

OTS: 60-41,088

JPRS: 5189

1 August 1960

STUDIES OF SOME HEAT LOSS PHENOMENA IN SOLDIERS  
UNDERGOING PHYSICAL EXERTION

- POLAND -

by M. Boguszewska, T. Kraska,  
R. Kobylinski, and H. Lotach

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STUDIES OF SOME HEAT LOSS PHENOMENA IN SOLDIERS  
UNDERGOING PHYSICAL EXERTION\*

∟ This is a translation of an article written by M. Boguszevska, T. Kraska, R. Kobylinski, and H. Lotach in "Postepy Higieny i Medycyny Doswiadczalnej," Vol. XIII, No. 6, 1959, Warsaw, Pages 787-803. ∟

The physical fitness of soldiers and their ability to meet the obligations of military service largely depend on the suitability of their uniforms, their adjustment to climatic conditions and to specific military requirements. The selection of proper field uniforms requires that studies be made of the influence of various kinds of clothing upon the course of thermoregulatory phenomena.

Our project was a study of some thermoregulatory phenomena under climatic conditions commonly occurring in Poland. These conditions create numerous prospects for excessive cooling and may lower the efficiency of the organism and its productivity. The need to find the best kind of field uniforms indicated the importance of research on heat exchange between the organism and the environment, contingent on clothing.

Available foreign literature abounds in studies dealing with the problem of military uniforms, particularly those used in the air force (15, 22).

In Polish literature, Millak (22) proposed a method of studying the heat characteristics of clothing fabrics with the aid of a cathetometer. Gadzikiewicz (13) used this method in his research on woolen fabrics worn by the highlanders of Podhale. Safarewicz (20) conducted a hygienic appraisal of fabrics used in the prewar Polish army, applying the familiar methods of the Rubner school. The United States army conducted research by means of laboratory,

\*Work performed in the Committee of General and Social Hygiene (Komitet Higieny Ogolnej i Spolecznej) of PAN  
∟ Polska Akademia Nauk; Polish Academy of Science. ∟

practical, polling and other methods, establishing technical requirements for field uniforms. Weiner and Kennedy (34) called attention to the lack of precision and the shortcomings of the current research. Burton and Edholm (11) provided many observations and comments on the influence of the arctic climate on the human organism, such as on soldiers of different service branches. Numerous papers in the Soviet literature (14, 18, 21, 23, 28, 31) are devoted to the effect of cold upon man, and the ways of counteracting its effects.

The nature of the Polish climate, its demographic peculiarities, the degree of acclimatization of its inhabitants, their various habits and living conditions, greatly restrict the possibility of applying the results of foreign research to our domestic conditions.

Polish military authorities have displayed considerable interest in these problems. Studies were undertaken on the hygienic value of current and projected uniforms, and the results of studies (8) were taken into consideration when preparing new patterns for field clothes.

Of considerable importance in the process of heat loss is the relation of a given part of the body's surface, measured in square centimeters, to its volume expressed in cubic centimeters; for the trunk it is  $0.1 \text{ centimeter}^{-1}$ , for the arm  $0.6 \text{ centimeter}^{-1}$ , and for the fingers  $2.2 \text{ centimeter}^{-1}$ . Thus, the further the heat is transferred along the circumference by the blood, the larger is the surface which participates in the loss of excess heat to the environment.

According to Aschoff (3), the quantity of heat exuded by an individual at rest is 0.018 for the trunk, 0.032 for a foot, and for a finger tip  $0.040 \text{ calorie/square centimeter}$  in 1 minute with 1 degree centigrade in temperature difference.

The layer of immobile air, known as the border layer, which directly surrounds the surface of human bodies, has some influence on the liberation of heat. The thickness of this layer depends on air pressure, the speed of the air's motion, and the ratio of the surface of the body to its volume (or its various parts - trunk, limbs). At the minimal air movement, the border layer has a depth of 4 to 8 millimeters. The thicker the layer, the smaller the amount of heat lost to the environment. When the air pres-

Temperature and the speed of air movement are constant, the thickness of the border layer shrinks with the ratio of the body's surface to its capacity.

Limbs have a larger surface and a thinner border layer than other parts of the body. They therefore enable a faster disposal of excess heat when the temperature of the environment is higher or the heat output large. Another of their attributes plays an important part in this process: the possibility of substantial changes in the flow of blood in the vessels. The quantity of blood in the torso skin may change in a 1:6 ratio, depending on the contraction or expansion of the vessels, but the flow of blood in the fingers may fluctuate in a 1:100 ratio (1). With a drop in outside temperature, the limb vessels contract, diminishing the flow of blood and, consequently, the quantity of exuded heat.

Examples of the amounts of heat produced by various human organs in a state of rest (weight 65 kilograms, consumption of O<sub>2</sub> = 270 millimeters/minute) and in the course of medium-heavy work (consumption of O<sub>2</sub> = 1,800 millimeters/minute) are shown in table 1.

Table 1. After Aschoff and Wever (3) and Lehmann (19)

Organ	% of whole body's weight	Output of Heat			
		at rest		at medium-heavy work	
		cal/min	%	cal/min	%
Skin and muscles	52	232	18	2528	70
Brain	2	208	16	218	6
Organs of the thorax and abdomen	6	733	56	792	22
Whole organism		1200		3600	

The organs of the thorax, and abdomen, and the brain, account for about 8 percent of the body's weight, but at rest produce 72 percent of the total heat quantity, while the skin and muscles, representing 30 percent of the body's weight, produce only 18 percent of the heat. A resting organism may there be divided, on the basis of the quantity of the heat produced, into the so-called inside, whose organs produce 10-45 calories/minute per 100 grams of tissue, and skin and muscles, which produce only 0.5-1.0 calories/minute for every 100 grams of tissue.

