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Research article

ASSESSING FUNCTIONAL STATE OF THE BODY WHEN WEARING A REUSABLE PROTECTIVE SUIT TO MINIMIZE RISKS OF CONTAGION AMONG MEDICAL PERSONNEL

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Personal protective equipment has become the last line of protection for medical personnel during the pandemic of the new coronavirus infection since it allows minimizing risks of biological contagion. Given the existing staffing shortage, medical workers have to spend from 4 to 12 hours a day in the "red zone" where they necessarily wear personal protective equipment. Protective clothing is known to produce negative effects on functional state of the body and personnel's working capacities. Assessment of up-to-date protective suits will allow developing recommendations on their suitable application bearing in mind a balance between necessary protection, providing favorable ergonomics, and reducing risks of adverse effects on functional state and working capacities.

Our research aim was to hygienically assess health risks for medical workers who had to wear reusable protective suits.

Our research object was a reusable suit made from polyether fabric with polyurethane membrane coating and antistatic threads. We performed an experiment aimed at evaluating thermal state of the body, psychophysiological state, and responses by the volunteers' cardiorespiratory system in laboratory conditions during an 8 hour working shift under controlled microclimate. Participants in the experiment were questioned in order to assess suits' ergonomics.

Heat exchange dynamics and amount of changes in thermal physiological parameters caused by wearing a protective suit determined heat contents of volunteers' bodies that conformed to optimal standard values. Data on psychophysiological and mental state taken in research dynamics didn't have any statistically significant changes. Gas exchange indicators naturally grew during the "load" phase; however, there were no significant changes detected in any phase in the research.

Hygienic assessment of the thermal state, functional state of the cardiovascular and respiratory systems, and psychophysiological indicators confirmed that wearing a protective suit was quite safe and didn't involve any health risks for volunteers.

***Key words**: personal protective equipment, health risk, thermal state of the body, functional state of the body, gas exchange, psychophysiological indicators.*

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On March 11, 2020 the World Health Organization (WHO) declared the beginning of a new coronavirus infection pandemic which involved the necessity to provide additional beds in hospitals for treating patients with it. Staffing shortages resulted in greater loads on medical personnel who were engaged in treating people with the infection regardless of their specialty or a position [1, 2]. Given that the new infection was assigned into the second group of pathogenicity (according to the classification accepted in the Russian Federation) and there were scarce data on how this new infection was transmitted, wearing personal protective equipment (PPE) was considered obligatory for minimizing risks of biological contagion [3, 4]. Since there was apparent staffing shortage in medical organizations, medical workers had to spend from 4 to 12 hours a day working in protective suits in "red zones" [5–8].

Most materials PPE is made from have low air and vapor permeability and this creates favorable conditions for the body getting overheated even under optimal air temperature [9–12]. According to recommendations given by the WHO and Rospotrebnadzor[1] medical personnel exposed to risks of contagion should use PPE that protects from biological agents, similar to anti-plague ones [13]. Such suits provide reliable protection; however, medical workers complain about certain discomfort they have to face when wearing them and also mention poorer functional state of the body and lower working capacities associated with disrupted heat exchange and unsatisfactory ergonomic properties of protective suits [14–17]. Medical personnel's work during the pandemic often had to be done under high air temperature, especially in summer, and it aggravated adverse effects produced by PPE and led to elevated risks of overheating [18, 19].

There is a wide range of protective suits available at the moment; they are manufactured from different materials and produce different effects on the body. This requires evaluating their impacts on functional state of the body as well as on mental and physical working capacities of medical personnel.

Our research aim was to hygienically assess health risks for medical workers due to wearing reusable protective suits.

The research involved solving the following tasks:

1. To examine heat indicators of volunteers who had to wear a protective suit for 8 hours in a stationary laboratory.
2. To examine volunteers' mental and psychophysiological indicators.
3. To examine responses by the cardiorespiratory system to working in a protective suit.
4. To evaluate ergonomic properties of a protective suit through questioning.

Materials and methods. Six practically healthy male volunteers took part in the research. They were aged from 36 to 45 years, their average body weight was 85.9 ± 16.4 kg; average height, 176 ± 4.7 cm.

The research program was approved by the local ethical committee of the State Scientific Test Research Institute of Military Medicine of the RF Ministry of Defense.

