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SOME OBSERVATIONS ON MEN SITTING QUIETLY IN EXTREME COLD

By STEVEN M. HORVATH,[1] HOWARD GOLDEN,[2] AND JOHN WAGER [2]

(From the Armored Medical Research Laboratory, Fort Knox, Kentucky)

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Military operations in cold weather naturally pose many problems. One of the most important is related to immobilization of men for long periods of time, preventing them from indulging in even the smallest movements from fear of having their presence detected. The experimental work being reported is concerned with the reactions of soldiers sitting quietly for periods of 2 to 3 hours in environmental temperatures ranging from 1° to -40° C.

METHODS

Forty-five young men in excellent physical condition served as subjects for a total of 430 tests. The largest number of exposures for a single individual was 35. Two to 5 tests were performed on each subject in a single environment. One group of 5 subjects was exposed to all environments, with the exception of 1.1° C. The average characteristics of the entire group were as follows: Age, 20.5 years; height, 67.6 inches; weight, 149 pounds; and surface area, 1.79 sq. M.

All exposures were made in the morning between 8 and 12 o'clock. The subjects ate a light breakfast 2 to 3 hours prior to their entrance into the cold room. The men put on thermocouple harnesses of 5 to 15 copper-constantan couples, and after donning their underwear, remained lying quietly for at least ½ hour in a control room, environment 22° C., 50 per cent relative humidity. Basal measurements of skin and rectal temperatures (with a thermocouple or a calibrated rectal thermometer) were then obtained, and the men proceeded to dress in their Artic clothing.[3]

RESULTS

The data obtained are presented in Tables I to III, and Figures 1 to 5. All data presented in the tables are mean values, but in order to indicate to some extent the variability that was encountered, ranges are also given.

Metabolism of seated, clothed men. When men were quietly seated in a relatively cool environment of 22° C. for a 3-hour period, only slight alterations of approximately 5 per cent in metabolism were observed (Table I). Exposure to cold environments was accompanied by increased metabolic rates, and this was evident even in the very first hour of the sitting period. However, irregularities in response were common, varying from no change to increases of over 30 per cent. This latter value, obtained at an environmental temperature of 1.1° C., was exceptional for the first hour; the majority of the increases were around 10 per cent. During the second hour of exposure a striking rise of the metabolic rate occurred at all environments. The highest increase of 53 per cent was observed at the lowest environmental temperature, − 40° C., although no correlation between ambient temperature and metabolic response was noted. The metabolism continued to rise during the third hour, reaching in the − 40° C. environment a value of almost 74 per cent above basal.

Skin and Rectal Temperature. The data are presented in Tables II and III and Figures 1 to 5. The mean skin temperatures were calculated from the 5 skin areas included in Table II (1). The major portion of fall in mean skin temperature occurred in the first hour of exposure. The average mean curves plotted in Figure 1 illustrate this rapid fall. The rate of decreasing temperatures was very slow in the last half of the exposure. While this may be related to the increased metabolism of the later period, more probably it indi-

[1] Major Sn. C.—Now at the Department of Physical Medicine, Graduate School of Medicine, University of Pennsylvania, Philadelphia.

[2] Tec. 3.

[3] "Artic clothing," with insulative value of approximately 4 clo., consisted of:

Underwear, wool 50-50
Trousers, field, alpaca pile (⅜ inch)
Trousers, field, cotton
Jacket, field, pile (⅜ inch)
Parka, field, pile (⅜ inch)
Parka, field, cotton
Socks, cushion sole, 1 pair
Socks, ski, wool, 2 pair
Shoes, felt or
Muklaks, with burlap insoles
Mittens, wool
Mittens, shell, outer