During physical work the muscles can produce large quantities of heat. During medium-heavy work about 70 percent of the total heat output is in the muscles, and the share of the inside drops to about 20 or 25 percent. A rise in the heat output in the muscles is manifested by an increase in their temperature. Observations of the effects of cold have shown, for example, that at a rate of blood circulation of 3 millimeters/minute per 100 grams of tissue, the temperature of the more deeply situated muscles can maintain a level of about 37 degrees centigrade, but that the level drops to 18.5 degrees at a rate of 0.75 millimeter/minute per 100 grams of tissue. (11)

The quantity of heat given out through the skin varies in relation to the degree of its blood content, fluctuating from 0.02 to 0.14 K calories per 1 square meter in 1 hour with 1 degree centigrade in temperature difference (16, 33).

The quantity of heat rising from inside the body to its surface is in direct proportion to the temperature difference between the inside of the body and the skin's surface, out in reverse proportion to its heat resistance. Heat resistance of the skin increases when blood vessels contract and diminishes when they expand. The skin's heat resistance at a maximum contraction of peripheral vessels is in a 1:7 ratio to its resistance at a maximum expansion. At a higher environmental temperature, the skin vessels dilate, the quantity of blood in the skin greatly increases, and the heat resistance drops to its minimal value. Even a small temperature difference between the inside of the body and the surroundings then suffices to push the heat produced in the organism to the outside. When the temperature of the environment exceeds 30 degrees centigrade, the difference in temperatures is so small that an inadequate quantity of heat is transferred to the outside, in spite of the insignificant

Heat resistance of the skin. Then, however, the flow of perspiration increases and its evaporation from the skin's surface represents a very effective factor in thermoregulation. We measured the skin's heat resistance with a small-plate calorimeter invented by Aschoff and Wever (2).

#### Experimental Research

To measure dynamic work in doses we used an ergometer associated with a bicycle, also known as the bicycle-ergometer (Fig. 1). The device has a copper shield in place of the rear wheel. With the pedals turning the shield rotates between 2 electromagnets suspended on a two-arm lever. Weights may be added to one end of the lever by means of a special attachment. After the experiment the work performed was computed according to the formula:

$$\text{work} = F \cdot S$$

where F denotes resistance in kilograms, and S distance in meters.



Figure 1. Measuring dynamic effort on a bicycle-ergometer.

F is obtained by multiplying the value of the selected weight by the coefficient 6, which is derived from the computation of forces active in the mechanical structure of our bicycle-ergometer. S equals the distance of overcoming resistance as shown on the meter of the apparatus.

Before performing work on the bicycle-ergometer, the subject rested under specific climatic conditions. During this period measurements were taken of his pulse, skin temperature at several points of the body, and the microclimate temperature under the clothing. The subject then performed work on the bicycle-ergometer, maintaining a given travel speed by turning the pedals. The travel speed was regulated so as to keep the aforementioned two-arm lever of the bicycle-ergometer in balance. The duration of travel was strictly defined. Clothing and the environmental temperature were the variable factors in the experiment. After the work was performed, the following were recorded:

- 1) plethysmogram of the forearm,
- 2) temperature of the skin and of the area under the clothing, at several given points of the body,
- 3) pulse.

Skin temperature was measured by means of a dermatic thermometer and a universal electric thermometer, as well as by a thermometer based on the working principles of the thermoelectric cell (Fig. 2).



Figure 2. Measuring skin temperature by means of a dermatic thermometer.

Temperature under the clothing was measured by means of an electric universal and a mercury thermometer with a scale divided into 0.1 degrees centigrade. The mercury containers were wrapped in insulating covers with holes cut out. This was aimed at isolating the mercury container from the skin, in order to measure correctly the air temperature between body and clothing.

The functional behavior of the vessels, under various kinds of clothing and changing climatic conditions, was registered and marked on suitably prepared paper, and wound on a cymographic roll, by means of a plethysmograph with liquid transmission (Fig. 3) and an electric finger plethysmograph.

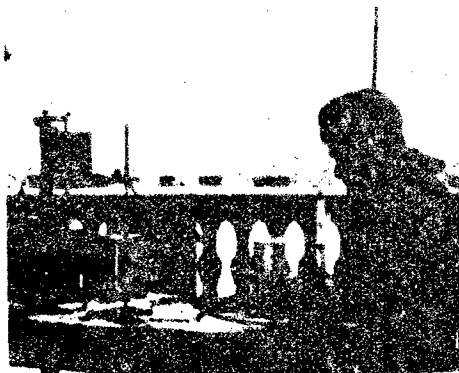


Figure 3. Plethysmographic research in the open, in Winter.

Under laboratory conditions, a rate of air motion of from 0 to 760 meters/minute was obtained with the aid of a large electric ventilator.

When studying the static effort, the subject under observation was loaded with a knapsack, weighing about as much as a fully equipped military knapsack, and then in equal time periods - the same measurements were taken under identical conditions as in dynamic work. In the course of further experiments the load was changed; for example, the knapsack was replaced by a given weight carried by the subject in one hand, etc. During all studies of the static effort, the load and the time of its impact were subject to modifications.

The subject's ability to sustain effort was measured by a Mosso-type ergograph, recording the ergograms of the middle finger. In our experiments a meter was attached to the ergograph to facilitate a direct computation of the distance from the beginning of work to its cessation due to fatigue. Simultaneously with the ergogram of the given finger, the plethysmogram of the other hand was recorded. Figures 4-15 show the obtained plethysmograms.

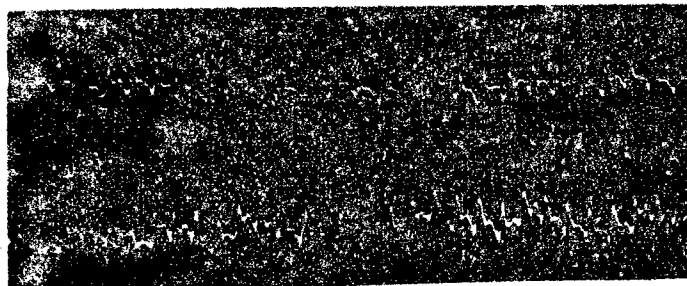


Figure 4. Plethysmograms of Subject D.S. in cloth uniform (60 percent wool); a - "zero" curve at 18 degrees centigrade; b - curve during static work equalling knapsack load of 27 kilograms for 15 minutes at 18 degrees centigrade. Beta waves are already visible on the curve.