We evaluated functional state of the volunteers who wore a reusable protective site made from a polyether fabric with polyurethane membrane coating and antistatic thread (hereinafter called the suit). The suit consisted of overalls and shoe covers. The volunteers also wore two pairs of surgical nitrile gloves on each hand, safety goggles, and FFP2 type respirator (KN95). Cotton underwear was put on beneath the suit (boxers and a long-sleeve T-shirt) and it was the same for all volunteers; they also put on cotton socks and sneakers.

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[1] MR 3.1.0229-21. Rekomendatsii po organizatsii protivoepidemicheskikh meropriyatii v meditsinskikh organizatsiyakh, osushchestvlyayushchikh okazanie meditsinskoi pomoshchi patsientam s novoi koronavirusnoi infektsiei (COVID-19) (podozreniem na zabolevanie) v statsionarnykh usloviyakh [MG 3.1.0229-21. Recommendations on how to organize anti-epidemic activities in medical organizations rendering medical aid to patients with the new coronavirus infection (COVID-19) (a suspected disease case) in in-patients hospitals (approved by the RF Chief Sanitary Inspector on January 18, 2021)]. *Konsultant-Plus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_374488/ (May 16, 2021) (in Russian).

A suit for each volunteer was carefully selected from 6 options with different sizes depending on a person's weight and height. The suits were worn uninterruptedly for 8 hours (a typical working shift). The volunteers didn't eat or drink water during the experiment.

The experiment was accomplished in a laboratory at air temperature being 25.4 ± 0.1 ºC; air humidity, 33.9 ± 1.1 %; air speed, 0.2 ± 0.1 m/sec.

The experiment involved using the following equipment:

1. KMTP-01 kit for monitoring over thermal and physiological indicators of the body ("Spetzmedtekhnika" LLC, Saint Petersburg) applied to measure temperature and heat flow within a temperature range from 0 ºC to 50 ºC (measuring inaccuracy was ± 0.05 ºC).

2. "MES-200" meteometer ("NPP "Ellektrostandard" Ltd, Saint Petersburg) to register microclimatic conditions.

3. "TVM-150" electronic scales with measuring accuracy up to 50 grams ("Massa-K" PLC, Saint Petersburg), and "V1-15" electronic scales with measuring accuracy 2–5 grams depending on a range necessary for measuring weights of examined samples ("Massa-K" PLC, Saint Petersburg); these devices were applied to determine the volunteers' body weight and weights of different pieces included into the protective equipment set.

The experiment involved determining and evaluating the following:

– whether it was possible for the volunteers to wear suits (both at rest and under mild physical loads) under air temperature being 25.0 ºC and average air humidity not exceeding 80 % for 8 hours without any risks for their health;

– dynamics of heat exchange and heat state of the body;

– intensity and efficiency of moisture losses;

– microclimatic conditions at a workplace (air temperature, relative air humidity, and air speed).

The experiment involved measuring and registering the following indicators:

– rectal temperature (Tr);

– skin temperature on 11 body parts selected for examination (Ts);

– heat flow density on 11 body parts selected for examination (HFD);

– how heat was felt by the volunteers, overall and locally;

– the volunteers' body weight without the suit and accessories;

– a mass of each piece included into the overall PPE set.

All the aforementioned thermal and physiological indicators as well as microclimatic conditions were determined prior to the experiment (background values), after each 30 minutes during the experiment and at the end of it. The volunteers' body weight and masses of PPE pieces were determined prior to and after the experiment. The volunteers were thoroughly examined after the experiment to detect any possible skin irritation.

Integral indicators of the volunteers' heat state were calculated based on measuring results; these indicators included average weighted skin temperature (AWST), average body temperature (ABT), average weighted heat flow (AWHF), total heat losses, and a change in heat content in the body (ΔQ). Sweat evaporation efficiency was calculated and considered an integral characteristic of PPE hygienic properties that influenced heat exchange in the body.

Volunteers had mild physical loads for 5 minutes at the beginning of each hour (walking on a treadmill at a speed equal to 5 km/hour without any rise of the running belt) with indicators of gas exchange being registered during it. To do that, we used *"MetaLyzer 3B"* system for spiroergometry and gas analysis (Cortex, Germany) and *T-2100* treadmill compatible with the spiroergometry system (General electric, USA).

