure for evaluating filter mediums has been worked out, in a theoretical and experimental way, in order to guarantee the best breathing conditions despite constant dust deposition inside a filtering medium.

Forming an adequate visual field of equipment is an extremely vital problem in equipment used by rescue services because limitation of visual field and its range can create additional danger. The results of the conducted research were the development of optimum solutions for a visor's position with reference to the user's face and its size, and the radius of curvature of panoramic windows in the range of solutions assuming no more than 30% limitation of visual field with reference to the physiological one. Panoramic windows are a solution, which enables a change of the angle of the visor according to whether an operation is carried out on the eye-level or not, that is, under or above it.

2.5. Ear Protectors

The application of ergonomics in designing PPE is illustrated by the example of electro-acoustic ear protectors. Difficulties connected with using traditional protectors arise from a conflict between comfort and the necessity for the shell to fit tightly in order to isolate from noise. Ear protectors with an electronic system of active noise reduction put into the earcap are a new solution in this field. Active noise reduction ensures greater protection, particularly against low-frequency noise, as well as auditory contact and lower pressure.

2.6. Research on New PPE Design

Research conducted now or planned for the future on designing new PPE taking into account ergonomic aspects concerns, for example, protective clothing and gloves as well as equipment against falls from a height.

Heat resistant equipment against falls from a height is necessary for work at a height in contact with thermal hazards. Lack of such equipment, not covered by European standards either, means that some alternative solutions must be applied like protective clothing shielding standard equipment against sparks, flames, and so forth. Such a set-up can cause an excessive load of the body. To avoid such a situation, special non-flammable harness has been designed in CIOP. It is resistant to sparks, splashes of molten metal, short contact with flames, and high temperature. This harness has the required property of dynamic loads' shock absorption.

A design of clothing to be worn under a tight suit protecting against liquid chemicals has been also developed in **CIOP** (Figure 5). It makes creating a proper microclimate under the barrier clothing during intensive work (with high perspiration and heat emission) possible. The proposed model of a set of materials has the following properties (Bartkowiak, 1999):

- it is composed of two permanently connected layers,
- the inner layer is a knitted fabric made of hydrophobic fibres enabling water vapour diffusion and liquid transport,
- the outer layer can be a knitted or unwoven fabric made of hydrophilic fibres or other fabric with high sorption. **Its** purpose is to absorb moisture from the inner layer.

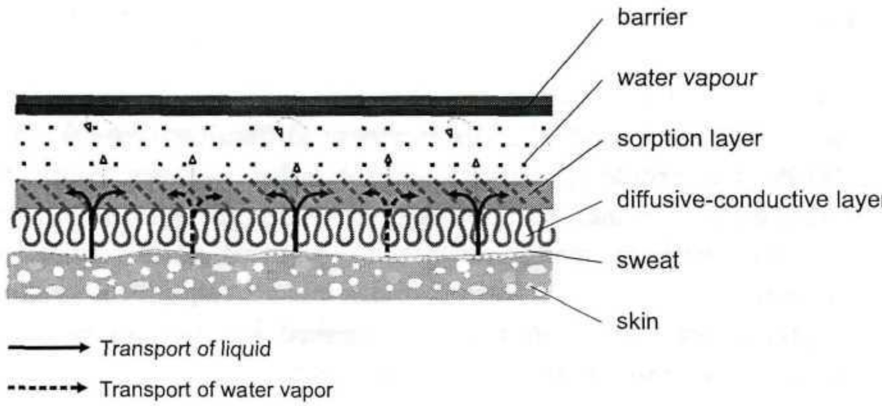

Figure 5. Model of a set of materials under a tight barrier.

After making a batch of fabrics, with one, two, or three layers, they were evaluated, on the basis of the theoretical model, for liquid-sweat sorption and the influence on microclimate dynamics under barrier clothing. Taking into account physicochemical and structural properties, it was established that textured polyester (close-to-body layer) and viscose (sorption layer) are the best raw materials for fabrics designed for clothing to be used under barrier clothing. Such a material set enables high efficiency and sorption dynamics.

The development of a model of so-called "intelligent clothing" is also considered. This clothing will actively support the thermoregulation process of the human body during physical effort, that is, it will absorb sweat produced by the human body and use heat generated in this process as a heating medium. Research will start in CIOP after the bibliography on this subject and the achievements of other laboratories have been studied.

Similarly to the clothing model just described, a research project concerning a glove model is considered. The gloves should present a compromise between high resistance against chosen chemical substances, physicomechanical properties, and water vapour permeability. This would have a favourable influence on proper microclimate modelling in the zone of hand-glove-environment.

3. CONCLUSIONS

The results of research conducted in CIOP can be taken into account when developing instructions for manufacturers of PPE and their users.

They can be a basis for working out criteria of a product's evaluation with regard to the safety and ergonomics rules as well as guaranteeing the highest possible comfort of the user. They enable Polish representatives to take an active part in the meetings of Working Groups (WG) and Technical Committees of the European Union.

It must be mentioned that Polish regulations do not cover the obligation for employers to take into account ergonomics properties when selecting PPE for workers. Such a statement will be created when Directive 89/656/EEC (Council Directive 89/656/EEC) is implemented into Polish law and it will be a supplement to the Polish Minister of Labour and Social Policy's regulation of September 26, 1997 (Minister of Labour and Social Policy, 1997) concerning general safety rules.

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