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REACTION OF THE FEMALE BODY TO STRESS IN A CHEMICAL PROTECTIVE CLOTHING

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Research article

Abstract: This article deals with the reaction of the female body to the use of an insulation chemical protective clothing combined with working - thermal and mental stress to which the female is exposed. The article provides a concise overview of protective chemical clothings and factors affecting their comfort; it describes the regularities corresponding to the physiological reaction, important for the body's reaction to the use of a chemical protective clothing. Further, the article contains a description of the measurement and evaluation of physiological parameters of non-acclimated women during testing of these clothings and, finally, comparison with the results for males under the same stress which is unfavourable for women.

Keywords: Female body, protective chemical clothing, climate chamber, heat stress.

Introduction

The surrounding world, with its hazards of industrial and traffic accidents, terrorism, ecological catastrophes, epidemics and even international conflicts requires personal protective equipment which is essential for specialists who remove hazards to persons, property and the environment. This applies mainly to fire rescue departments, special army units, special medical centres and other laboratories and institutions which are confronted by, and work with, such hazards. All such personnel must be acquainted with this equipment and must know how to use the same in order to protect themselves and to reliably remove any potential hazard. In light of the above it is clear that such situations will not only be faced by men, but that a growing number of women will be involved who will focus mainly on monitoring, controlling decontamination efficiency or attending to injured persons. Therefore, they will also be exposed to the negative impacts related to the use of chemical protective equipment.

The aim of chemical protective equipment is to protect persons against the dangerous effects of the external environment. However, that is only the so-called protective side of the matter, where the equipment provides a protective barrier for safe work. The other aspect of this issue is the provision of heat comfort, i.e. essential heat balance, which is quite natural without the use of protective equipment because it can be controlled by varying the amount of clothing or bodily coverage. However, this is impossible in protective equipment, especially in insulation equipment such as special protective clothings, so-called first response equipment. Depending on the physical exertion, ambient climatic conditions, but also on the mental exertion in extraordinary situations, the human body can quickly overheat, which can endanger the health of the clothing user just like in the case of intoxication from the external environment (Goldman, 2007). There are many studies documenting the reaction of firefighters or soldiers in such situations, but almost no special surveys on the behaviour of women in such situations (Montain et al., 1994). This article provides the results obtained from testing only women in a special protective clothing.

Types of protective clothings

Protective clothings are divided mainly according to the hazard to which persons using the clothing can be exposed. The highest hazard level is an environment with an unknown substance in various states of matter, concentration and life-threatening risk. In these cases, persons use only special clothings with autonomous breathing,

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which absolutely isolate the environment inside the clothing from the surrounding environment. If the concentration and type of substance is known, or if it is only in a liquid state, less sophisticated protective clothings are used, not airtight clothings which do not require autonomous breathing apparatus, but only filter the supplied air, or filtration clothings for trapping aerosol or low concentrations of vapours, or common working clothings with a protective face mask and gloves (Anna, 2003). The heat stress corresponds to the above, where it is highest in the case of insulation clothings, especially with breathing apparatus integrated under the clothing, where moist air is also expelled inside the clothing (ISO 7243, 1989). The insulation materials (airtight) used for clothings are typically polymers and elastomers, selected according to the type of chemical substance; e.g. fluorine-rubber, butyl-rubber, nitrile-rubber, polysulphonated rubber, chloroprene rubber, polyethylene phthalate, polytetrafluoroethylene, polyvinyl chloride, but also polyethylene and polypropylene. In most cases the clothing is a system of several layers (e.g. butyl-rubber and fluorine-rubber), such as clothings from Draeger, Trellchem, and Auer, or polypropylene and polytrifluoroethylene (Tychem F), which provide for high barrier protection against most chemical substances, including military substances. In the Czech Republic clothings are produced on the basis of halogenated rubber (bromobutyl-rubber), e.g. OPCH 90PO or Sunit.

Besides the material itself, another important aspect is the clothing design, which must not be tight, due to the inelasticity of the material, because this would restrict movement, but it must also not be too loose, as this would impede necessary movement. The type of material, or its weight respectively, and also design affect the physical stress of the user (Zimmerli, 2000).