Responses by the cardiorespiratory system (CRS) were evaluated at 9 time points: 1, 2, 3, 4, 5, 6, 7, 8 and 9 hours after taking the suit off.

We analyzed primary (lung ventilation (LV), partial pressure of oxygen and carbon dioxide during inhalation and exhalation, heart rate (HR), respiratory rate (RR), lung volume (RLV)) and derived indicators (oxygen volume (VO_2), carbon dioxide volume (VCO_2), respiratory quotient (RQ), lung volume (LV), metabolic intensity (MI)).

The volunteers had moderate intellectual loads during time periods free from registering indicators of their functional state (20–30 minutes during each hour in the experiment). These intellectual loads involved several psychodiagnostic tests (a comprehensive personality test and a 16-factor personality inventory) and this allowed us to model occupational activities performed by medical personnel in "red zones".

Each hour we took blood pressure and performed psychophysiological tests (simple visuomotor reaction time (SVMRT), complex visuomotor reaction time (CVMRT) and determined volunteers' activity, mood, and wellbeing with "CAM" questionnaire (cenesthesia, activity and mood). Psychophysiological indicators were assessed using "*NS-Psychotest*" software and hardware complex ("Neurosoft", Ivanovo, Russia).

After the experiment was over, each volunteer took part in a poll by filling in a specifically designed questionnaire; it was done to analyze how comfortable the suit was for wearing it and working in it as well as to evaluate subjective feelings regarding health and heat during the experiment.

The results were statistically analyzed using STATISTICA for Windows applied software package, Version 10.0. We applied Wilcoxon's T-test to determine authenticity of differences between two samplings of pair measurements; correlations between variables in a dependent sample were determined with the Spearman correlation coefficient (rxy) at the significance level being 95 % ($p \leq 0.05$). In case values of an indicator were distributed normally, we took a simple mean (*M*), statistical error of the mean (*m*) and standard deviation (*SD*) to describe averaged values. In case this distribution wasn't normal, averaged values were described with median (*Me*), and the 1st (*Q1*) and the 3rd (*Q3*) quartiles were applied to describe spread in values. We applied one-factor dispersion analysis to examine indicators of gas exchange.

Results and discussion. Table 1 provides data on dynamics of heat indicators measured for the volunteers who had to spend 8 hours in the suit.

Our assessment of the heat state revealed that rectal temperature grew slightly (by 0.2 ºC on average) in all volunteers by the end of the experiment under the experimental conditions described above. Overall, the volunteers subjectively assessed their state as "feeling warm". We should note that this self-assessment was given by several volunteers only under physical loads and just after them during first 3–4 hours in the experiment. When the volunteers were at rest, they evaluated their overall feeling of heat as "comfortable". This fact is proven by objective data since there were no rises in rectal temperature during that period or they didn't exceed 0.1 ºC. As a result, the ultimate levels of rectal temperature at the end of the experiment conformed to permissible physiological standards for a person who was in a state of relative rest (37.2 ± 0.5 ºC) and optimal values for easy physical labor (37.4 ± 0.2 ºC).

Overall slight heating of the body is confirmed with dynamics of temperature measured at some surfaces of the volunteers' bodies which were selected for analysis as well as with volume of "dry" heat emission (mostly by convention or radiation, and to a lesser extent by conduction) on these surfaces.

We detected certain differences in dynamics of thermal physiological indicators on various surfaces of the body. The greatest skin temperature rise (from 2.8 to 3.4 ºC) was detected on the body, except from the area near the shoulder blades where this rise didn't exceed 1.4 ºC. Heat emission from the chest, stomach and waist surface on average amounted to 22.1–25.0 Wt/m^2 during the experiment. The same indicator measured on the back surface of the chest was objectively higher and amounted to 30.8 Wt/m^2; this fact to a certain extent can explain a smaller temperature rise on this area in comparison with other surfaces on the body.