Figure 5. Plethysmograms of subject K.J. in cloth uniform; a - zero curve at 18 degrees centigrade; b - the same curve at 8 degrees; c - the same curve at 8 degrees and 15 minutes of static effort, with a knapsack load of 27 kilograms. The beta waves on it are clear.



Figure 6. Plethysmograms of subject M.S. in cloth uniform; a - zero curve at 18 degrees centigrade; b - the same curve at 18 degrees and a dynamic effort equalling 2,700 kilograms/minutes for 10 minutes (intense sweating). Beta waves very clear; c-the curve at 18 degrees, 2 hours after dynamic work (as in b). Vanishing beta waves.



Figure 7. Plethysmograms of subject K.J. in denim jacket with fleece lining and a plush collar; a - curve at minus 5 degrees centigrade in the open air; b - curve under the same conditions during static work. Beta waves indicated; c - the same curve half an hour after the temperature of the environment rose to 18 degrees centigrade above zero.

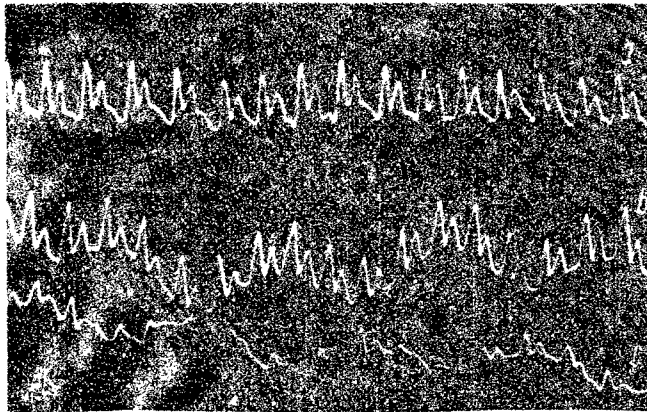


Figure 8. Plethysmograms of subject K.J. dressed as at measurements on Fig. 7; a - zero curve at 18 degrees centigrade; b - the same curve at a static effort equalling 27 kilograms for 15 minutes. Beta waves very clear; c - the same curve after a drop in temperature to 10 degrees. Apparent beta waves and the effect of cooling.

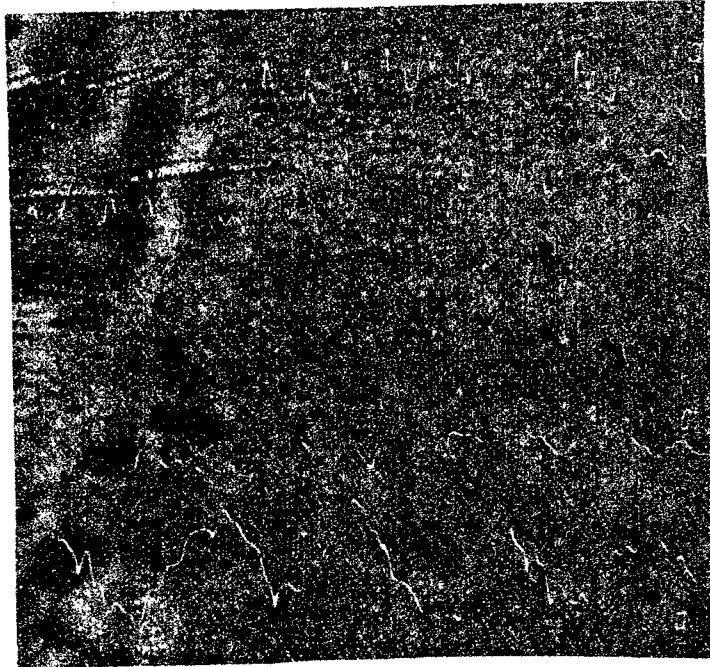


Figure 9. Plethysmograms of subject B.J. in cloth uniform; a - zero curve at 18 degrees centigrade; b - the same curve with a finger load of 2 kilograms on the ergograph. Beta waves indicated. Plethysmograms of subject D.S. in cloth uniform; c - zero curve at 18 degrees; d - the same curve after work on the ergograph, with a 2 kilogram weight suspended from the middle finger. Beta waves very clear.

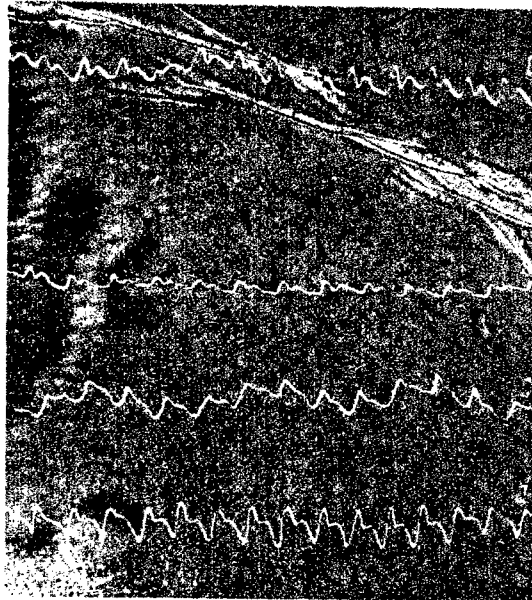


Figure 10. Plethysmograms of subject D.S. in cloth uniform; a - zero curve at 18 degrees centigrade; b - the same curve at 8 degrees; c - the same curve at 8 degrees after static effort equalling a load of 27 kilograms for 15 minutes. Beta waves lightly marked; d - curve at 8 degrees and after dynamic effort equalling 2,610 kilograms/minute for 5 minutes.

