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Determination of a Comfort Class for Protective Clothing Based on Ergonomic Tests

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Abstract
In addition to compliance with requirements concerning specific protective properties, protective clothing should also provide a sense of comfort to the user. No clearly identified evaluation criteria for the ergonomic properties of protective clothing is currently available. Methods applied do not allow for quantitative assessment of protective garments that enables to compare the various types of clothing. A new methodology of testing and ergonomic evaluation of protective clothing based on comparative studies of protective clothing versus reference clothing was developed herein. The use of reference garments enable a quantitative ergonomic assessment of protective clothing by placing it in an appropriate comfort class. Ergonomic studies in accordance with the methodology developed were carried out on two types of protective clothing, i.e. protective clothing for firefighters and clothing that protects against chemical agents. Based on these studies, the protective clothing was assigned to an appropriate comfort class.

Key words: *protective clothing, ergonomics, comfort class, reference clothing.*

Introduction

Protective clothing should meet the requirements of the relevant standards not only with respect to its protective properties, but also in terms of ergonomics. Chen et al. [1] pointed out that in the case of clothing, not only aesthetics and functionality are important, but above all the safety aspect. It turns out that protective clothing, when designed incorrectly or poorly fitting to the user's figure, can cause a significant limitation to his/her physical activity, and sometimes, even by itself, cause an increase in risk [2, 3]. Recent studies [4-6] show that higher comfort and greater freedom of movement is provided by personalised clothing, designed using 3D scanning techniques. However, the low availability and high price of human body scanners are still the factors inhibiting the development of personalised products.

In accordance with Regulation (EU) 2016/425 of the European Parliment and of the Council [7], it is required that personal protective equipment, including protective clothing, should be designed so as to preclude risks and other inconveniences in the foreseeable conditions of use. Hence, ergonomic studies of protective clothing are important. Currently, studies of this type are usually carried out following test methodologies developed on the basis of assumptions contained in ISO 13688:2013 "Protective Clothing – General Requirements" [8]. The above standard provides the sample questions that can be used by the person testing and evaluating protective clothing for the purpose of its approval or rejection. Similarly, the general assumptions of the ergonomic assessment are included in the EN 469:2014 standard [9], presenting the requirements for protective clothing to be used by firemen during firefighting actions.

There have been numerous studies undertaken to develop methodology of ergonomic evaluation of protective clothing, including, inter alia, ballistic vests for special services such as the police, the Government Protection Bureau and border guard [10, 11]. The methodology proposed that tests with the participation of volunteers should be conducted both under laboratory and training ground conditions, justified, first of all, by the possibility to obtain a reliable assessment of the ballistic products tested. There was a double rating of the vests, both by the participants and the person conducting the test. The authors concluded that the methodology developed allowed to develop guidelines for the design of the ballistic vests assessed.

Breeze et at. [12] compared the effect of the design of ballistic collar neck protectors on the comfort of use and battlefield performance (i.e. shooting accuracy). The study was conducted on 71 volunteers wearing a standard British battlefield uniform, and their job was firing a shot with a rifle, crawling over a distance of 20 m, and carrying a load of 70 kg weight over a 20 m distance. After the simulation of activities performed during combat operations, a survey was conducted. The studies have made it possible to evaluate the ergonomic properties of only an element of ballistic vests i.e. a collar, failing to provide, however, a comprehensive solution to the problem of assessment of the whole set of clothing.

Another method of ergonomic evaluation of protective clothing involves as-

Table 1. *Characteristics of clothing subjected to ergonomic tests.*

Clothing type	Material characteristics	Product description
Protective clothing for firefighters (S)	– Outer fabric: 100% aramide woven fabric, – Vapor-permeable membrane, – Thermal insulation layer: aramide-viscose woven fabric (50% Aramide, 50% Viscose FR) quilted with flame-retardant aramid nonwoven. Lining is an integral part of the garment, it cannot be removed.	2-garment set: – Jacket with a stand-up collar, with a double-slider zip, covered with a strip fastened with snaps and velcro tape; sewn-on reflective tape strips around the sleeves as well as on the upper and lower part of the trunk – Trousers with suspenders with a back bib; sewn-on reflective tape strips around the legs .
Protective clothing against chemicals (C)	Polyester knitted fabric coated with PVC.	1-part garment: Overall with a hood, fastened with a zip , covered with a strip fastened with snaps; sleeves and trousers legs with an internal puller; at the back, at the level of the waist there is an elastic tape in a tunnel for adjustment to waist circumference.
Reference clothing (R)	65% PES/ 35% cotton woven fabric	2-garment set: – Jacket with a collar, elongated at the back, fastened with buttons; sleeves finished with knitted strippers; vents in the sleeve seam under the armpits; at the back the are 2 bellows and 6 vents at the level of the scapulae, – Waist-high trousers with a waist circumference adjustable by means of elastic tape fastened with buttons.

sessment of the range of motion (ROM) in the joints. This method is based on the measurement of the maximum flexion angles of the joints and the distance which the research participant is able to reach while carrying out remote operations. The above method was applied, among others, by Huck [13] in order to compare the range of motion in 2 variants of protective clothing for firefighters differing, inter alia, in the design of the sleeve. The research was conducted using a flexometer to measure the flexion angles at the elbow and shoulder joint in 9 men, testing individual variants of protective clothing. The studies showed that a greater range of movement is possible in garments which have sleeves with a gusset than in the case of clothing with sleeves of simple design.

Coca et al. [14] studied the effect of firefighter clothing on the user's mobility and productivity. ROM measurements were first performed on volunteers dressed in light clothing (a cotton shirt and shorts, sports shoes), and then analogous measurements were conducted on the firefighter clothing tested, including gloves, shoes, a helmet and personal breathing apparatus. The measurements were performed using a goniometer for static movements (e.g., flexion of the elbow joint, bending the knee joint, lifting the arms up) and during dynamic movements (e.g., kneeling, crawling and squats).