Factors impacting comfort in the clothing

A human being is able to tolerate an internal temperature (so-called core temperature) of only 4°C, without it impacting his/her optimal physical and mental abilities. If the normal core temperature is 37°C, then an increase to 41°C already borders on life-threatening conditions because it can lead to irreversible cellular tissue changes and irreversible damage of the brain, liver and kidneys (Kerslake, 1972). The reason is the production of the metabolic temperature M which is a result of the metabolism. This heat increases with physical stress (physical work) W. As the mechanical efficiency of physical work reaches a maximum of 25% of the total energy production, the excess heat energy (metabolic heat) must be discharged to the environment because the body core temperature must be maintained in a narrow range of 4°C, ideally at 37°C. No difference is made between men and women. A naked person has several mechanisms to provide for the above: radiation R, convection C, contact L and evaporation E. However, depending on the surrounding conditions, the said factors can discharge or even supply heat; with the exception of perspiration (Montain et al., 1994). Therefore, an energy balance expressed as follows applies (1):

$$M - W = \pm R \pm C \pm L + E + \Delta S \qquad (1)$$

where: ΔS - is the discharged heat which is accumulated in the body. This heat increases the body core temperature because it reduces the difference between the internal temperature and skin temperature, as heat cannot be transferred to the surrounding environment. A protective clothing which creates a barrier against the incursion of dangerous substances is also a barrier, because it reduces or even eliminates the respective cooling factors, the better the insulation from the surrounding environment. This is the case of special clothings which prevent more intensive cooling by perspiration because they prevent evaporation of sweat (McLellan et al., 2013).

The result is the accumulation of heat and an increase in the internal temperature measured most appropriately in the recta (t_{re}) and the related increase in the average skin temperature (t_s) and increase in heart rate (*HR*). An increase in the *HR* is the result of physical stress and mental strain, and also an increased strain on the blood circulation for cooling the blood in the skin. Therefore, limit values are set for the safe use of protective clothings, i.e. rectal temperature t_{re} = 38.5°C and heart rate *HR* = 220 - age.

One of the parameters which use the rectal temperature and heart rate to evaluate stress of the body in a protective clothing from data measurement is the *PSI* index (physiologic strain index), which can be calculated according to formula (2). It ranges from 0 to 10, where higher values mean a greater stress of the body during activity.

$$PSI = 5\left(t_{re} - t_{re0}\right) / (39.5 - t_{re0}) + \\ +5\left(HR - HR_0\right) / (180 - HR_0) \qquad (2)$$

where: t_{re} - is the rectal temperature in time τ [°C], t_{re0} - is the rectal temperature at the start [°C], 39.5 - is the rectal temperature limit value [°C], *HR* - is the heart rate in time τ [beats.min^{-1}], H_{R0} - is the heart rate at the start [beats.min^{-1}], 180 - is the heart rate limit value [beats.min^{-1}].

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Tab. 1 Classification of stress to *PSI* and corresponding *HR* and t_r values

Body stress	*PSI*	Heart rate *HR* [beats/min]	Rectal temperature t_r [°C]
None/minor	0 1 2	71 90 103	37.1 37.1 37.3
Low	3 4	115 125	37.6 37.8
Medium	5 6	140 145	38.0 38.3
High	7 8	159 175	38.6 38.7
Very high	9 10	180	39

Materials and methods

Measurements were performed at National Institute for Nuclear, Chemical and Biological Protection in Příbram in a climate chamber controlled by a control unit from Moravské přístroje a.s. (Czech Republic). The required microclimatic conditions in the climate chamber are controlled by computer via complex technological equipment enabling, for example, simulation of tropical or arctic environments. The chamber provides for a temperature range of -35°C to +70°C for testing persons. Relative humidity can be set up to 100% and air flow speed up to 5.5 m/s. (See diagram in Figure 1).