Dynamics of skin temperature and heat emission on feet were comparable to values obtained for the body. The greatest temperature rise and the lowest heat emission were detected on feet. By the end of the experiment skin temperature grew by 3.8 ºC and reached

Table 1

Heat indicators taken in dynamics

Examined indicators	Values ($M \pm m$)		
	initial ($n = 6$)	ultimate ($n = 6$)	average ($n = 6$)
Air temperature, ºC	25.0 ± 0.2	25.2 ± 0.1	25.4 ± 0.1
Relative air humidity, %	35.2 ± 1.6	34.1 ± 1.2	33.9 ± 1.1
Air speed, m/sec	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Body temperature (rectal), ºC	37.3 ± 0.1	37.5 ± 0.1	37.4 ± 0.1
AWST, ºC	31.9 ± 0.4	34.2 ± 0.1	33.8 ± 0.1
Overall feeling of heat, scores	0	+1.0	
ABT, ºC	35.7 ± 0.1	36.8 ± 0.1	36.6 ± 0.1
AWHF, Wt/m^2	43.5 ± 2.3	35.3 ± 1.6	36.4 ± 0.8
Forehead skin temperature, ºC	32.2 ± 0.7	34.1 ± 0.3	33.6 ± 0.3
Heat flow density (HFD) on the forehead surface, Wt/m^2	86.5 ± 9.3	61.3 ± 6.4	65.2 ± 2.9
Chest skin temperature, ºC	32.2 ± 0.8	35.0 ± 0.2	34.5 ± 0.2
HFD on the chest surface, Wt/m^2	19.5 ± 3.5	23.7 ± 2.2	22.1 ± 2.7
Skin temperature near the shoulder blade, ºC	31.9 ± 0.6	33.3 ± 0.2	33.1 ± 0.3
HFD near the shoulder blade, Wt/m^2	28.2 ± 6.8	36.2 ± 2.8	30.8 ± 2.6
Stomach skin temperature, ºC	31.7 ± 0.6	35.1 ± 0.2	34.4 ± 0.2
HFD near the stomach, Wt/m^2	25.7 ± 4.3	20.8 ± 5.1	25.0 ± 2.9
Waist skin temperature, ºC	30.7 ± 0.5	33.5 ± 0.3	33.0 ± 0.2
HFD near the waist, Wt/m^2	16.2 ± 2.5	22.8 ± 2.2	23.9 ± 1.0
Shoulder skin temperature, ºC	31.9 ± 0.3	34.0 ± 0.5	33.6 ± 0.4
HFD on the shoulder surface, Wt/m^2	38.8 ± 2.2	38.2 ± 3.3	35.1 ± 1.9
Hand skin temperature, ºC	31.7 ± 0.8	34.2 ± 0.2	34.2 ± 0.2
HFD on the hand surface, Wt/m^2	67.2 ± 5.7	62.5 ± 5.0	60.8 ± 1.6
Thigh skin temperature, ºC	31.5 ± 0.3	33.6 ± 0.2	33.1 ± 0.2
HFD on the thigh surface, Wt/m^2	45.8 ± 3.8	34.2 ± 2.6	39.5 ± 2.2
Shin skin temperature, ºC	32.7 ± 0.3	34.4 ± 0.3	34.1 ± 0.2
HFD on the shin surface, Wt/m^2	64.7 ± 4.0	40.8 ± 2.6	39.8 ± 2.1
Sole skin temperature, ºC	32.6 ± 0.2	35.4 ± 0.2	35.3 ± 0.3
HFD on the sole surface, Wt/m^2	50.2 ± 9.1	24.2 ± 1.8	25.8 ± 1.5
Foot skin temperature, ºC	32.0 ± 0.3	35.8 ± 0.3	35.6 ± 0.3
HFD on the foot surface, Wt/m^2	27.2 ± 4.0	16.5 ± 1.6	21.5 ± 3.5

35.8 ºC on them but the ultimate heat emission amounted to only 16.5 Wt/m^2; this was due to greater heat insulating properties of clothing on this part of the body. Meanwhile, a temperature rise on soles wasn't so intense and amounted to 2.8 ºC with heat emission being a bit higher, 25.8 Wt/m^2 on average.

A rise in skin temperature on the upper and lower extremities, excluding their distal sections (hand and feet) was objectively lower in comparison with the same indicators measured on the body. Thus, by the end of the experiment skin temperature on the thigh and shoulder didn't rise by more than 2.1 ºC against its initial values and by more than 1.7 ºC on the shin. Heat emission on these body surfaces was within 35.1–39.8 Wt/m^2. We should note that a temperature rise was more apparent on hand skin (2.5 ºC) together with rather high heat flow density in this surface (60.8 Wt/m^2). On one hand, this is due to poor heat insulating properties of surgical gloves and absence of inert air layer between their inner surface and skin and, on the other hand, due to practically absent efficient sweat evaporation producing cooling effects on this surface.