Hu et al. [15] also undertook to carry out an ergonomic evaluation of clothing by means of standard ROM measurements, additionally supplementing these studies by testing the grip/crush force, as well as the accuracy and operational efficiency while screwing the nuts.

An interesting method of assessing ergonomic properties which also allows quantified evaluation of protective gloves based on measurements of muscle load using surface electromyography was presented by Irzmańska et al. [16].

In order to improve the mobility of users of traditional firefighter clothing, Luo et al. [17] proposed introducing some changes in its structure (i.e. bellows under the armpits, extending the back of jackets, profiling trouser legs at the level of the knees, and the introduction of diamond-shaped gussets in the crotch). As a method to examine and compare the ergonomic properties of both variants of firefighter clothing, the range of motion (ROM) test method was used. These studies confirmed the positive impact of structural changes on the improved mobility of users.

In turn, Havenith et al. [18] proposed a set of tests to study the ergonomic properties of firefighter clothing where the results obtained are compared with those for the reference clothing. Any clothing that does not have protective properties but allows full freedom of movement can be used as reference clothing. The authors draw attention to the important fact that ergonomic assessment of the same protective clothing can vary according to the conditions in which it is carried out, however, it is not possible to carry out tests in all possible conditions of its application. Therefore, the authors propose analysing the conditions of use of the protective clothing assessed, its main functions, and the tasks that will be performed in it prior to designing the test conditions. In accordance with the ergonomic test methodology developed, the temperature distribution in the garments was studied, and an assessment of the subjective experience of heat and moisture of 8 volunteers wearing different types of protective clothing under repeatable conditions of simulated radiant heat and high temperature hazards was carried out. Then, the possibility of free movement in the clothing tested was carried out by comparing the duration of the specific activities in the protective clothing assessed versus the reference clothing.

The methodology of ergonomic research on protective clothing based on comparative studies of protective and reference clothing was also shown in this publication. The use of a reference variant in the form of reference clothing has allowed the development of point score-based criteria for the assessment of protective clothing, on the basis of which the protective clothing is assigned to the relevant comfort class.

The aim of the studies presented in this publication was to verify the test methodology developed by examining and comparing the ergonomic properties of two types of protective clothing i.e. protective clothing for firefighters and against chemicals. This publication was aimed at presenting a new methodology for testing and ergonomically evaluating protective clothing, and not assessing the protective clothing itself.

Materials and methods

Characteristics of garments tested

Two types of protective clothing of complex structure: 1 – clothing that protects against chemicals and 2 – protective clothing for firefighters (***Table 1***) were

selected for the studies. While conducting the tests, both protective clothing variants were compared with reference clothing developed specifically for that purpose. The reference clothing did not have protective properties, but was made of a material that provides a high level of physiological and sensorial comfort [19, 20]. In addition, the clothing was designed using 3D scanning technology to minimise the restrictions of movement that may occur while carrying out professional activities. ***Figure 1*** shows photographs of the variants of personal protective clothing tested and reference clothing.

Testing metodology

An ergonomic study was carried out with the participation of 5 volunteers (men) of varied body constitution, age (mean ± SD): 25-44 years old, height: 178.20 ± 4.21 cm and weight: 80.60 ± 9.34 kg. Each of the participants was tested for two sets of clothing in one day, first the reference clothing, and then either protective clothing for firefighters or clothing that protects against chemicals. Each garment was studied in a set with underwear in the form of a cotton shirt with short sleeves and boxer shorts. The tests, with the same volunteer, taking place on the same day, were carried out with an at least 1-hour interval.

The tests took place in an air-conditioned laboratory at a constant temperature of the ambient air, i.e.: (20.0 ± 3.0)°C, at a relative humidity of (50.0 ± 5.0)%.

