RCC1.960715.002

ARCTIC AEROMEDICAL Laboratory

THE METABOLIC AND BODY TEMPERATURE RESPONSE OF MEN EXPOSED TO AN ACUTE COLD STRESS BEFORE AND FOLLOWING AN ARCTIC BIVOUAC

TECHNICAL REPORT 57-37

LADD AIR FORCE BASE

A L A S K A

USAF SCHOOL OF AEROSPACE MEDICINE
AEROMEDICAL LIBRARY
BROOKS AIR FORCE BASE, TEXAS

AD 294 054

THE METABOLIC AND BODY TEMPERATURE RESPONSE OF MEN EXPOSED TO AN ACUTE COLD STRESS BEFORE AND FOLLOWING AN ARCTIC BIVOUAC

DONALD W. RENNIE, Captain, USAF (MC)
THOMAS ADAMS, First Lieutenant, USAF

Department of Physiology
Arctic Aeromedical Laboratory

TECHNICAL REPORT 57-37

Alaskan Air Command
ARCTIC AEROMEDICAL LABORATORY
LADD AIR FORCE BASE
July 1958

ABSTRACT

The metabolism and body temperatures of six subjects were recorded during a standardized cold test before and following a 24-day arctic winter bivouac in order to determine if any changes, which might be ascribed to living in a cold environment, took place in their thermoregulatory response. The body heat debt, total body heat loss, tissue and environmental insulation and blood flow to certain skin areas were estimated from these data. Basal metabolism and thyroid function using I^{131} uptake were also measured in each subject before and following the bivouac.

No change in basal metabolism of I^{131} uptake was noted in any subject following the field exposure. During the cold test, the metabolism increased by an identical amount before and following the field exposure. Total body heat loss was slightly but not significantly greater during the post-bivouac tests; and the insulation of the subject's environment and mean body tissue insulation were the same during both test periods.

There were significantly higher skin temperatures of the arms, hands, lower legs, and feet at the completion of the post-bivouac test when compared with the pre-bivouac values. The temperatures of other skin areas and the rectal temperature were identical from one test period to another. The warmer extremity temperatures indicate a relatively reduced vascular constriction in response to cold in the limbs of the acclimatized subjects.

Acclimatization to the degree of chronic cold to which these men were exposed was localized to the heat distribution function of the peripheral vasculature. No evidence was found for any generalized acclimatization involving altered metabolism.

THE METABOLIC AND BODY TEMPERATURE RESPONSE OF MEN EXPOSED TO AN ACUTE COLD STRESS BEFORE AND FOLLOWING AN ARCTIC BIVOUAC

INTRODUCTION

Recent attempts to demonstrate any appreciable degree of cold acclimatization in man have met with disappointing results. Brown (8), in a recent review, strikes a particularly pessimistic note in his concluding sentence when he states: "If the only goal of work on cold acclimatization is the increase of the functional capacity of the white man in the Arctic, it may be a relatively unprofitable field of endeavor." Horvath et al. (22) also point out the lack of any appreciable change in physiologic function accompanying chronic cold exposure and contrast this with the more obvious acclimatization to other environmental stresses such as altitude or heat. Yet, practical experience such as Frazier's (17), while poorly documented with scientific fact, suggests that changes do occur in body function and cold tolerance and that these changes measurably increase man's efficiency in the cold. Undue pessimism on the importance of such a complex phenomenon as cold acclimatization in man seems unwarranted until more is known about its nature.

Information is particularly sparse and conflicting on man's heat production and heat distribution mechanisms during the development of cold acclimatization. Basal heat production, following varying degrees of chronic cold exposure, has been reported as elevated by some investigators, notably Newburgh and Spealman (28), Horvath et al. (22), and by Ames and Goldthwait (2) on one of their subjects who experienced an unusual degree of cold exposure. Ingbar et al. (23) have recently reported a rise in thyroid hormone

production in a series of five subjects who lived continuously for 13 days at an air temperature of 13° C. while clothed in cotton shorts. This was calculated from thyroidal radioiodine clearance rates and plasma inorganic iodine levels. They present evidence suggesting an increased peripheral utilization of thyroid hormone. Unfortunately, no basal metabolism data on these subjects were presented. Most investigators (2, 3, 4, 16, 33 and 34) report no change in basal metabolism following chronic cold exposure. Perhaps part of the discrepancy in results is due to variations in the severity or duration of cold exposure. More data are needed on the basal metabolism of humans exposed to severe cold for prolonged periods of time, such as members of arctic or antarctic expeditions.