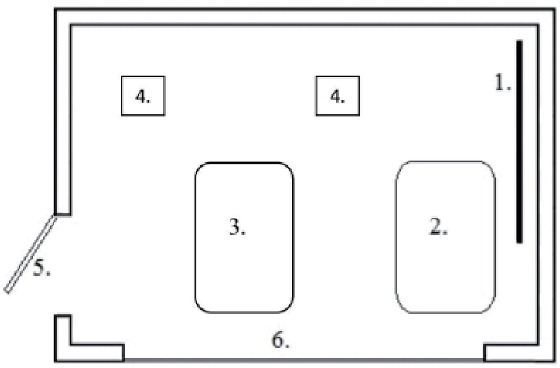

Fig. 1 Climate chamber diagram
1 - Heat emitter, 2 - Treadmill No. 1, 3 - Treadmill No. 2, 4 - Resting chair, 5 - Entrance, 6 - Inspection window

The following measuring and recording equipment was used to measure the microclimatic conditions inside the chamber and monitoring of the physiological parameters of probands:

- Almemo, type 3290-8, multipurpose apparatus. Produced by Ahlborn (Germany) for measuring the mean radiation temperature (t_r - using a spherical thermometer); in the external environment and for measuring the skin surface temperature using special sensors (thermocouples).

  Range of measurement: t_r: from -50°C to 200°C, accuracy 0.01°C; Thermocouple: from -30°C to 100°C, accuracy 0.01°C.
- Temperature (t_a) and relative humidity (*rh*) recorder Comet, type S3120, produced by Comet System s.r.o. (Czech Republic) for measuring air temperature (internal and external environment, including the space inside the insulation clothing).

  Range of measurement: t_a: from -30°C to 70°C, accuracy 0.1°C; *rh*: from 0% to 100%, accuracy 0.1%.
- Personal scales SOEHNLE S10-2720, produced by SOEHNLE (Germany) for measuring the weight of probands (weight decrease for calculation of perspiration loss).

  Range of measurement: 0-200kg, accuracy 100g.
- Mercury tonometer sphygmomanometer, produced by Labtron (Japan) for measuring the blood pressure of probands.

  Range: 0-300 mmHg.
- Viridia system (Cardiomonitors V24E), produced by Philips (Germany) for displaying the heart rate and rectal temperature of probands during the tests in the climate chamber. These values are stored on a computer hard disk.
- Treadmill ergometer Lauband LE 3000 and Laufergotest LE3, produced by Jaeger GmbH (Germany) for simulation of physical stress (walking) in the climate chamber.
- Mechanical stopwatch Kienzle (Germany) for recording the time frame of tests of probands.

To determine the reaction of the body to the use of a chemical protective clothing the tests were conducted using the OPCH 90 PO clothing, which is one of the most commonly used chemical protective clothings by fire rescue departments. OPCH 90 PO is a gas-tight, overpressure, sealed chemical protective clothing, yellow in colour, which comprises a one-piece suit with hood, which has an integrated panoramic visor, see Figure 2. The suit is designed with a pouch for a self-contained breathing apparatus. The suit is closed using a longitudinal gas-tight zipper, protected by a protection flap (Kratochvíl and Kratochvíl, 2007).

Fig. 2 OPCH 90 PO chemical protective suit and close-up of the visor

The suit is finished with integrated socks which slide into a pair of high boots which provides for dual protection of the feet. The boots have steel reinforcement in the sole and tip. The external cuff with elasticized end of the suit's leg is pulled over the boots to prevent liquids running into the boots, e.g. during contamination. The protective rubber gloves are not an integrated part of the suit (Kratochvíl and Kratochvíl, 2007).

The clothing is shaped for use with all types of self-contained breathing apparatus connected to a face mask. The self-contained breathing apparatus is worn under the chemical protective clothing. Expelled air from the breathing apparatus fills the inside of the clothing. Pressure relief valves on the clothing ensure a slight overpressure inside the clothing which increases its safety against incursion of hazardous substances into the chemical protective clothing. The clothing size is universal for persons up to a height of 190 cm and weight of 100 kg (Kratochvíl and Kratochvíl, 2007).