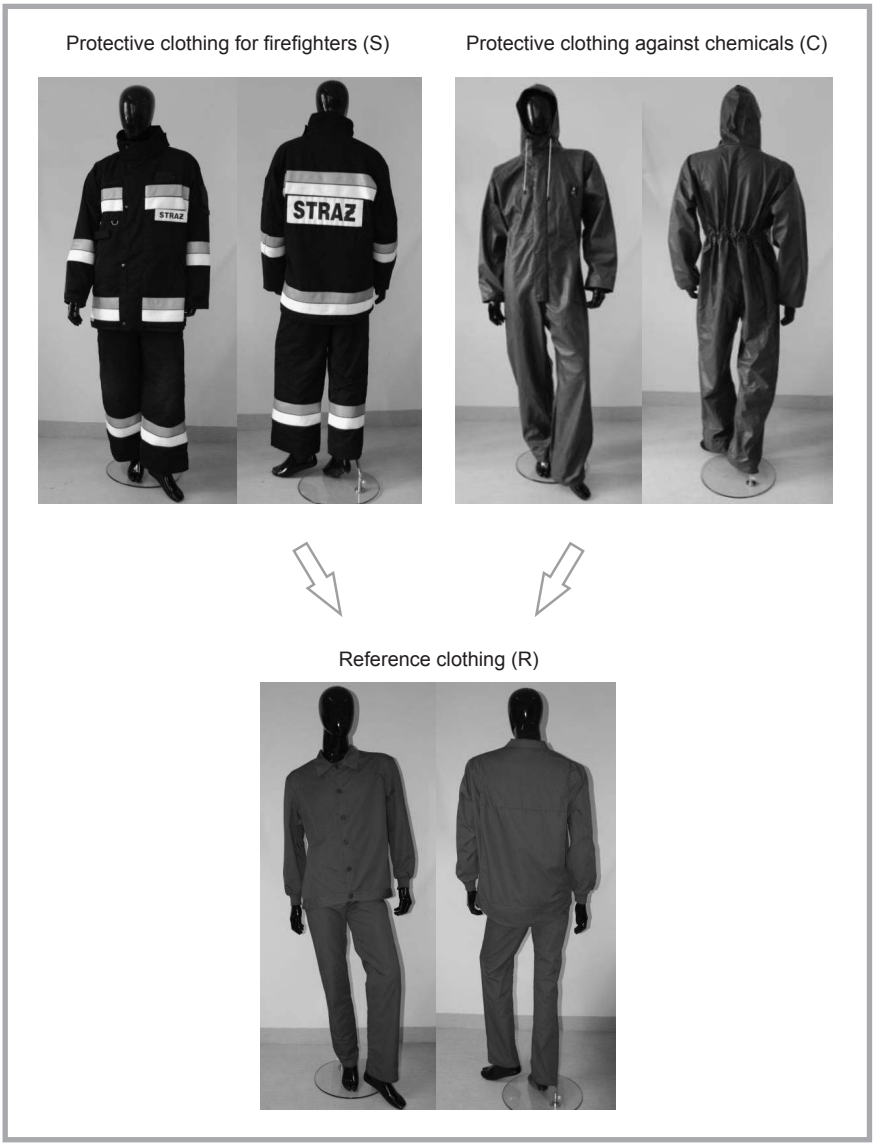

Figure 1. *Photographs of protective clothing and reference clothing assessed.*

Table 2. *List of test activities for the types of protective clothing assessed.*

BASIC MODULE (all kinds of protective clothing)	
a) climbing up and down stairs, b) raising both hands up, c) in a sitting position, using both hands, grasping any object (e.g. a ruler), lying on a table in front of the test participant at a distance of 70 cm, d) reaching out in a standing position with one hand upwards to get a small object (e.g. a pencil) lying on a rack at a height of 2 m, e) reaching out in a standing position with both hands upwards to get a small object (e.g. a pencil) lying on a rack at a height of 2 m, f) bending the arm at the elbow and straightening it out in a standing position, g) stooping and lifting a small object from the floor (e.g. a pencil) in the standing position, h) in a standing position, twisting the torso to the right with the right hand outstretched backwards, then turning the torso to the left with the left hand outstretched backwards, i) squats, j) kneeling on the right knee, kneeling on the left knee, kneeling on both knees, and then rising from the kneeling position, k) position with the legs apart, the body inclined forward, arms bent at the elbows, l) marching on a treadmill in an erect position – at a speed of 6 km/h for 5 min.	
EXTENDED MODULE	
Protective clothing for firefighters (S)	**Protective clothing against chemicals (C)**
a) marching on a treadmill in an erect position – at a constant speed of 6 km/h for 5 min, running for 1 min at 8,0 km/h speed. b) crawling on a horizontal surface at a height of (0.7 ± 0.05 m) for 5 min, c) climbing up and down a ladder, d) unwinding and rewinding a fire hose.	a) climbing up and down a ladder, b) kneeling position – on one knee, filling a basket with pieces of rubber imitating a bulk material, c) stooping position, legs slightly bent, lifting a box of 3 kg weight lying on the floor, carrying it for a distance of 10 m and putting it in the place indicated, d) movements imitating the collection of oil, liquid, dust or granulate with an aspirator (using an industrial vacuum cleaner for this purpose) – 5 min.

Table 3. *Questions of the BASIC MODULE questionnaire concerning the comfort of use of clothing.*

Question No.	Question content	Response rating
2	Can the clothing be put on and taken off easily and without the help of other persons?	0 – yes, 1 – there were minor difficulties, 2 – there were major difficulties, 3 – no
3	Do the fasteners function correctly when the clothing is put on and taken off, as well as during the execution of movements?	
4	Does the clothing fit correctly or have an appropriate adjustment range guaranteeing comfort of use?	0 – yes, 2 –jacket/trousers too loose, 3 – jacket/trousers too tight, 4 – whole set too loose, 6 – whole set too tight
5	Does the clothing cause compression, impairment of blood flow?	0 – no, 2 – slight compression, 3 – there was difficulty in execution of movements, 4 – impossibility of execution of movements
6	Are the particular parts of the garments (e.g. armpits, crotch) positioned correctly?	0 – yes, 1 – there were minor difficulties in execution of movements, 2 – there were major difficulties in execution of movements, 3 – impossibility of execution of movements
7	Does the clothing have any sharp edges, protruding elements, rough surfaces, fasteners, seams or junctions which made the execution of movements difficult?	0 – no, 1 – there were minor difficulties in execution of movements, 2 – there were major difficulties in execution of movements, 3 – impossibility of execution of movements
8	Did the clothing cover particular parts of the body at rest and during the test activities?	0 – yes, 1 – exposed wrist/ ankles/ back/ others (specify)
9	Is the clothing compatible with the following personal protective equipment: a) footwear, b) gloves, c) others (specify)?	0 – yes, 1 – no

Before commencement of the tests, each of the participants was familiarised with the purpose and scope of the research, and instructed how to put on and adjust the different types of clothing. Then the participants rested in a sitting position for 5 min, replenishing fluids (approx. 200 ml). After the rest phase, the participants put on the test set of clothing along with the underwear and performed the set of 12 exercises used in the ergonomic evaluation of each type of protective clothing – the BASIC MODULE. Then these same participants started to perform activities typically associated with the evaluation of the specific type of protective clothing – the EXTENDED MODULE. ***Table 2*** shows the list of activities for the variants of protective clothing assessed, carried out within the framework of the individual modules.

Directly after having followed the steps above while wearing the specific variant of clothing, each of the participants evaluated the clothing's functionality by responding to question 1 in the BASE MODULE and EXTENDED MODULE questionnaires: *"Were there limitations in the execution of movements?"*
The test participant could award the test clothing with a certain number of points according to the following score scale:

Positive assessment:
(-1) point – higher level of comfort than that of the reference clothing (answer applicable only for the assessment of protective clothing),
0 points – no limitations,

Negative assessment:
1 point – slight restriction of movement,
2 points – difficulty in execution of movements,
3 points – impossibility of execution of movements.