Since the suit hood was not fit tightly with the face and didn't cover the forehead completely we can't consider data on heat exchange on this body surface to be truly informative. Nevertheless, a rise in forehead skin temperature amounted to 1.9 ºC against the initial level together with rather high heat emission being equal to 65.2 Wt/m^2.

Apart from dynamics of temperatures measured on various body surfaces, we should mention certain indicators that describe how efficiently sweat was removed from the skin surface into upper layers of the clothing and also how efficiently it evaporated.

We established that intensity of sweat excretion amounted to 111.5 g/hour on average in the volunteers wearing the suit. On average, pieces of the overall PPE set held 40.8 g of sweat and this indicated its evaporation was quite efficient and amounted to 95.5 %. As a result, heat losses due to sweat evaporation amounted to 34.4 Wt/m^2 for a person wearing the suit.

Dynamics of body temperature regimes, "dry" heat emission and heat emission due to sweat evaporation determined character and volumes of changes in integral heat indicators determined for the volunteer's bodies.

By the end of the experiment an average rise in AWST amounted to 2.3 ºC, mostly due to rises in temperatures on the body and distal sections in the extremities. But the ultimate value of this indicator (34.2 ºC) conforms to permissible heat state of the body when easy physical labor is performed (33.0 ± 2.0 ºC) and optimal values detected for the body at rest or activities performed by operators (33.5 ± 1.0 ºC). Dynamics of rectal temperature and AWST determined changes in the integral indicator of the body temperature regime, ABT. Its value grew by 1.1 ºC over the 8-hour period and this indicated there was only slight strain of thermal regulation mechanisms in the volunteers' bodies and that heat exchange with the environment was quite balanced. This is also confirmed by the character and volumes of overall heat losses by the body. Thus, on average 36.4 Wt/m^2 of heat was emitted from the volunteers' bodies by convection and radiation, and, as it was described above, 34.4 Wt/m^2 were emitted by sweat evaporation, that is, practically the same volume. Therefore, total heat losses amounted to 70.8 Wt/m^2.

Overall, heat exchange dynamics and values of changes in thermal physiological indicators determined excessive heat contents in volunteers' bodies to be equal to 5.6 Wt/m^2 and this was within optimal standard values (from –16.0 to +16.0 Wt/m^2).

Changes in the volunteers' psychophysiological indicators were examined during uninterrupted use of the suit based on concepts about multi-level morphological and functional organization of the human body.

Data analysis didn't reveal any statistically authentic changes in the volunteers' psychophysiological and mental indicators (except from a number of mistakes in SVMRT test); given that, all dynamics of the examined processes is described as certain trends. Statistical significance might be absent due to several reasons, for example, too small a sampling, variability of values obtained for the analyzed indicators, and absence of significant data dynamics.

Having compared SVMRT and CVMRT, we revealed some fluctuations within reference ranges without any apparent regular correlation with microclimatic conditions and cycles involving physical and intellectual loads (Tables 2 and 3)

Table 2

Dynamics of volunteers' simple visuomotor reaction time

No.	Background, msec	Load, msec							
		1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour	7th hour	8th hour
1	209.4	199.1	234.23	241.53	268.43	237.17	232.11	242.936	230.74
2	235.28	237.84	239.54	243.59	237.5	236.51	248.01	234.97	256.77
3	202.04	191.54	198.69	201.09	195.3	199.1	202.04	191.94	198.54
4	273.74	256.64	303.1	274.19	274.24	277.57	275.79	288.76	266.77
5	205.19	201.53	221.57	220.44	230.27	213.64	205.09	211.93	223.33
6	216.76	201.12	208.8	221.66	221.34	219.24	223.97	234.41	211.54