TABLE I

Metabolism of men sitting quietly at different environmental temperatures

Room temp. °C	First hour			Second hour			Third hour		
	Cal. per M² per hr.			Cal. per M² per hr.			Cal. per M² per hr.		
	Mean	Range	Per cent change*	Mean	Range	Per cent change*	Mean	Range	Per cent change*
22.2	50.5	36 to 68		48.0	33 to 62		49.0	35 to 62	
1.1	66.0	65 to 67	30.7				59.5	56 to 63	21.4
−17.8	53.8	46 to 63	6.5	60.8	50 to 75	26.7	62.8	54 to 80	28.2
−23.3	56.1	43 to 66	11.1	67.8	45 to 99	41.2	79.1	57 to 110	61.4
−26.1	56.0	54 to 58	10.9	66.7	56 to 78	39.0			
−28.9	57.0	38 to 75	12.9	66.0	31 to 99	37.5	68.0	59 to 78	38.8
−34.4	49.8	40 to 59	−1.4	63.0	52 to 84	31.2	84.7	57 to 109	72.8
−40.0	57.3	48 to 74	13.5	73.6	55 to 87	53.3	85.2	66 to 106	73.9

* Per cent change in means, the mean values at 22.2°C being used as references.

TABLE II

Skin temperatures of men sitting quietly in the designated environmental temperatures

	1.1°C		−17.8°C		−23.3°C		−26.1°C		−28.9°C		−34.4°C		−40.0°C	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C
Mean skin														
Basal	33.0	31.3 34.6	32.8	31.1 34.4	32.7	26.9 35.7	31.5	29.7 33.3	32.5	28.7 34.3	32.8	32.1 33.9	33.0	30.0 35.5
1 hour	32.1	30.7 34.1	30.4	26.7 31.7	28.5	23.4 33.4	29.4	27.9 30.9	27.8	23.7 31.6	28.2	27.2 29.3	26.5	22.4 29.7
2 hours	31.7	28.7 33.0	28.5	25.1 30.6	26.9	22.5 31.5	28.2	27.2 29.2	26.1	22.7 30.3	27.6	25.0 27.6	25.0	20.7 28.6
3 hours			27.2	24.7 29.5	26.0	21.0 30.1			25.5	22.8 29.1	27.0	26.3 27.3	24.5	20.5 27.9
Thigh														
Basal	31.4	26.6 35.2	33.1	30.5 36.0	32.5	21.9 36.8	29.9	20.7 36.4	31.9	25.0 35.9	31.6	28.0 33.8	32.3	28.1 35.7
1 hour	30.5	29.7 31.6	29.9	24.4 37.7	27.8	18.8 35.7	28.0	17.7 34.1	28.4	18.7 35.6	26.9	23.1 30.7	24.9	15.5 29.8
2 hours	29.3	28.6 30.5	28.5	22.0 37.1	26.2	16.3 33.0	26.4	16.4 33.9	27.3	16.9 36.4	25.6	21.7 30.4	23.9	11.9 31.6
3 hours			26.3	21.3 31.7	25.1	17.1 31.5			24.1	18.3 31.6	25.6	21.3 30.1	23.1	12.0 28.6
Toe														
Basal	32.2	30.0 35.9	29.0	15.8 36.0	29.9	16.3 39.9	26.9	16.2 35.1	26.7	9.2 34.8	30.0	22.5 33.6	30.5	21.2 35.4
1 hour	24.3	15.0 30.1	22.9	9.6 30.8	23.2	5.0 34.4	11.9	5.2 20.0	15.8	2.4 30.8	17.0	11.2 25.8	19.4	7.5 26.6
2 hours	19.0	12.6 29.2	19.4	6.4 29.1	18.4	−1.8 29.4	7.0	−0.3 12.1	9.1	−0.8 21.8	7.1	3.2 13.4	14.2	−0.4 22.1
3 hours			16.7	8.7 26.1	15.1	−0.3 28.0			6.0	0.0 11.5	4.8	1.3 9.5	12.5	−1.6 26.7
Arm														
Basal	33.2	27.0 36.5	33.1	29.9 34.7	33.4	22.4 37.3	32.9	31.1 34.7	32.3	27.4 36.2	33.5	30.5 35.0	33.2	29.2 36.1
1 hour	33.3	29.3 36.8	30.8	27.6 32.0	29.4	14.7 37.4	30.8	27.9 35.7	30.4	21.2 35.8	32.4	29.1 35.8	26.2	19.1 31.2
2 hours	33.0	30.6 36.3	29.5	26.1 31.1	27.6	15.3 34.7	30.8	17.9 27.4	29.3	20.7 35.7	31.3	26.9 35.3	24.3	16.6 31.3
3 hours	33.6	32.4 35.5	27.6	24.0 30.2	26.6	13.0 33.8			31.9	23.2 32.3	30.0	28.3 32.7	22.7	14.8 28.1
Calf														
Basal			31.2	29.7 32.8	31.2	20.5 36.8	32.1	27.9 34.4	32.0	26.9 34.4	32.8	30.5 34.6	32.4	28.9 34.9
1 hour			24.7	21.0 28.4	23.2	12.1 32.2	23.8	21.0 26.9	23.1	18.7 29.7	24.9	21.8 29.7	23.3	18.6 31.0
2 hours			22.6	17.5 28.5	21.2	11.4 31.4	21.6	17.9 25.3	21.2	14.3 26.3	22.9	19.0 28.5	21.1	15.6 28.7
3 hours			21.0	16.7 27.8	20.7	13.0 31.3			20.3	15.6 25.8	22.7	19.4 28.7	20.1	15.4 28.4
Chest														
Basal	33.1	28.3 35.7	34.1	31.9 35.7	34.1	26.4 37.9	34.0	31.4 35.7	33.0	28.2 36.1	34.6	33.4 35.4	34.6	30.3 37.1
1 hour	34.6	31.5 37.0	34.6	31.2 37.8	33.4	23.0 36.7	34.9	30.4 38.2	33.3	27.1 37.6	34.6	31.7 37.6	33.6	17.3 37.8
2 hours	34.7	32.3 36.4	34.0	29.1 38.7	32.9	25.9 36.4	35.3	32.7 36.8	33.4	28.9 37.6	34.7	31.8 37.6	33.4	19.0 36.6
3 hours			34.4	31.0 35.4	32.8	23.1 37.5			33.4	31.0 37.4	33.9	31.9 35.8	33.4	18.9 35.9