Probands

Measurement was performed with 4 women of an average age of 21 years, designated further in the document as D1 - D4. Their anthropometric values, incl. BMI (Body Mass Index) and physical fitness level results, based on a performance test, and heat resistance are shown in Table 2. The heat resistance of the probands was evaluated on a scale of 1 - 5, where the values were allocated the frequency of visits to a sauna (1 - at least twice a week; 5 - never). Their final values were compared with the results measured at the same working-heat stress only in underwear without the use of a chemical protective clothing, where the weight of the underwear, including shoes, was 1.1 kg, as well as with the results for men determined in earlier measurement projects.

Tab. 2 Anthropometric parameters of probands

Probands	Age [years]	Weight [kg]	Height [m]	BMI coefficient [kg/m²]	Fitness level	Heat resistance
D1	21	84.4	1.70	29.20	2	5
D2	22	70.2	1.66	25.48	1	3
D3	20	69.0	1.72	23.32	2	4
D4	21	73.1	1.66	26.53	2	5

Prior to testing in the climate chamber the probands were subject to a performance test, medical examination and they signed a form in which they were informed about the course of the testing. They were weighed, had pressure measured, attached sensors for measuring temperature and heart rate and were dressed into underwear and the chemical protective clothing. The progress of the respective steps is documented in Figure 3. The total weight of the chemical protective clothing, including breathing apparatus, was 25.3 kg.

Fig. 3 Preparation of probands for measurement

During the experiment the following parameters were monitored: body core temperature using a rectal thermometer (t_r), heart rate (*HR*), skin temperature

(t_s) calculated to ISO 9886 (ISO 9886, 2004) as the weighted average of the respective values from eight measurement points (forehead, right shoulder blade, chest, right arm, left arm, left hand, right thigh, left calf), temperature inside the clothing (t_o) and relative humidity inside the clothing (r_h).

Based on previous tests, the physical stress for testing in the climate chamber was selected as walking at a speed of 4 km/h on a treadmill with a gradient of 10%.

Results

The thermal-humidity conditions during the respective experiments were always kept the same, see Table 3.

Tab. 3 Thermal-humidity conditions in the climate chamber

Air temperature [°C]	40
Relative humidity [%]	16
Air flow speed [m.s^{-1}]	0.2

The average production of sweat converted to an hour did not change much during the various stages and was about 1.38 l/h. The average skin temperature at the end of the stress was 37.0°C to 37.9°C for the first experiment, respectively 37.2°C to 38.0°C for the second experiment, which means an increase of 3.7°C to 4.7°C in the first experiment, respectively 4.6°C to 5.6°C in the second experiment when compared to the initial temperature. The heart rate values at the end of the measurement nearly reached the maximum values, i.e. 198 - 200 beats/min. Also, the body core temperature measured in the rectum reached the limit value of 38.5°C in most cases. In other cases, when the tests were interrupted at the request of the proband due to unbearable heat, the rectal temperature was 38.1°C to 38.3°C. In the second experiment all the indicators showed lower values than in the first experiment. The rate of body stress evaluated using the *PSI* index was 4 - 8, which indicates medium to high stress. The probands also evaluated the heat stress subjectively using a questionnaire as 1 and 2 most often (slightly hot to hot, i.e. medium to high stress inducing medium intensity unpleasant subjective feelings; however which can be tolerated for a relatively long period of time). This also corresponds to the evaluation of the environment which was evaluated as acceptable in 75% cases.

The minimum and maximum, respectively start and end values of physiological indicators: body core temperature measured in the rectum (t_r), heart rate (*HR*) and skin temperature during the respective experiments are shown in Tables 4 and 5.