The BASIC MODULE questionnaire is used as a research tool in the ergonomic assessment of any type of protective clothing, and that is why, besides the questions concerning the functionality of clothing while performing simple activities, it also includes questions about the overall comfort of use of the garments (questions 2-9). The answers to these questions are also scored. ***Table 3*** presents the contents of the individual survey questions along with scores for the particular responses.

Questions No. 4 and 5 have a very large impact on the safety and ergonomics of clothing use, therefore the way of awarding points is slightly different than in the case of other questions.

Answers to question No. 4 are scored on a scale from 0 (for correctly fitted clothing) to 6 (for clothing too tight), excluding 1 and 5. Even one part of a clothing set too loose (eg. trousers, jacket) may pose a threat to the workplace caused, for example, by the tangling of the trouser legs; therefore, the answer "the jacket/ trousers too loose" was marked 2 points. A whole clothing set which is too loose, i.e. both the upper and lower part of clothing can double the threat, hence the answer "the whole set too loose" was marked 4 points.

A serious problem is too tight clothing, because it makes it difficult, or even not allow, to perform movements due to the compression of body parts, hence the answer "the jacket/trousers too tight" was given 3 points, while the answer "the whole set too tight" was marked two times more, i.e. 6 points.

The answers to question No. 5 were assigned points from 0 to 4, excluding point 1, because it was recognised that barely slight compression of the body can have large health consequences and cause significant difficulties in movement. Hence, the answer indicating slight compression on the human body causing the impairment of blood flow was marked not 1, but 2 points. A higher rank of 3 points was given to the answer "there was difficulty in the execution of movements", because in this case it means that the pressure of clothing on the body causes not only discomfort but also some physical limitation, oppressive for the user. The biggest problem is clothing which does not allow to perform movements due to the large compression of the body

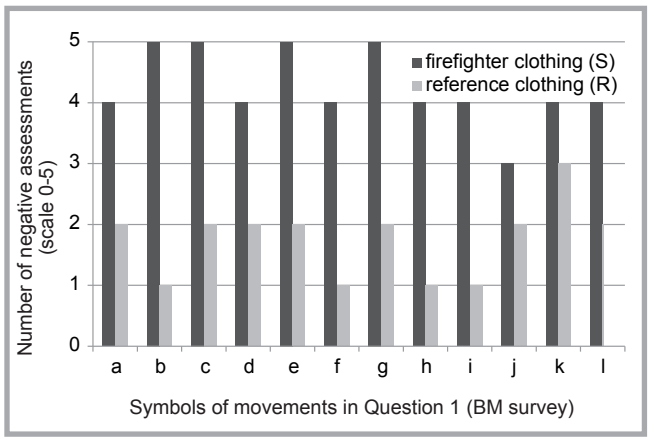

Figure 2. *Results of functionality tests of protective clothing for firefighters (S) and referenced clothing compared therewith (R) while performing activities included in the basic module (survey question 1).*

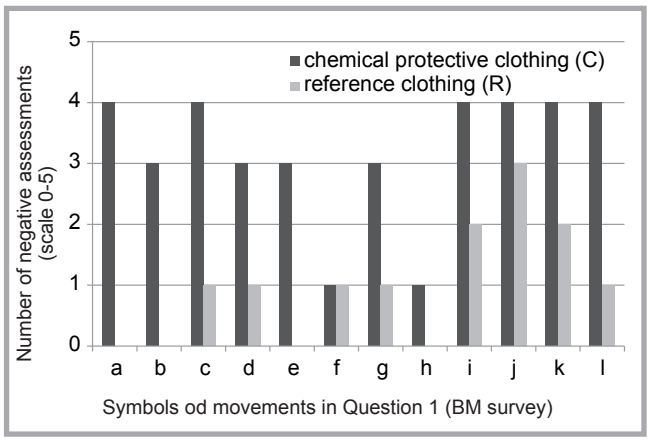

Figure 3. *Results of functionality tests of protective clothing against chemicals (C) and referenced clothing compared therewith (R) while performing activities included in the basic module (survey question 1).*

and the accompanying pain. Therefore, it was considered that in question no. 5, such clothing should be rated 4 points.

After testing the specific clothing variant, the survey responses of the individual participants in the study were summed up and the average scoring values for a particular garment determined. Then, the difference between the mean value of the scores for the protective clothing and the reference clothing tested on the same day was calculated in accordance with the testing methodology laid down for the particular type of protective clothing. The difference obtained allowed to assign the protective clothing to the appropriate class of comfort in accordance with the following criteria:

Comfort class I – difference of up to 6 points (only the answers scoring -1 to 1 point should be taken into account, with max. 3 answers of 1 point to questions other than question 1 acceptable),

Comfort class II – difference of 7-15 points (only the answers scoring -1 to 1 point should be taken into account, with max. 6 answers of 1 point to questions other than question 1 acceptable),

Comfort class III – difference of 16-24 points (only the answers scoring -1 to 2 points should be taken into account, with max. 3 answers of 2 points to questions other than question 1 acceptable),

Comfort class IV – difference of 25-33 points (only the answers scoring -1 to 2 points should be taken into account, with max. 6 answers of 2 points to questions other than question 1 acceptable),

Unacceptable product – difference exceeding 34 points.

Test results and dicussion

Clothing functionality during physical activities carried out within the framework of the basic module (BM)

Test results concerning the functionality of the variants of protective clothing evaluated and the reference clothing compared with it while performing basic physical activities are illustrated in the form of bar charts (***Figure 2*** and ***3***) showing the total number of negative responses of the participants of the research to survey question 1 concerning the BASIC MODULE.