Table 3

Dynamics of volunteers' complex visuomotor reaction time

No.	Background, msec	Load, msec							
		1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour	7th hour	8th hour
1	346.31	380.75	438.99	504.87	418.01	408.98	417.97	399.06	351.28
2	403.45	419.93	372.24	388.2	345.64	421.37	360.93	334.84	326
3	344.51	357.87	353.59	332.35	339.49	337.4	311.47	306.87	288
4	415.9	424.5	428.48	445.93	424.84	434.38	417.64	426.97	439.64
5	411.76	398.64	414.17	411.57	464.58	412.13	423.24	426.94	398.04
6	376.92	357.16	379.45	406.48	364.91	369.13	379.89	376.89	370.58

Average SVMRT tended to grow by the end of the experiment against its initial values (216.76 [209.4; 235.86] and 236.63 [233.5; 245.71] msec accordingly, $p < 0.08$) but there were no significant differences in CVMRT (Figure 1).

All volunteers made by 1 mistake more in SVMRT test after the experiment was over (0 [0; 0] and 1 [1; 1] mistake accordingly, $p < 0.04$) and this might be due to either certain fatigue or "mental demobilization" occurring when the experiment was over.

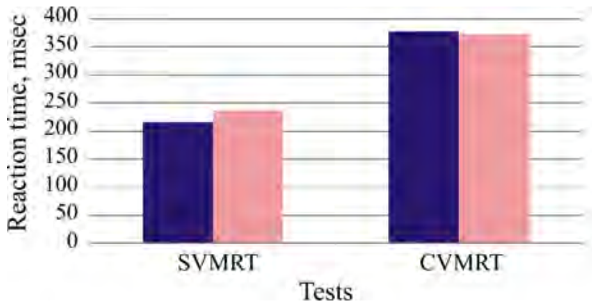

Figure 1. Average (*Me*) SVMRT and CVMRT test results of the volunteers prior to and after the experiment ($n = 6$): the blue column shows values prior to the experiment and the red column after it

We also performed a test that allowed the volunteers to give subjective evaluation of their state (Cenesthesia, Activity, and Mood – CAM test); the test revealed that all three indicators went down slightly within reference ranges. But still, after all the tests were over, there was certain discord in the indicators since cenesthesia and activity went down (5.95 [5.9; 6.0] and 5.7 [5.4; 5.8] scores accordingly, $p < 0.08$) but the mood didn't. This indicates that the volunteers were only physiologically tired and doesn't mean that the overall depression of the central nervous system occurred in comparison with its initial state (Figure 2).

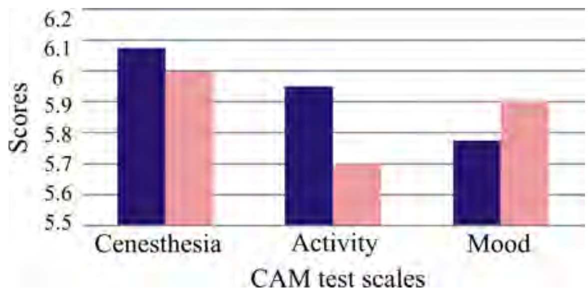

Figure 2. Average indicators (*Me*) measured with CAM test in the volunteers prior to and after the experiment ($n = 6$): the blue column shows values prior to the experiment and the red column after it

In our opinion, subjectively assessed better mood after the experiment ended was primarily due to all the trials being over and the volunteers being able to relax.

Test results obtained for the 1st volunteer made the greatest contribution to negative dynamics of activity since there was a drop in this indicator detected during the 4th and 8th hour; it was the most probably due to initial anthropometric and physiological peculiarities of this volunteer (Table 4).

Table 4

Dynamics of indicators determined as per Activity scale in CAM

No.	Back-ground, scores	Load, scores							
		1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour	7th hour	8th hour
1	6	5.5	5.5	5.7	4.7	5.4	5.6	5.5	4.7
2	6	6.2	6	6	6	6.1	5.8	5.7	5.9
3	6	5.6	5.6	6.1	6	6	5.9	5.7	5.6
4	6.2	6	5.8	5.8	5.5	5.3	5.8	5.7	5.4
5	5.7	5.8	5.8	5.9	5.8	5.8	5.8	5.8	5.8
6	5.9	6	5.7	6.1	5.9	5.6	5.9	5.6	5.9

Therefore, we examined changes in objective psychophysiological and subjective psychological indicators of the volunteers in the experiment aimed at evaluating a probability to wear the suit uninterruptedly for several hours. Our examination allows us to conclude that there were no statistically significant changes in indicators of the volunteers' psychophysiological and mental state and they all varied within reference ranges. Subjective feeling of high spirits against poorer cenesthesia and activity as well as a growing number of mistakes in SVMRT test were due to "mental demobilization" after all the experimental trials were over.