cated the attainment of an equilibrium between input and loss of heat from the clothed body. The relative stability of the rectal temperature in this last 1½ to 2 hours of exposure (Table III) adds additional emphasis to this suggested leveling-off phenomenon. With the exception of the curves for environments of − 26.1° and − 34.4° C., there appeared at the end of 3 hours to be a greater drop and a lower final mean skin temperature the colder the environment.

The ranges of skin and rectal temperatures are presented as an indication of the variability to be expected, and the futility of depending upon observations made on a few subjects in experiments of this nature. The frequency distribution of the mean skin temperature during the 3-hour exposure to 2 of the environments studied, viz., – 17.8°, and – 40.0° C. is shown in Figures 2 and 3. They emphasize the rapidity of drop in mean skin values and the scatter that can be expected. Unfortunately, they fail to show that an individual may start off with one of the higher initial temperatures, but end the period of exposure with one of the lowest. For example, at the – 40° C. environment, one subject had an initial value of 35.3° C. and a final value of 17.2° C. while another started with 35.2° C. and ended with 28.3° C. In these cases, neither subject complained of the cold; only the first subject shivered, and this occurred after 170 minutes of exposure.

The data on values obtained for arm, chest, thigh, calf, and toe are also given in Table II as additional evidence of variability, and to show the regional differences in rate and degree of change in the temperatures of these parts. The susceptibility of the extremities to low environmental temperatures, and the progressively greater inadequacy of foot protection, are indicated by the frequency distribution diagrams of Figures 4 and 5. Toe temperatures below 0° C. were recorded in

TABLE III

Rectal temperatures of men sitting quietly at designated environmental temperatures

Room temperature	Basal			First hour			Second hour			Third hour		
	Mean	Range		Mean	Range		Mean	Range		Mean	Range	
°C	°C	°C		°C	°C		°C	°C		°C	°C	
22.2	37.8	37.4	38.1	37.1	36.1	37.6	37.0	36.4	37.4	37.0	36.3	37.6
1.1	37.4	37.2	37.6	36.9	36.6	37.2	36.8	36.4	37.0			
−17.8	37.4	37.0	37.9	37.2	36.6	38.1	36.9	36.3	37.7	36.7	36.3	37.3
−23.3	37.8	36.9	38.4	37.2	36.7	37.5	36.8	35.9	37.6	36.8	35.8	37.6
−26.1	37.4	37.0	37.8	37.0	36.8	37.4	36.7	36.4	36.9			
−28.9	38.0	36.1	38.2	37.0	36.0	37.6	36.8	35.8	37.2	36.7	35.4	37.1
−34.4	37.3	36.9	37.6	37.1	36.8	37.3	36.6	36.4	36.7	36.4	36.1	36.7
−40.0	37.4	37.0	38.1	36.9	36.8	37.2	36.8	36.2	37.2	36.7	36.1	37.1