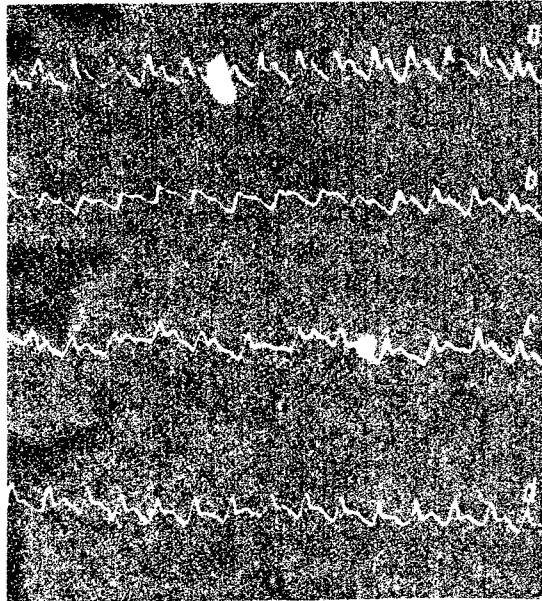


Figure 11. Plethysmograms of subject B.J. in cloth uniform; a - zero curve at 18 degrees; b - curve at 8 degrees; c - curve at 8 degrees and after static effort equalling a load of 27 kilograms for 10 minutes; d - the same curve but after dynamic effort equalling 2,610 kilograms/minute for 5 minutes.

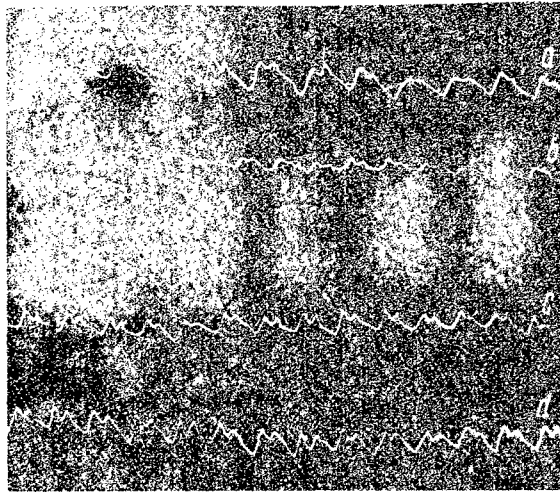


Figure 12. Plethysmograms of subject M.I. in cloth uniform; a - zero curve at 18 degrees centigrade; b - curve at 8 degrees; c - the same curve, but after a static effort equalling the load of 27 kilograms for 15 minutes; d - the same curve drawn half an hour after the effort and with the temperature of environment rising to 18 degrees.

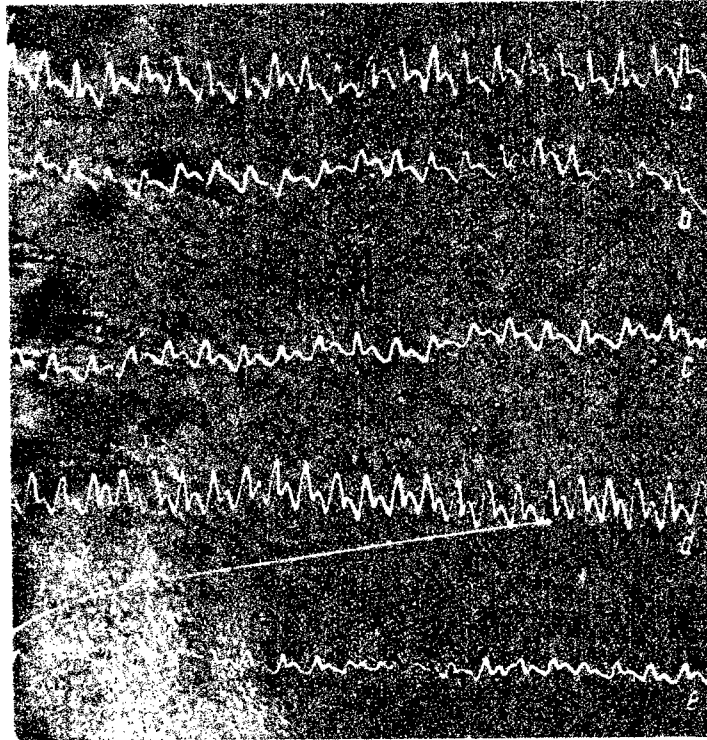


Figure 13. Flexhysnograms of subject D.S. in cloth uniform: a - zero curve at 18 degrees centigrade; b - the same curve, but after a drop in the temperature of the environment to 10 degrees. Smaller amplitude of fluctuations; c - the same curve after static effort equalling a load of 27 kilograms for 10 minutes; d - curve at 10 degrees after dynamic effort equalling 3,000 kilograms/minute for 5 minutes. Evident increase in the deviations of the curve; e - the same curve after the effect of air current increased to 150 meters/minute for 10 minutes.

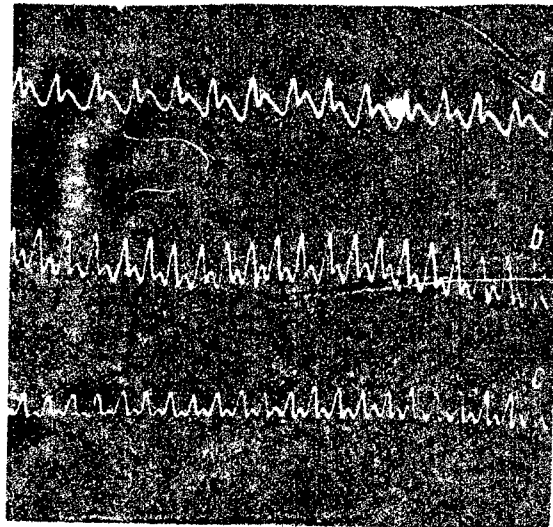


Figure 14. Plethysmograms at a static effort amounting to one hand's load of 5 kilograms for 5 minutes. Subject K.J. in cloth uniform; a - zero curve at 18 degrees; b - the same curve at 8 degrees; c - the same curve with one arm's (bent at the elbow and supported by the knee) load of 5 kilograms.