Tab. 4 Results of all probands 1st test day

Test in OPCH90 PO clothing	**Code D1**	**Code D2**	**Code D3**	**Code D4**
Start/end *HR* [beat.min^{-1}]	104/172	88/186	112/190	104/165
Start/end *RT* [°C]	38.0/38.3	37.8/38.5	38.2/38.5	38.2/38.5
Start/end skin temperature t_s [°C]	33.4/37.1	33.3/37.6	32.8/37.0	33.3/37.9
Test duration [min]	17	23	19	25
PSI	5	7	7	5
Reason for test termination	Unbearable heat	Limit *RT*	Limit *RT*	Limit *RT*

Tab. 5 Results of all probands 2nd test day

Test in OPCH90 PO clothing	**Code D1**	**Code D2**	**Code D3**	**Code D4**
Start/end *HR* [beat.min^{-1}]	110/179	79/130	99/198	82/133
Start/end *RT* [°C]	37.5/38.3	37.7/38.1	38.1/38.5	37.6/38.1
Start/end skin temperature t_s [°C]	32.5/37.9	32.4/38.0	32.6/37.2	32.4/37.6
Test duration [min]	25	36	23	36
PSI	7	4	8	4
Reason for test termination	Unbearable heat	Unbearable heat	Limit *RT*	Unbearable heat

The tables below show complex data for determining the stress of male and female bodys in underwear, without chemical protective clothing stress.

Tab. 6 Demonstration of complex data for selected person - male: 47 years, acclimated proband; weight 79.4 kg, body surface 1.98 m^2, perspiration loss 233.1 g.m^{-2}.h^{-1}, *PSI* in 25th min. = 2

Technical underwear, acclimated male					
t_a **[°C]**	t_w **[°C]**	v_a **[m.s^{-1}]**	***WBGT* index [°C]**	***w* [km.h^{-1}]**	***f* [%]**
40	22.1	0.2	27.4	4	10
W_{ext} **[W.m^{-2}]**	***M* [W.m^{-2}]**	***τ* [min]**	t_r **[°C]**	***SF* [beat.min^{-1}]**	***PSI***
44.6	132.4, 183.9/ 1st stress/	65 (max. test duration	37.3	86	2

Note: t_a - ambient temperature; t_w - psychrometric temperature; v_a - air flow rate; *WBGT* index - calculated temperature of moist spherical thermometer according to formula $WBGT = 0.7\ t_w + 0.3\ t_a$; $W_{ext} = 0.163 m_b \cdot V \cdot f/S_D$ (mechanical work); f - relative gradient of terrain (treadmill); w - walking speed; S_d - body surface (1.8 m^2).

Tab. 7 Demonstration of complex data for selected person - female: 23 years, acclimated proband; weight 70.5 kg, body surface 1.8 m^2, perspiration loss 256.2 g.m^{-2}.h^{-1}, *PSI* in 25th min. = 4

Technical underwear, acclimated female					
t_a [°C]	t_w [°C]	v_a [m.s^{-1}]	***WBGT* index [°C]**	w [km.h^{-1}]	f [%]
40	22.1	0.2	27.4	4	10
W_{ext} [W.m^{-2}]	M [W.m^{-2}]	τ [min]	t_r [°C]	***SF* [beat.min^{-1}]**	***PSI***
43.7	140.9, 185.4/ 1st stress/	65 (max. test duration)	38.0	173	6

Note: t_a - ambient temperature; t_w - psychrometric temperature; v_a - air flow rate; *WBGT* index - calculated temperature of moist spherical thermometer according to formula $WBGT = 0.7\ t_w + 0.3\ t_a$; $W_{ext} = 0.163 m_b \cdot V \cdot f/S_D$ (mechanical work); f - relative gradient of terrain (treadmill); w - walking speed; S_d - body surface (1.8 m^2).

Demonstration of complex data for selected person - non-acclimated female - is shown in Table 8.

Tab. 8 Example of complex results for one person

Insulation overpressure clothing OPCH90 PO, non-acclimated female					
t_a [°C]	t_w [°C]	v_a [m.s^{-1}]	***WBGT* index [°C]**	w [km.h^{-1}]	f [%]
40	20.4	0.2	26.1	4	10
W_{ext} [W.m^{-2}]	M [W.m^{-2}]	τ [min]	t_r [°C]	***HR* [beat.min^{-1}]**	***PSI***
5.0	317.9, 360.2/ 1st stress/	22 (limit *RT*)	38.5	186	7

Underclothing temperature and air humidity - non-acclimated female			
Test start		**Test end**	
t_a [°C]	*rh* [%]	t_a [°C]	*rh* [%]
26	61	33	94

Note: t_a - ambient temperature; t_w - psychrometric temperature; v_a - air flow rate; *WBGT* index - calculated temperature of moist spherical thermometer according to formula $WBGT = 0.7$ tw $+ 0.3\ t_a$; $W_{ext} = 0.163 m_b \cdot V \cdot f/S_D$ (mechanical work); f - relative gradient of terrain (treadmill); w - walking speed; S_d - body surface (1.8 m^2).