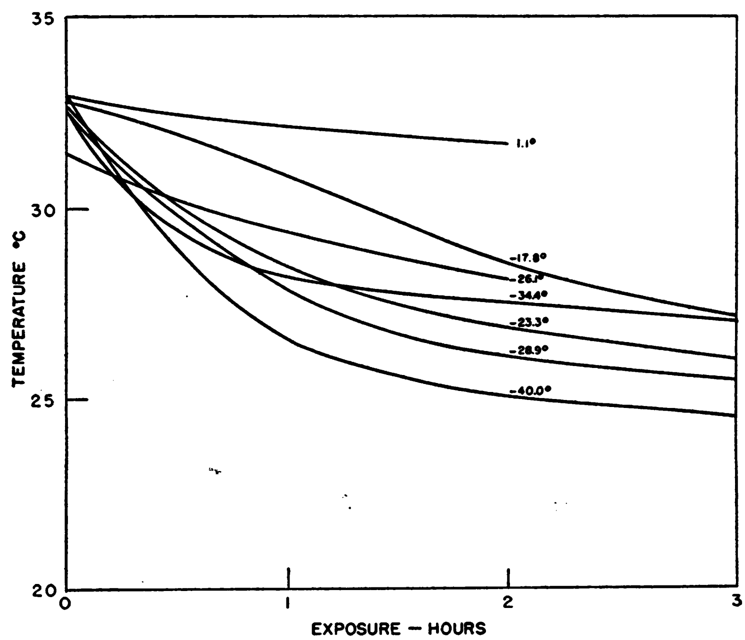

FIG. 1. MEAN SKIN TEMPERATURES OF SITTING MEN EXPOSED TO LOW ENVIRONMENTAL TEMPERATURES

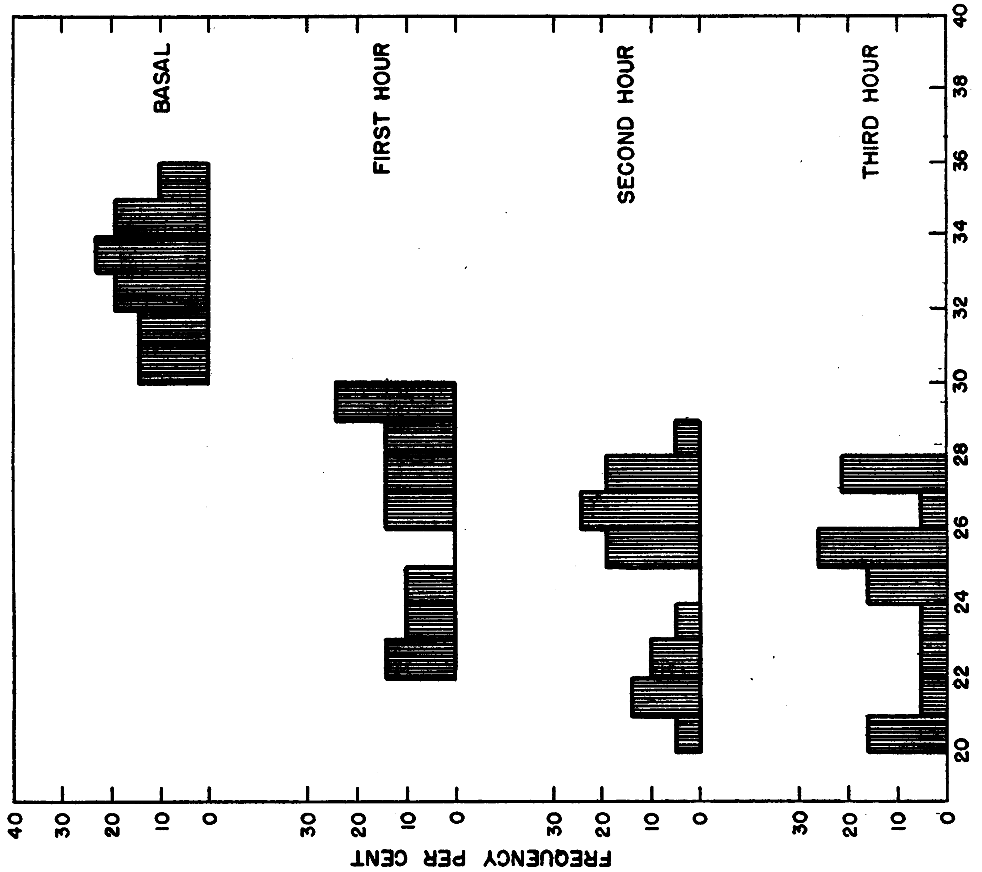

FIG. 3. FREQUENCY DISTRIBUTION IN MEAN SKIN