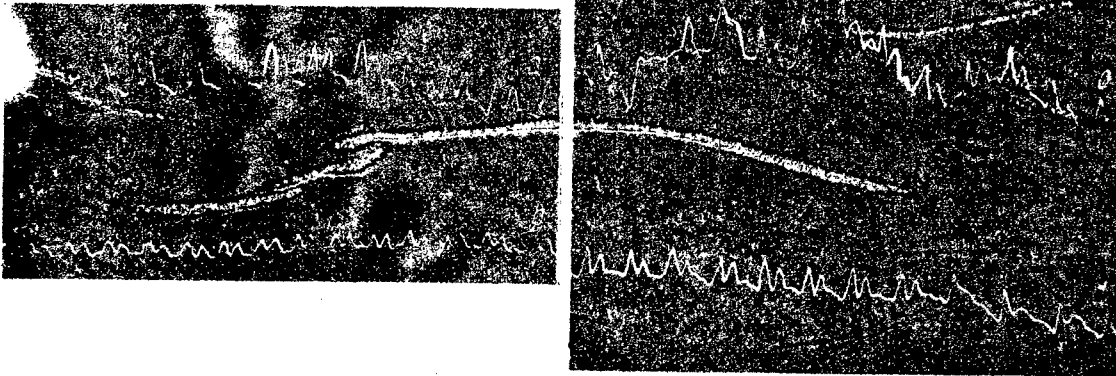


Figure 15. Plethysmograms at a static effort after loading the arm with 5 kilograms. Subject K.J. in cloth uniform; a - zero curve at 18 degrees centigrade; b - curve at 8 degrees; c - curve at 8 degrees after loading the arm (bent at the elbow and resting on the hip) with a 5 kilogram weight; d - curve after returning to the initial position.

An analysis of the recorded plethysmograms confirmed the well-known fact that the subjects under observation displayed considerable individual differences, necessitating a comparative appraisal of the curves obtained on the same subject. This relativity of results was underscored in our previous studies (6-8). As is known, the plethysmograph registers mainly the amplitude of blood content in the vessels. The effect of cooling factors is recorded in the form of a varying degree of reduction in the deviations of the curve. The deviations of the curve appear to straighten out in varying degree. The effect of clothing upon the plethysmogram is similar, depending on its heat-protecting attributes. Static effort influences the course of the plethysmographic curve, inducing a wavy line, the so-called beta waves. At a somewhat more intense dynamic effort, the amplitude of the plethysmographic curve increases. The effort of small groups of muscles, for example, the arms, was reflected faintly on the plethysmograms, but more clearly with physically weaker persons. In all our studies, the appearance and intensification of beta waves was connected with fatigue, and increase in the amplitude of the curve's deviations was associated with metabolic processes and an increased loss of heat. A bigger amplitude of the plethysmogram and beta waves may appear parallelly. Under unfavorable climatic conditions of the environment this phenomenon may be a warning signal of excessive cooling.

During ergographic studies, the load and duration of effort were identical, but the climatic parameters were subject to change: temperature, air movement and clothing. Tests were conducted on how and to what extent climatic conditions and clothing influence the performance of a selected muscle group and, at the same time, the general effort capacity of the tested person. Subject B.J. in cloth uniform performed the following quantity of work under the climatic conditions given below:

- at 18 degrees centigrade work amounted to 5.6 kilograms (Fig. 16);
- at 10 degrees work amounted to 5.8 kilograms (Fig. 17), an increase of 3.5 percent.

At 10 degree temperature and an air movement of 520 meters/minute work increased to 6.28 kilograms or by 19.1 percent in relation to work performed at room temperature. (Fig. 18)

Now the same person in denim uniform:  
at 18 degrees centigrade work amounted to 5.6 kilograms (Fig. 19);  
at 10 degrees temperature work amounted to 6.0 kilograms (a 7.1 percent rise ) (Fig. 20);  
at 10 degrees temperature and air movement of 520 meters/minute work equalled 6.8 kilograms, which is an increase of 23.4 percent in comparison with room conditions (Fig 21).

Similar results were obtained after testing some ten other persons. In all cases a rise in the efficiency of muscle work was established when the temperature of the environment dropped to a certain level. The air movement, increasing heat losses by the organism, contributed even to this effect. Subjects wearing denim uniforms displayed a higher rise in physical fitness than those dressed in cloth uniforms. The results agree with the observations of Muller and Nukada who, in testing the capacity for work on a bicycle-ergometer, found that the cooler the skin on the legs, the longer the work period, although the efficiency level remains the same. According to these authors, the cooling of the skin during dynamic effort improves the circulation of working muscles at the expense of the skin's blood content. German (3) and Soviet (31) authors believe that an increase in the flow of blood through the muscles, while the temperature of the environment is dropping, is a reflex result of an irritation of the heat receptors placed on the skin's surface by the decreased temperature.

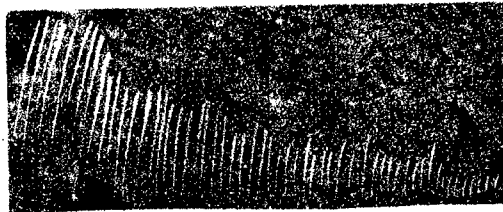


Figure 16. Subject B.J. Clothing: cloth uniform.  
Climatic conditions: 18 degrees centigrade, air movement: standstill.. Load = 4 kilograms; time = 40 seconds: distance = 132 meters; work = 5.6 kilograms.