Protective clothing for firefighters

The results of the survey conducted among the participants testing protective clothing for firefighters (S) indicate that during the execution of all movements within the basic module, at least 3 out of 5 of them experienced restrictions of movement (***Figure 2***).

When raising both hands (movement b) as well as when reaching with both hands for the object lying on the rack (e) while wearing firefighter clothing, all the participants experienced discomfort caused by pulling of the material under the arms. The restrictions were usually perceived as minor (1 point), although in the case of movement (e) 2 answers for 2 points appeared, indicating a higher level of discomfort. In turn, during the movements marked with symbols (c), (d) and (g), besides the restrictions under the arms, also pulling of the jacket material on the back or of the material width within the hips/waist region occurred. During similar movements in the reference clothing, some inconvenience was also reported, but by a much smaller number of participants (max. 2), and significantly less intensive (responses for max. 1 point). The reason for discomfort was gentle pulling of the material under the arms, and in the case of movement (b) 1 of one of the participants, the front part of the jacket failed to cover the upper part of the trousers.

During the execution of elbow joint flexion (f) in the firefighter clothing, 4 participants of the test made some comments. They claimed that the reflective tape sewn on around the sleeves hurts in full flexion of the arm. Despite the fact that, in all these cases, the restrictions were assessed as minor ones (1 point), it can be assumed that maintaining such a position for too long can be cumbersome for the user. When executing a similar movement in the reference clothing, a negative rating was given by only one participant, who did not indicate, however, what the cause of the discomfort was.

A problem often reported in the case of firefighter clothing, especially during movements (a) and (l), was the tangling and rubbing of the trouser legs against each other. Comments of this type were reported by 4 participants, with a slightly larger inconvenience found after 5-min marching on a treadmill (l). In the case of the reference clothing, there were 2 responses indicating the occurrence of small mobility restrictions; however, neither of the participants identified the cause of the discomfort.

The tests conducted demonstrated that while kneeling (j) and squatting (i), 3-4 participants felt excessive tightness

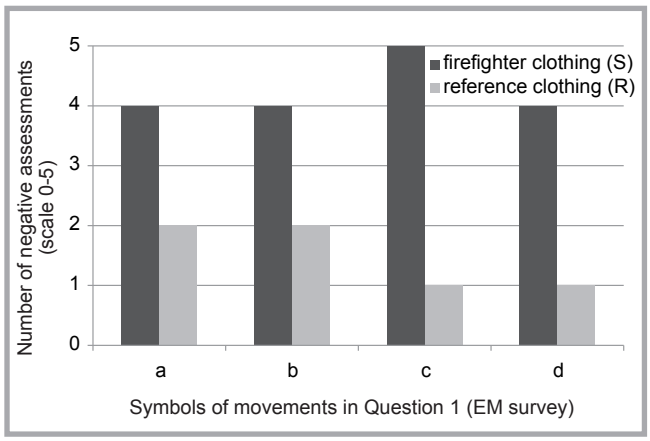

Figure 4. *Results of functionality tests of protective clothing for firefighters (S) and reference clothing compared therewith(R) while performing activities included in the extended module (survey question 1).*

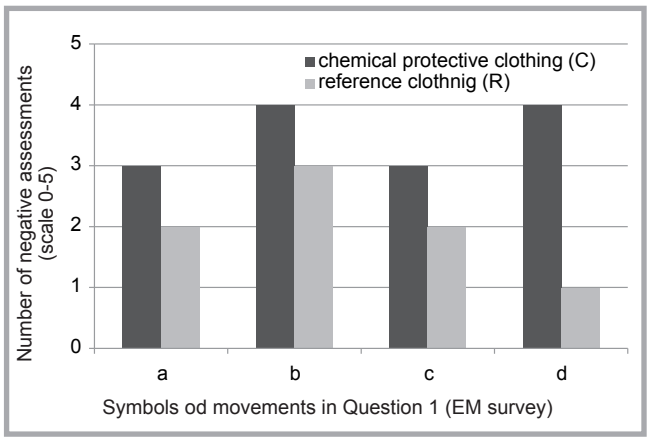

Figure 5. *Results of functionality tests of protective clothing against chemicals (C) and reference clothing compared therewith (R) while performing activities included in the extended module (survey question 1).*

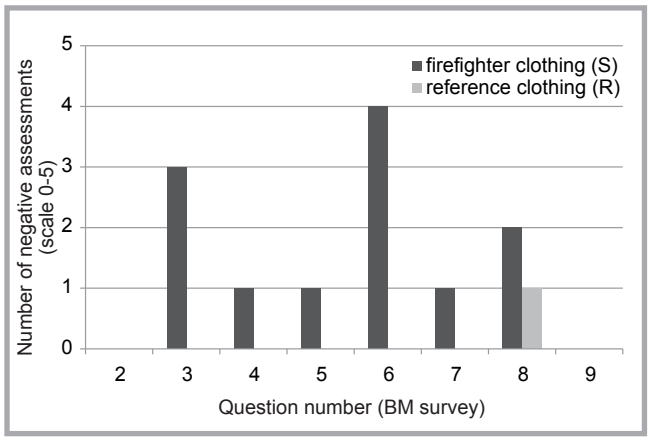

Figure 6. *Results of the survey concerning user comfort tests of protective clothing for firefighters (S) and the reference clothing compared therewith (R) according to the basic module (survey questions 2-9).*