TEMPERATURE OF MEN SITTING DURING A 3-HOUR EXPOSURE TO − 40.0° C.

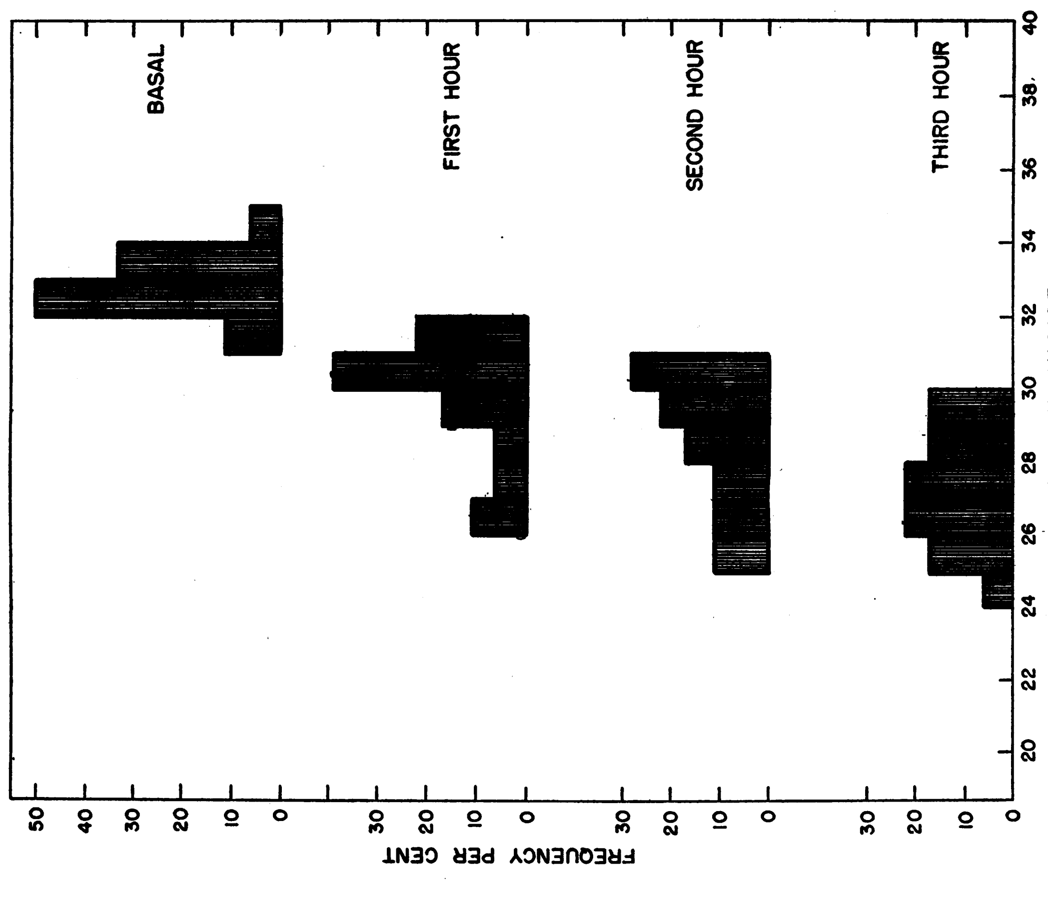

FIG. 2. FREQUENCY DISTRIBUTION IN MEAN SKIN TEMPERATURE OF MEN SITTING DURING A THREE-HOUR EXPOSURE TO − 17.8° C.