Figure 3 provides the results of gas exchange (VO_2, VCO_2) indicators. We analyzed data obtained in all phases in the experiment including rest, loads, and recovery.

Gas exchange indicators in volunteers naturally grew during the load phase; however, there were no significant changes detected in either experimental phase during 8 hours of wearing the suit. CRS indicators including heart rate, respiratory rate, lung volume, and minute ventilation also grew naturally only when a volunteer was walking on the treadmill; however, they didn't change during 8 hours of wearing the suit. The great dispersion of the values is due to different anthropometric data and initial levels of the volunteers' physical working capacities (Figure 4).

Statistical analysis didn't reveal any significant influence exerted by wearing the suit on indicators of gas exchange and the cardiorespiratory system both at rest and under mild physical loads.

Ergonomic properties of the suit were assessed by a poll performed among the volunteers. Our specifically designed questionnaire was made up of 50 questions regarding the suit ergonomics and the overall estimate was made by summing up the scores. Each positive answer gave 1 score; each negative one, 0 scores; 0.5 scores were given if a volunteer found it difficult to answer this particular question. Overall assessment of the ergonomic properties had the following grades:

♦ *good* was 40–50 scores;
♦ *satisfactory* was 30–40 scores;
♦ *unsatisfactory* was less than 30 scores.

Average score estimate amounted to 43 scores and this meant that the ergonomic properties of the suit conformed to the assessment grade "good".

We also asked the volunteers about their feeling of heat and their answers allowed concluding that subjective estimates corresponded to objective data obtained in the research. Subjective feelings of heat were described by the volunteers as "warm" or "comfortable" and none of them told they were feeling "hot" under the air temperature being 25 ºC during the experiment. The ergonomic properties of the suit didn't prevent the volunteers from accomplishing their tasks.

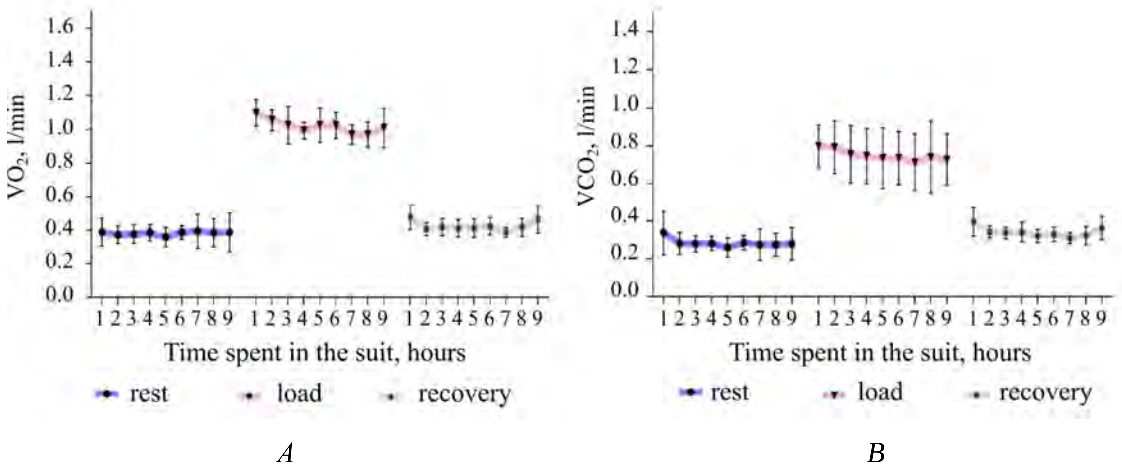

Figure 3. Dynamics of changes in gas exchange indicators depending on time spent wearing the suit: *A* is for VO_2; *B* is for VCO_2