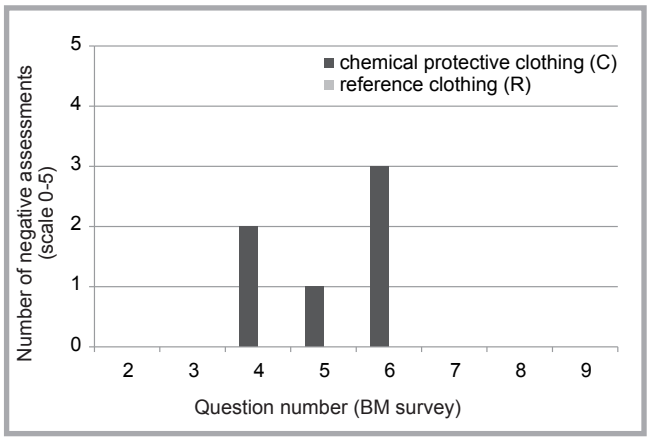

Figure 7. *Results of the survey concerning user comfort tests of protective clothing against chemicals (C) and the reference clothing compared therewith (R) according to the basic module (survey questions 2-9).*

of the firefighter's jacket on the hips. The limitations were mostly rated at the level of 1 point. Difficulty in performing squats (i) was reported by only one participant. While performing a similar exercise in the reference clothing, 1-2 participants reported gentle pulling of the trouser material at the height of the thighs or crotch.

Protective clothing against chemicals

Ergonomic studies of clothing protecting against chemicals showed that during the execution of movements included in the basic module, the clothing caused restrictions to at least 1 in 5 participants.

During activities carried out with one or both hands raised (movements b, d, e), 3 participants reported restrictions under the armpits. These restrictions were, in most cases, regarded as minor (1 point), although in the case of movements (d) and (e), 1 of the participants assessed it at 2 points, indicating a higher level of discomfort. Moreover, during the execution of the movement marked with symbol (c), besides the aforementioned inconvenience, the participants also reported pulling of the suit material on the perimeter of the back. The total number of negative assessments reported in the case of that movement amounted to 4. In the case of reference clothing, minor restrictions caused by pulling of the material under the arms were recorded only during the execution of movements marked with symbols (c) and (d), with such comments reported only by 1 participant. Comparing the results obtained (***Figure 3***) with those for the firemen's clothing (***Figure 2***), it can be concluded that the execution of the above movements, i.e. (b), (d), (e), and (c) in protective clothing against chemicals received a smaller number of negative assessments during the survey, which evidences its better ergonomic properties.

In the case of protective clothing against chemicals when stooping to reach for a small object lying on the floor (g), 3 participants complained about pulling of the suit material at the level below the waistline. These restrictions were assessed as minor (1 point). In the case of the same movement executed in reference clothing, a negative response with a 1 point rating was obtained only from 1 of the participants. However, the participant did not indicate what the cause of the discomfort was.

When performing squats (i) in protective clothing, as many as 4 participants experienced discomfort extending from the shoulders, through the back and down to the crotch. In all these cases the inconvenience was rated at the level of 1 point. The same number of negative assessments was obtained during the execution of movement (k). The reported cause of the discomfort was pulling of the suit

material at the height of the loins or in the crotch. In the case of the reference clothing, minor restrictions were experienced by 2 participants when performing both movements, but only in the case of (i) was the cause of the discomfort specified, i.e. pulling of the trouser fabric at the level of the thighs.

Relatively many negative assessments (i.e. 4) in the case of clothing protecting against chemicals and a little fewer in the case of the reference clothing (i.e. 3) were obtained for exercise (j), involving kneeling on one and both knees. While testing the protective clothing, none of the participants identified the cause of the discomfort. However, in the case of the reference clothing gentle pulling of the trouser material in the crotch was experienced when performing a stride.

While climbing the stairs (movement a), as well as when walking on the treadmill (movement l) in protective clothing, 4 to 5 participants complained about too long and too wide trouser legs, which tangled and caught each other. Common restrictions were usually regarded as small (1 point), but 1 of the participants assessed them at level 2, indicating a higher level of discomfort. As mentioned above, similar restrictions also occurred during the tests of protective clothing for firefighters. In the case of the reference clothing, a negative response of point 1 was given by only 1 participant.

Clothing functionality during physical activities carried out within the framework of the extended module (EM)

Due to the fact that the variants of protective clothing analysed are assigned to the group of protective clothing with a complex structure, it was proposed that they should be assessed not only during the execution of the basic movements, but also during the performance of activities simulating movements characteristic of the specific type of protective clothing. Results of the research concerning the functionality of the variants of protective clothing assessed and the reference clothing compared with them during the execution of professional activities, have been illustrated in the form of bar charts, (***Figure 4*** and ***5***), showing the total number of negative responses of the test participants to survey question 1 of the EXTENDED MODULE.

Protective clothing for firefighters

The tests demonstrated that when performing all four movements as part of the extended module, at least 4 out of 5 participants testing the garment that protects against chemicals experienced discomfort.

Most of the negative assessments were obtained for climbing up and down the ladder (c). The participants complained, among others, about too wide trouser legs, tangling with each other, as well as about pulling of the jacket material at the elbows and on the back. The restrictions were assessed in 2 out of 5 cases at the level of 2 points, indicating difficulties when this type of action is executed. During execution of the same movement in the reference clothing, a negative response was given by only 1 participant, but without indicating the cause of the discomfort.

Inconvenience caused by the tangling and catching of the trouser legs of firefighter clothing also appeared during the movement marked with symbol (a). In 3 out of 5 cases, these limitations were awarded a score of 1 point, and 1 of the participants assessed it at the level of 2 points. When carrying out a similar activity in the reference clothing, a negative response of 1 point was indicated by 2 participants. However, none of them specified the cause of the discomfort.