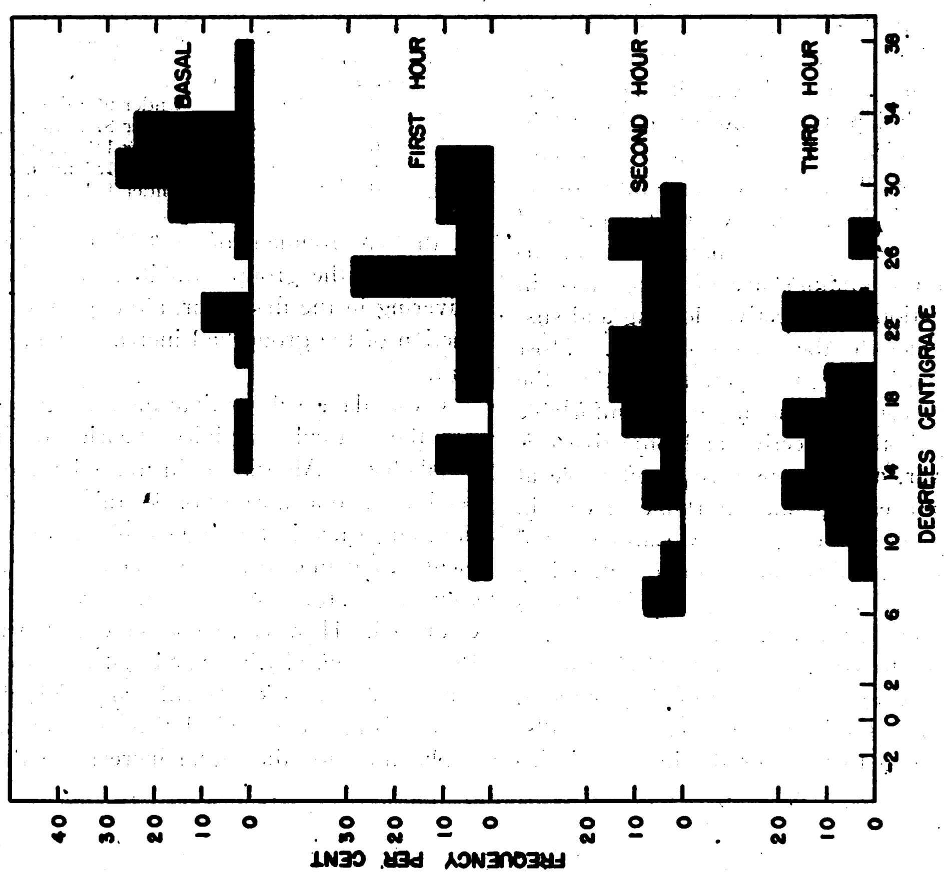

FIG. 4. FREQUENCY DISTRIBUTION IN TOE TEMPERATURE OF MEN SITTING DURING A 3-HOUR EXPOSURE TO − 17.8° C.