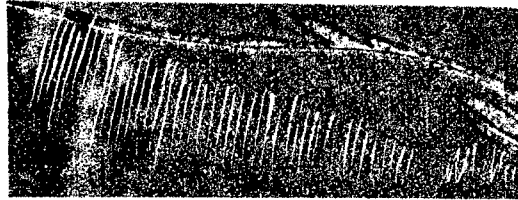


Figure 17. Subject, clothing, load, time - as measurements in Fig. 16. Climatic conditions: temperature 10 degrees, air movement: standstill. Distance = 1.46 meters; work = 5.8 kilograms.

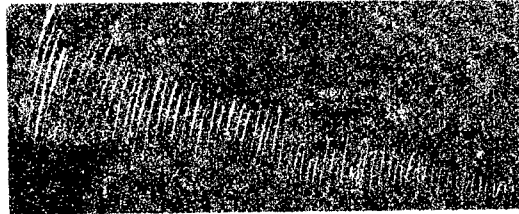


Figure 18. Subject, clothing, load, time - same as in Figure 16. Climatic conditions: temperature 10 degrees, air movement: 520 meters/minute. Distance = 1.57 meters; work = 6.28 kilograms.

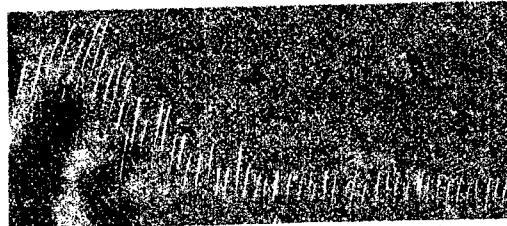


Figure 19. Subject B.J. Clothing: denim uniform. Load and time - same as in Fig. 16. Climatic conditions: temperature 1<sup>st</sup> degrees, air movement: standstill. Distance = 1.4 meters; work = 5.6 kilograms.

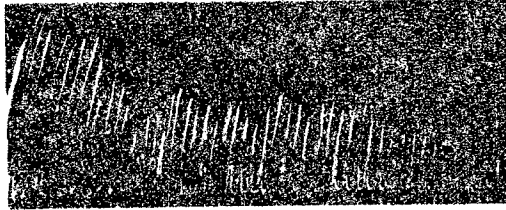


Figure 20. Subject, clothing, load, time - same as in Fig. 19. Climatic conditions: temperature 10 degrees, air movement: standstill. Distance = 1.5 meters; work = 6 kilograms.

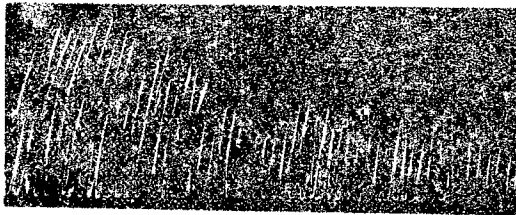


Figure 21. Subject, clothing, load, time - same as in Fig. 19. Climatic conditions: temperature 10 degrees, air movement = 520 meters/minute. Distance = 1.7 meters: work = 6.8 kilograms.

Our research on the effect of measured effort upon the loss of heat included, in addition to plethysmography and ergography, an appraisal of the individual microclimate or, to be precise, of the temperature under the clothing, between its layers, and of skin temperature at various points of the body. Tests were conducted under various thermal conditions of the environment, with other components of the climate approximately constant. Similarly as in other tests (7-9), we have taken into consideration two kinds of uniform: cloth and denim with fleece lining. The graphs (Figs. 22-25) present the more important results of our experiments. The results pertain to the dynamic effort, the amount of which was measured and computed by means of a bicycle-ergometer. Values given on the sectioned axis denote the amount of work performed each time in a 10-minute period. The graphs should be treated as examples, because it is impossible to demonstrate all measurements.

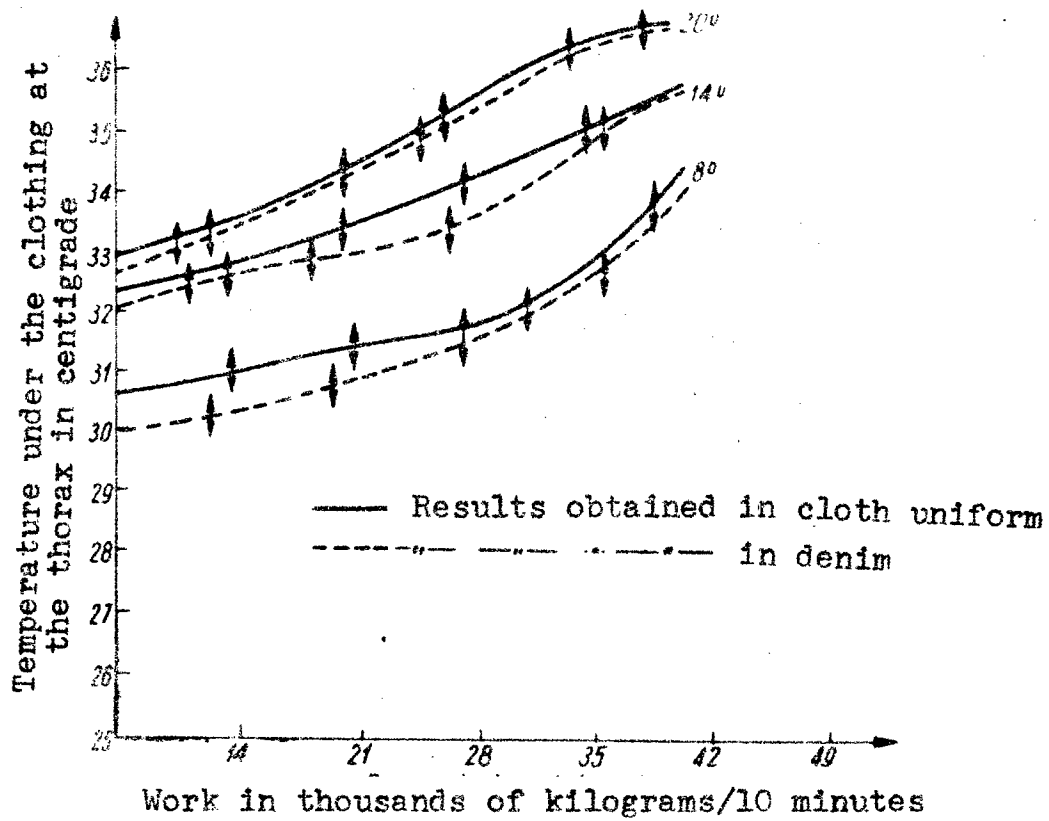


Figure 22. Temperature under cloth and denim uniforms on the thorax in relation to dynamic work performed and the temperature of the environment.