During 5-minute crawling on a horizontal surface (b), as well as unwinding and rewinding the fire hose (d), limitations of movement were reported by 4 participants, with greater inconvenience experienced during execution of the movement marked with symbol (b). During this type of movement, 2 subjects felt difficulty, rated by choosing the survey answer for 2 points. In other cases, the movement restrictions were rated at the level of 1 point. During movement (b) executed in the reference clothing, 2 participants had problems associated with the slipping of the jacket from the abdominal surface. In both cases, these restrictions were assessed at the level of 1 point. In contrast, while unwinding and rewinding the fire hose (movement d) in clothing of that type, 1 of the participants felt a slight discomfort caused by the gentle pulling of the jacket material at the height the shoulders. Other participants did not report any irregularities.

Protective clothing against chemicals

The test results obtained for clothing protecting against chemicals indicate that during the execution of the particular movements within the framework of the extended module, at least 3 out of 5 participants experienced restrictions of movement.

As is apparent from ***Figure 5***, most of the negative assessments in the case of protective clothing were obtained during filling of the basket with pieces of rubber in the kneeling position (kneeling on 1 knee) (b). Restrictions of that movement were reported by 4 participants, 2 of whom an answer for 2 points. Most often the cause of the discomfort was identified as pulling of the suit material under the arms and on the back. In addition, some participants felt light tension of the hood along the seam line in the middle and pressure on the front of the neck. When carrying out a similar activity in the reference clothing, concerns were reported by 3 participants. Gentle pulling of the trouser material at the level of the thighs or crotch was indicated as the cause of the discomfort experienced. In all these cases, the restrictions were assessed at the level of 1 point.

During the tests of protective clothing, the same number of negative assessments (i.e. 4), but less intensive than in the case of movement (b), was obtained for the activities simulating collecting oil, liquids or granules using an aspirator (d). As follows from the responses given by the participants, the discomfort was associated with pulling of the suit material under the arms, and also in the rear part within the section extending from the shoulders through the back and down to the crotch or on the back rise. Comments of that type were also made during the execution of movement (c). However, in this case, the number of negative assessments amounted to 3. The restrictions experienced were rated as minor (1 point score). In the case of reference clothing, movement (c) was assessed by 2 participants as associated with the gentle pulling of the jacket material under the arms and on the back. On the other hand, a negative response concerning movement (d) was given by only 1 participant, but without indicating what the reason for discomfort was.

When climbing up and down the ladder (a) in protective clothing, 3 study par-

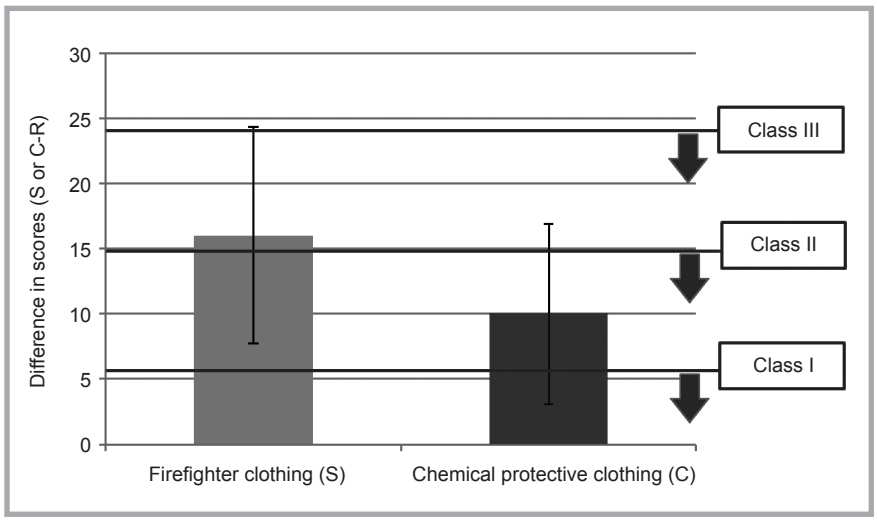

Figure 8. *Comfort classes of the assessed protective clothing variants.*

Table 4. *Determination of the comfort class of firefighter protective clothing and protective clothing against chemicals.*

	Kind of clothing	Mean points scored (± SD)	Difference: (S-R) or (C-R)	Comfort class of protective clothing
Test 1	Firefighter clothing (S)	22 ± 5.5	16	Comfort class III
	Reference clothing (R)	6 ± 6.0		
Test 2	Chemical protective clothing (C)	14 ± 7.2	10	Comfort class II
	Reference clothing (R)	4 ± 3.3		

ticipants complained about pulling of the suit material under the arms and on the back. They also indicated a too low position of the crotch as the reason for discomfort. In all cases, the restrictions of movement were assessed as minor (1 point score). When carrying out the same activity in the reference clothing, minor restrictions were reported by 2 participants, but without indicating the reasons for discomfort.

Testing and assessment of the comfort of use of the garments according to the basic module (BM)

The protective and reference clothing were also tested in terms of the overall comfort of use. Test results for the individual variants of protective clothing and reference clothing have been illustrated in the form of bar charts (***Figures 6*** and ***7***), presenting the total number of negative responses to survey questions 2-9 from the BASIC MODULE.

Protective clothing for firefighters

All participants in the study admitted unanimously that the protective clothing assessed for firefighters, as well as the reference clothing can be put on and taken off easily without the help of another person, as evidenced by the lack of negative assessments in the chart above for survey question 2 (***Figure 6***).

In the case of the protective clothing assessed, the fasteners applied to it were an important problem. The survey shows that as many as 3 out of 5 participants assessed the functionality of the fastenings at the lowest level of 3 points (answers to question 3). Most difficulties were associated with the system of adjustment of the trousers' suspenders. In addition, 2 participants had further problems with fastening the zip at the bottom. In contrast, no irregularities in this area were reported when the reference clothing was tested.

The question concerning garment fit to the body (question 4) in the case of protective clothing was answered negatively by only 1 participant, claiming that all the set tested was too tight. In contrast, the reference clothing was positively assessed in terms of fit by all the participants of the study.