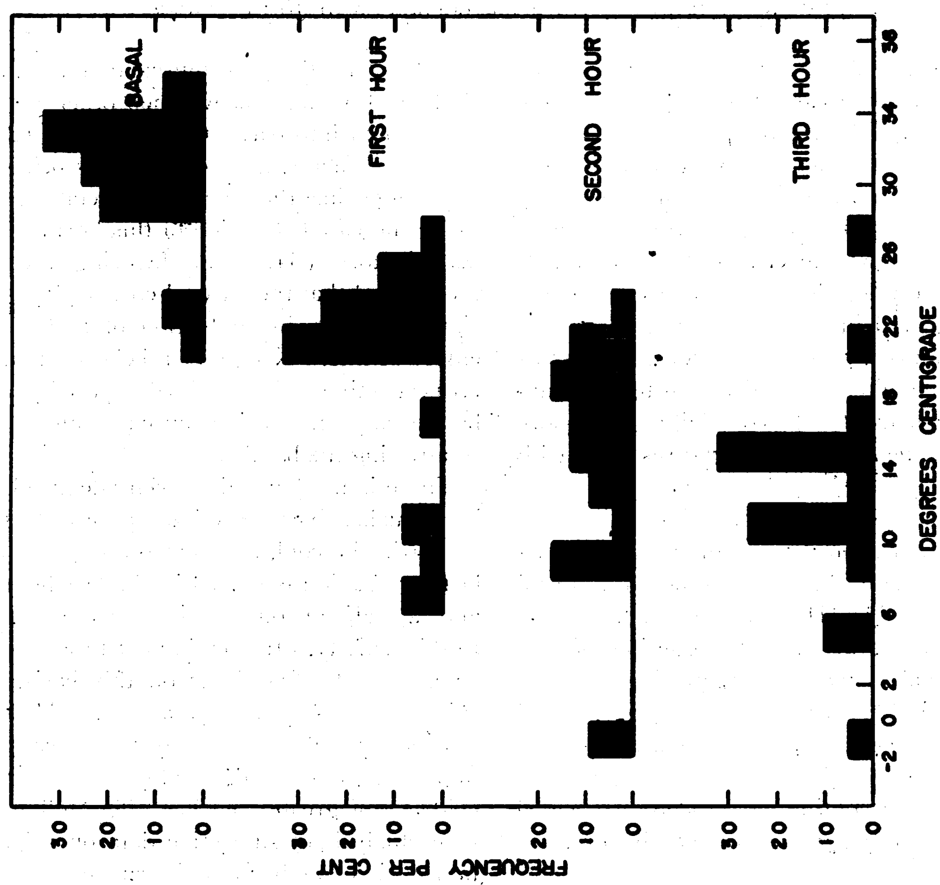

FIG. 5. FREQUENCY DISTRIBUTION IN TOE TEMPERATURE OF MEN SITTING DURING A 3-HOUR EXPOSURE TO − 40.0° C.

environments of − 23° C. and below. These occurred in a number of cases before 2 hours of the exposure had elapsed. In some individuals a phasic type of response was observed, in which the toe temperature, after the above amount of cooling, suddenly rose 5 to 10 degrees, but returned again very rapidly to lower levels. Other individuals remained at these low levels. No cases of frostbite were observed in any of the subjects. Subjective complaints regarding toes and other areas could not be definitely related to the temperature of the part. Frequently the complaints were more vigorous with the higher temperatures than with the lower.

The observations made on the diversity in rate and extent of fall in mean skin or individual part temperatures, were also observed with rectal temperatures (Table III). Considerable caution must be exercised in the interpretation of any single individual value. An interesting observation was the finding that after the men returned to a comfortable environment, 22° C., their rectal temperatures continued to fall. This is probably a reflection of the continuing transport of cooled blood from the body surface to the body core.

DISCUSSION

The variability observed in the reactions of men to cold environments are related, although not as a positive correlation, to the variations in metabolism, in mean skin, body and in unit area temperatures. Since all subjects wore clothing offering essentially similar insulative protection, and since tests were made on each man in several environments, these findings are of importance in the final evaluation of protective clothing and susceptibility of men to the effects of cold. Most subjects followed a regular pattern in that the colder the environment the more uncomfortable they were, by both subjective and objective criteria. However, a few men were comfortable at lower temperatures and uncomfortable at certain higher ones. The cause of these variations could not be determined, and remains a major stumbling block to a delineation of the physiologic responses of men to cold environments.

On exposure to cold, the total metabolism is increased (Table I). The cause of the increased heat production is not clear, and considerable dispute has arisen as to whether the increase is induced solely through muscular movements, including shivering, or whether other mechanisms are brought into play. Cannon *et al.* (2), favors a humoral factor, *i.e.*, adrenalin, as being the factor, suggesting that increased metabolism is due to the increased secretion of this hormone. Other investigators (3), while favoring the humoral theory, feel that the adrenal cortex plays the more significant role in adaptation of animals to cold environments. Krogh (4) believes that the increased activity of the animal exposed to cold may be the factor increasing muscle tonus at rest, and so affecting the basal rate.