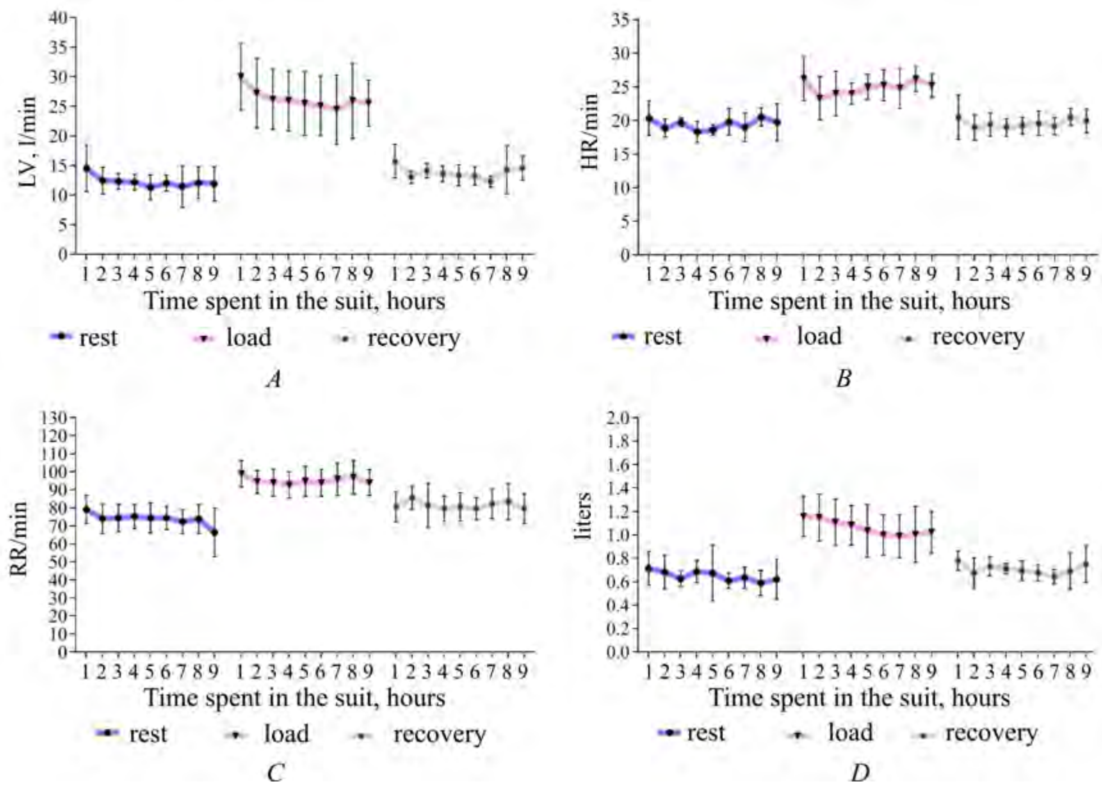

Figure 4. Changes in CRS indicators in dynamics depending on time spent in the suit:
A is for LV; *B* is for HR; *C* is for RR; *D* is for minute ventilation

Therefore, we performed the experiment to assess the heat state of the body taking into account functional state of the cardiovascular and respiratory systems as well as psychophysiological parameters at rest and under mild physical loads. Our experiment involved wearing the protective suit for 8 hours under air temperature being 25.0 ºC; it allowed confirming that it was safe for the volunteers to wear the suit for this amount of time since we didn't detect any health risks for them associated with wearing it or performing their tasks in it.

Conclusion:

1. Use of the suit under the air temperature being 25 ºC and mild physical loads provides adequate heat exchange and doesn't create any risks of overheating.

2. Data on psychophysiological and mental state of the volunteers taken in dynamics didn't have any statistically significant changes and varied within reference ranges. This indicates that there were no adverse effects produced on psychophysiological and mental functions of the volunteers who performed their tasks wearing the suit. Negative dynamics of subjective indicators evaluating cenesthesia, activity, and mood was caused by fatigue and was not associated with overall depression of the central nervous system. Subjective feeling of high spirits against poorer cenesthesia and activity as well as a growing number of mistakes in the simple visuomotor reaction time test were due to developing "mental demobilization" after all the experimental trials were over.

3. We didn't reveal any significant changes in indicators of the cardiorespiratory system depending on time spent in the suit. These data indicate that no adverse effects were produced on the cardiorespiratory system during the 8-hour experiment.

4. Use of the suit didn't result in violated ergonomics.

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