The next survey question (question 5) was: *Does the clothing cause compression, impairment of blood flow?* In the case of protective clothing for firefighters the answer ' yes ' for 2 points (indicating the presence of minor pressure) was given by only one participant. He did not indicate, however, the location of the pressure. In the case of the reference clothing, none of the participants made comments.

Question 6 concerned the correctness of the location of such clothing elements as the armpits or crotch. ***Figure 6*** shows that as many as 4 out of 5 assessed the firefighter clothing negatively in response to this question. One of the participants said that he had experienced considerable difficulties in carrying out the movements, due to the incorrect placement of these elements (the answer for 2 points), while the other participants had experienced only minor difficulties (1 point score). In the case of the reference clothing, no comments concerning the location of the armpits and crotch were reported.

In the next survey question, the study participants assessed whether the protective or reference clothing had any sharp edges, projections, rough surfaces, fasteners, seams, etc., that might interfere with the execution of movements. In the case of protective clothing for firefighters, the presence of these types of elements was reported by 1 participant only; however, he did not identify their specific names or locations in the garments. He claimed that these elements caused minor difficulties during the execution of movements (a 1 point response). In the case of the reference clothing, none of the participants reported the presence of such elements.

Survey question 8: *Did the clothing cover the particular parts of the body at rest and during the test activities?* was answered negatively in the case of firefighter clothing by 2 participants, 1 of whom had a problem with slipping sleeves only when executing movements, whereas in the case of the other participant, the problem of too short sleeves and trouser legs was present already at rest and exacerbated during the execution of movements. In the case of the reference clothing, 1 of the participants found that the jacket sleeves were sliding off his wrists, but only during the execution of movements.

The last survey question (question 9) concerned the compatibility of the clothing with other personal protective equipment, i.e. gloves and protective footwear of the boot type. As follows from the survey carried out among the participants, both the protective clothing for firefight-

ers and the reference clothing were compatible with the aforementioned PPE.

Protective clothing against chemicals

As is apparent from the chart above, protective clothing against chemicals was evaluated negatively only in response to 3 questions, i.e. 4, 5 and 6. However, in the case of the reference clothing, there were no irregularities in terms comfort of use.

Irregularities with respect to protective clothing fit to the body was reported by 2 subjects (question 4), one of whom claimed that the suit tested was too loose, while the second perceived only the part below the waist as too loose.

In question 5, the participants ranked the clothing with respect to pressure or impairment of blood flow. As demonstrated by the tests, in the case of protective clothing against chemicals, this problem occurred only in 1 participant. Compression of the head due to tightness of the hood was mentioned as the reason for discomfort, but it was rated as minor (2 points).

Incorrect placement of the crotch (question 6) was a big problem in the case of protective clothing against chemicals. Comments on this issue were reported by as many as 3 out of 5 participants. In all these cases, the reason for discomfort was too low position of the crotch. As follows from the surveys, major difficulty in the execution of movements was reported by only one participant (the answer for 2 points), while the other 2 had experienced only minor inconvenience (1 point scores).

The comfort class

The ultimate result of the ergonomic assessment of the clothing was its assignation to an appropriate class of comfort based on the survey results discussed above. The criterion taken into consideration was the difference between the number of points awarded to the protective and reference clothing. ***Table 4*** shows how to designate the classes of comfort of the individual protective clothing variants. The classes of comfort determined have been presented in the form of a bar chart (***Figure 8***).

Based on the results obtained, the protective clothing for firefighters assessed can be assigned comfort class III (***Figure 8***). Slightly better ergonomic properties were demonstrated by protective clothing against chemicals, as evidenced by its assignation to comfort class II. It can therefore be concluded that the indicator of the comfort of protective clothing in the form of a comfort class proposed allows a quantitative ergonomic assessment of protective clothing; however, it is necessary to take measures to limit the dispersion of the replies given by the test participants. A considerable diversity of the test results is reflected by the variation coefficient, which in the case of protective clothing for firefighters was over 50%, and in the case of protective clothing against chemicals – approximated 68%. It is advisable, therefore, that while selecting the participants for ergonomic studies, attention should be paid to psychological aspects, e.g. to their personality, which could contribute to reducing the dispersion of responses.

Conclusions

In conclusion, it can be said that the modular concept of testing and ergonomic assessment of protective clothing proposed in this publication is an appropriate approach because it allowed to evaluate the ergonomic properties of different types of protective clothing, i.e. protective clothing for firefighters and against chemicals, taking into account foreseeable conditions of use and the specifics of professional activities for which they are designed.

As expected, the research carried out in accordance with the new methodology allowed to perceive any construction errors in the clothing and inconvenience resulting from it. Based on tests carried out within the framework of the basic module, the overall convenience of protective clothing use was evaluated, as well as its functionality when basic operations are performed. In turn, the tests carried out within the framework of the extended module allowed to assess the functionality of protective clothing during the execution of movements simulating typical activities carried out in real working conditions.

The sets of exercises proposed for the test participants should be evaluated positively, because they allowed to locate clothing design flaws, as well as to assess the selection of the design and size of clothing for the anatomy of the test participants.

The application of a reference variant in the form of reference clothing in the methodology of ergonomic studies allowed a quantitative assessment of the aforementioned variants of protective clothing by assigning them to a specific comfort classes. In accordance with the assessment criteria adopted, the protective clothing for firefighters assessed is assigned to comfort class III, whereas the protective clothing against chemicals, due to the fact that it showed slightly better ergonomic properties, was placed in comfort class II.

The study has demonstrated that the criteria adopted for assessment of the comfort class of protective clothing are appropriate, as they enabled a proper differentiation of the variants of protective clothing tested in terms of ergonomic properties. At the same time, the study has shown that the choice of test participants, taking into account psychological aspects such as their personality, is very importance for proper assessment of clothing. This would reduce the significant dispersion of the responses provided by the participants.

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