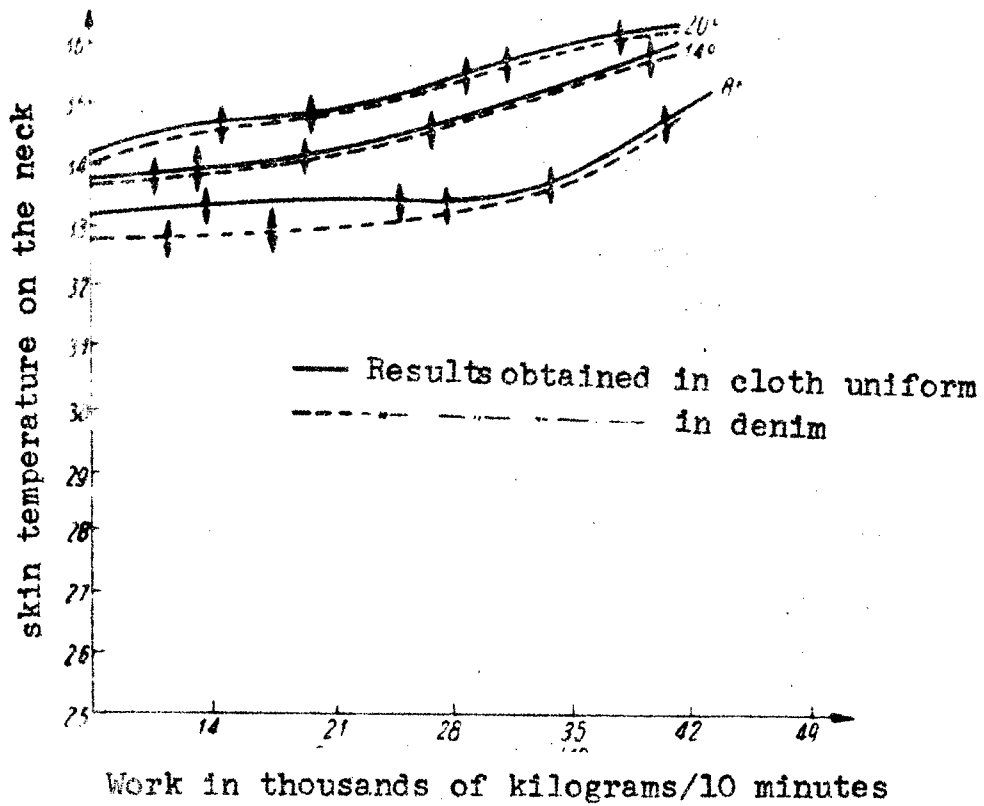


Figure 23. Skin temperature on the neck in relation to dynamic work performed and the temperature of the environment.

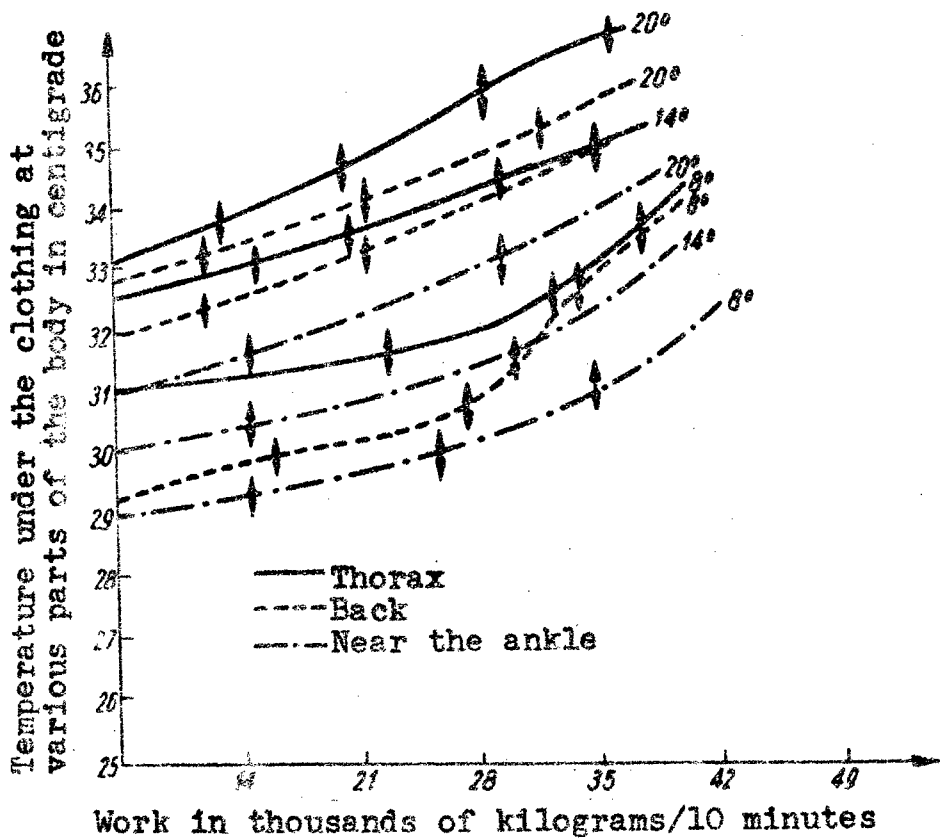


Figure 24. Temperature under cloth uniform at various points in relation to the quantity of dynamic effort performed and the environmental temperature.