Tab. 9 Reaction of male to physical and climatic stress in OPCH 90 PO

Insulation overpressure clothing OPCH90 PO, acclimated male					
t_a [°C]	t_w [°C]	v_a [m.s^{-1}]	***WBGT* index [°C]**	w [km.h^{-1}]	f [%]
40	20.4	0.2	26.1	5	10
W_{ext} [W.m^{-2}]	M [W.m^{-2}]	τ [min]	t_r [°C]	***HR* [beat.min^{-1}]**	***PSI***
74.8	292.2, 367.4/ 1st stress/	45 (limit *RT*)	38.5	170	7

Underclothing temperature and air humidity - acclimated male			
Test start		**Test end**	
t_a [°C]	*rh* [%]	t_a [°C]	*rh* [%]
27	60	34	100

For the comparison of measured values of non-acclimated females with data acquired for a group of males, it is necessary to show the data measured for the group of males. These men were dressed in Ribano underwear and the OPCH90 PO clothing. The measured values are shown in Table 9. The men's parameters were an average weight of 83.2 kg, body surface of 1.99 m^2, with a perspiration loss of 604.2 g.m^{-2}.h^{-1}. The microclimatic conditions were the same as for the tested females: t_a 40°C, *rh* 15%, v_a 0.2 m.s^{-1}.

The comparison of measured values between males and females provides the calculated *PSI* index values, which is an indicator of the body's stress during activity, in the 25th minute of testing - 7 for females and 4 for males.

Discussion

The evaluation of the permissible time of females in a chemical protective clothing of the insulation type such as OPCH 90 PO cannot be made without comparing the time spent by males in the same clothing. As the results in Tables 6 and 7 show, where under the same conditions and stress, the compared reaction of an acclimated male and female during work in underwear, comparable in age to the students, the difference is very small. The used underwear is used as an underclothing inside the protective clothing, an elastic layer over the whole body, without stressing the body by its weight, and very permeable for sweat, so that it enables cooling by evaporation. The *PSI* complex indicator, over the same period of time spent in the environment, shows a difference of four grades compared to females. Although there is not a great difference in the metabolic output, there is a significant difference for females in the increase in rectal temperature and heart rate. It is likely that in the case of females the psyche plays a role because the starting heart rate compared to males is over 100 beats per minute and the rectal temperature exceeds 37°C.

This is confirmed by the testing of probands in the OPCH 90 protective clothing. Comparison of a male and female in the same clothing and under the same conditions (viz Tables 8, 9) shows that the permissible clothing-use time was significantly shortened (almost by half), where women are often forced to abandon testing for subjective reasons (unbearable heat) or due to reaching the rectal limit temperature, which women reach after 20 minutes, while in the case of men the reason for abandonment is exclusively the limit temperature, however, reached after double the time compared to women. In this case it is necessary to compare the *PSI* values at the time of test termination by women, when the differences between men and women are at least three grades higher to the detriment of women. If lower *PSI* values were determined for women, it was only in the case of premature test termination, which did not reach even the comparable period of 20 minutes.

Conclusion

The results of the experiment, which investigated the reaction of the female body to the use of a protective clothing for specialists (OPCH 90), showed that this matter requires further attention, and this work can be considered as a pilot project. Although the conditions were extreme (40°C), in comparison to results for testing in underwear only (no additional stress), the reaction of objective *PSI* indicators is significantly higher, which can most probably be attributed to higher mental stress. This stress was particularly noticeable during testing in the protective clothing, where additional stress, mainly the conditions inside the clothing (high temperature at 100% humidity), led to premature abandonment of testing, in comparison to male testing.

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