There is no doubt that even adequately clothed individuals shiver, sometimes quite violently, while sitting in the cold, and that the large increases in heat production observed in the last hour to hour and a half in our subjects were mainly due to this activity. It was difficult to explain the increases in the first hour on this basis, as gross shivering was generally absent. Although increased muscular tonus may be the cause, it was impossible by methods employed to determine any evidence of greater tension. The following table is an analysis of subjective data on shivering obtained at an ambient temperature of − 28.9° C.

Number of subjects	Exposure time at onset of shivering
per cent	
10	Under 66 minutes
25	Under 87 minutes
50	Under 119 minutes
75	Under 151 minutes
90	Under 181 minutes

At this environment of − 28.9° C., only a small fraction of the group exhibited even the mildest shivering in the first hour, although the heat production of the group had increased almost 13 per cent.

These data substantiate neither the chemical nor the muscular activity theories of increased metabolism. Alterations in muscular tone cannot be eliminated as a cause of the raised heat production, and since it was impossible in these experiments to demonstrate an increased secretion of epinephrine, the role of this factor cannot be clearly evaluated. However, since the experiments of de Barenne, *et al.* (5) indicated that increased muscle tone is not associated with any high degree of metabolism, the chemical theory is an attractive explanation for the initial increase in the metabolism of clothed men sitting quietly in a cold environment. Furthermore, Hicks (6) has performed experiments on the Australian aborigine, suggesting that the increased heat production at low environmental temperatures is not brought about by shivering.

Higher skin temperatures were sometimes associated with high metabolic rates, but the contrary was also observed, *i.e.*, high metabolism with lowered skin temperatures. Swift (7) reported that his partially nude subjects began to shiver when the skin temperature reached 19° C. No such correlation was found in the present observations, but heavy clothing worn by these men may have interfered with their responses. When shivering did occur, skin temperatures of 29° C. to 16° C. were recorded. Individuals had different responses on different days under identical environmental conditions.

The changes in rectal temperature bore no relation to the metabolic rate. Swift's (7) data on lightly clothed subjects indicated that changes in rectal temperatures were not a stimulus to shivering and, therefore, were not related to the increased metabolic rates observed. Vaughn's (8) metabolic studies on subjects whose rectal temperatures had been lowered to approximately 84° F., disclosed that there was a relationship between rectal temperatures and metabolism, since all subjects had a markedly lowered metabolic rate. However, Dill and Forbes (9) in similar experiments reported the total energy exchange to be above basal levels due to shivering, voluntary activity, and a muscular rigidity of unknown origin.

The data that have been presented illustrate some of the physiological changes that occurred in men exposed to low environmental temperatures. The responses of man to cold is complicated by a number of extraneous factors which are, at present, poorly understood. Physiological and psychological studies in progress at the present time will, it is hoped, clarify a number of points regarding the variability of the response of clothed men to very cold environments.

SUMMARY

1. Continuous observations were made of the metabolic rate, skin and rectal temperatures of men while dressed in Artic uniforms and sitting quietly in extremely cold environments. Ambient temperatures ranged from 1.1 to − 40.0° C.

2. The heat production in the cold was above basal values during the entire test period. In the − 40° C. environment, average metabolic increases of 13, 53, and 74 per cent were recorded for the first, second and third hours respectively. The rise in heat output during the first hour could not be explained on the basis of shivering. In the third hour, shivering was present in the majority of the subjects. Neither the role of chemical mediators, nor that of increased muscular tonus, could be clearly delineated, and require additional investigation.

3. The fall in rectal temperatures was moderate, although values of 35.4° C. were occasionally observed. The absolute value was not correlated with the presence of shivering and, therefore, low rectal temperatures could not be considered as the stimulus for shivering.

4. Mean skin temperatures fell precipitously during the first hour of exposure, and were stabilized before the end of the test period. Considerable variability was observed in both the rate and extent of fall, not only in different men, but in repeat tests on the same subject.

5. Of all the skin areas, the hands and feet exhibited the greatest temperature changes in both rate and degree of fall. Toe temperatures below 0° C. were noted in several instances. The susceptibility of the extremities to cold environments was related to their sensitive vasomotor mechanisms, and to the fact that they were provided with the least amount of insulative protection.

6. The responses of men exposed to cold environments are subject to considerable variation, and extreme care must be exercised in the interpretation of data obtained, whether on a few or a large number of subjects.

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