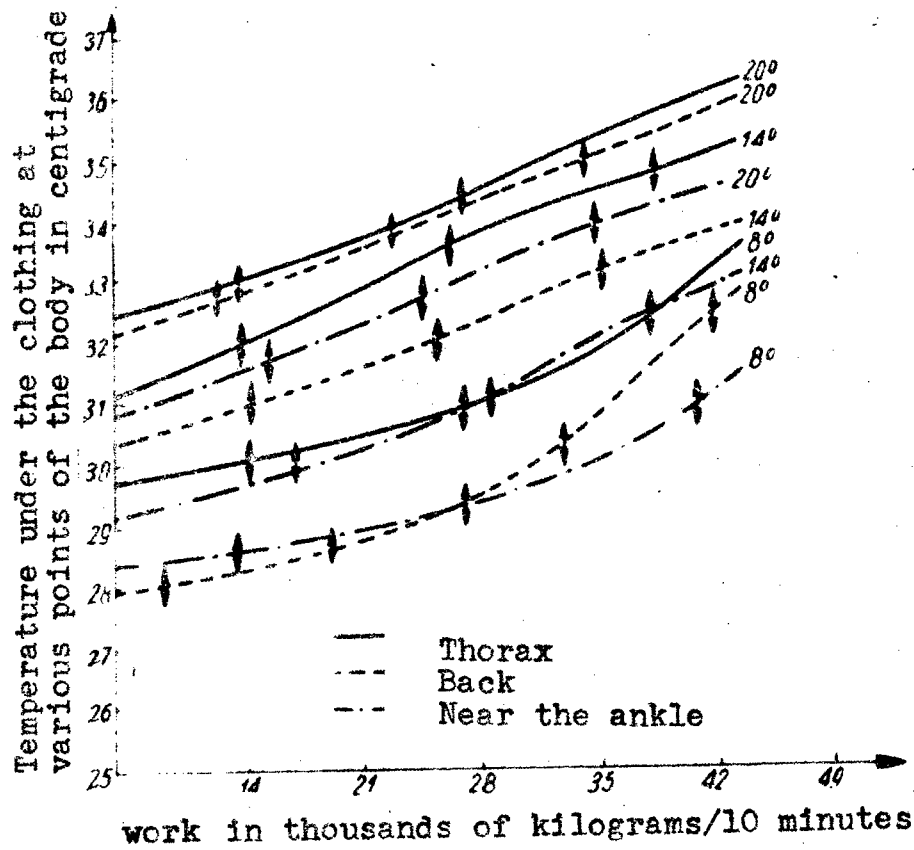


Figure 25. Temperature under denim uniform at various points in relation to the quantity of dynamic effort performed and the temperature of the environment.

These graphs show that the dynamic effort, as was proven by other reports on this subject (6, 18, 23), clearly influences the temperature of the area under the clothing and the skin temperature. Temperature changes reach a few degrees and depend - apart from the effort - on the temperature of the environment, type of clothing, and also on the choice of place where the tests were conducted.

In addition to the dynamic effort, the static effort was also studied. The forearm was loaded with a 6 kilogram weight, or the entire body with a knapsack weighing 27 kilograms, for 10 minutes. When the load was on the forearm, no clear temperature increase was noted either under the clothing or on the skin, but a small drop appeared under unfavorable thermal conditions. A slight heat increase was always observed in the area under the clothing immediately after the effort. The rise was insignificant when the environmental temperature was low, but quite obvious at room and higher temperatures. A similar result was obtained during the static loading of the body with a knapsack. The drop in temperature under the clothing and on the skin was slight, but the subsequent increase was more substantial. This becomes understandable if we consider that after an effort an improvement occurs in the blood content of the muscles which were previously in a state of tension. At the same time, the burning process of the products of substance changes of the oxygen-less cycle is intensified. Consequently, the phenomenon of temperature rise appears not during but after the static effort.

Physical effort, both static and dynamic, affects the circular reactions of the vessels. This influence is reflected in an amplitude change in the deviations of the plethysmographic curve or in the appearance of beta waves, or both phenomena jointly.

At a lower environmental temperature, properly dosed physical effort enlarges the range of adaptation, which enables the maintenance of the thermoregulatory processes of the organism in an undisturbed state. This results from the temperature's behavior in the area of individual microclimate and from the skin's temperature.

An analysis of the importance of clothing in ensuring a favorable microclimate of persons executing an effort, under changing thermal conditions of the environment, confirms the superior heat-protecting characteristics of cloth uniforms over denim uniforms.

Different clothing also affect the size of light reflection of the blood vessels of the skin. Well insulated uniforms containing air spaces (for example, wool), permit the fluctuation range of the skin vessels' expansion to remain at a certain level. Plethysmographic "zero" curves, obtained under conditions generating the feeling of warm comfort in young and healthy persons, were accepted as the basis for comparisons.

Plethysmographic studies, particularly those associated with other physiological methods, such as temperature measurements in the microclimate area under the clothing and of the skin, can furnish criteria for estimating the heat-protecting attributes of clothing.

Studies of heat loss phenomena during physical exertion in various kinds of clothing, under changing climatic conditions, concern one of the most important factors in the field of the hygienic characteristics of clothing.

The final result of our studies concurs in principle with the work of other authors (18, 20, 27, 29)

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for Sanitation and Hygiene  
and Institute of Labor Hygiene  
(Wojskowe Centralne Laboratorium  
Sanitarno-Higieniczne  
oraz Zakład Higieny Pracy A.M.)  
Warsaw, Chocimska Str. 24

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Received June 20, 1959

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