The heat production of men exposed to acute cold rises as a heat debt is incurred. Controversy still exists on the classical problem of "chemical regulation" vs. increased skeletal muscle activity in the genesis of this increased heat production. In addition, the effect of chronic cold exposure on this metabolic response is inconclusive. Balke et al. (3), following the course of a 3-week bivouac, noted a reduced metabolic response compared with the pre-bivouac values during immersion in a water bath at 20° C. Schwiegk (31) comments on a decreased tendency to shiver as one of the physiologic changes accompanying cold acclimatization. Ames and Goldthwait (2) felt that shivering was delayed somewhat in their subjects as they became cold acclimatized. LeBlanc (24) has recently reported a greatly reduced metabolic response to acute cold stress in men following a subarctic bivouac. Carlson et al. (12) observed a relatively reduced metabolism for a given average skin temperature among men chronically exposed to cold. On the other hand, Meehan (26), employing Alaskan natives, and Elsner (15),

studying Whites before and following an arctic bivouac, report an increased tendency to shiver among those chronically exposed to cold. Scholander et al. (29) have recently completed a study on native Laplanders and find that the metabolism of this group and of those not accustomed to living outdoors is the same when compared over the normal comfort zone and at temperatures below the "critical temperature" for man (around 27° C.). Part of these results are ascribed to the excellent microclimate which is part of the Lapps' cultural adaptation to cold weather living; in other words, they may not have any stimulus for generalized cold acclimatization changes. In a very rigorous field study yet to be reported in detail, Scholander et al. (30) noted that when men are exposed to environmental temperatures below the critical temperature and are denied sufficient clothing insulation, sustained shivering even during sleep is a prime requisite for successful adaptation. Further inquiry is warranted on the shivering and metabolic responses of acclimatized and non-acclimatized men during cold stress to determine what differences exist and the mechanisms involved.

Changes in the vascular response to cold arising from chronic cold exposure could alter heat distribution within the body as well as improve digital function and resistance to local cold injury. The bulk of data from numerous investigations employing a wide variety of cold tests indicates that the peripheral vascular constriction in response to cold is attenuated among cold acclimatized men (2, 15, 18, 22, 27, and 35). However, not all data support this conclusion. Adolph and Molnar (1) were unable to demonstrate any changes in skin temperature, rectal temperature, or metabolism which could be construed as acclimatization. Stein et al. (34) report an accelerated drop in toe temperature of their subjects as

cold acclimatization progressed and interpret this as indicating a more intense peripheral vasoconstriction. Glickman et al. (19) found that as cold acclimatization occurred in their subjects it was accompanied by a decreased drop in rectal temperature on exposure to cold. This suggests an increase in peripheral tone and a consequent increased tissue insulation. Goldby et al. (20), reporting on the comparative vascular reaction of Australian aborigines adapted to living at temperatures as low as 0° C. and of white members of his expedition, observed an increased vasomotor lability among the aborigines. However, Brown's numerous data on the Eskimo (5, 6, 7 and 8) indicate an elevated peripheral blood flow among these people compared with Whites exposed to the same cold test. Racial variations in the thermoregulatory response to cold may detract from the applicability of these latter studies.

From the above considerations and from additional data obtained while on Alaskan field trips, Carlson et al. (12, 13) have evolved a very interesting hypothesis of cold acclimatization in man. They feel that among cold acclimatized men there is a subtle and complex alteration in both the metabolic and vascular response to acute cold stress which results in a different pattern of thermoregulation. The extremity skin remains warmer, whereas the thermal gradient from rectum (core) to subcutaneous tissue is increased: cooling of the peripheral subcutaneous tissues of the body (shell) supplies a greater proportion of the total body heat loss than before acclimatization. For a given level of average skin temperature, the metabolic rate remains lower in the acclimatized than in the nonacclimatized man. This concept requires additional testing under a variety of experimental conditions, as Carlson et al. (12, 13) have acknowledged, to

establish more firmly the precise pattern of the heat production and distribution during acclimatization.

It was the aim of this study to determine the metabolic and body temperature response of men to an acute cold test before and following an arctic bivouac, using this response as a measure of cold acclimatization. In addition, basal metabolism was determined before and following the field phase as was thyroid function using the radioactive iodine uptake technique.

METHODS

Experimental Subjects

Six volunteers were chosen from among Ladd Air Force Base personnel. Four of these men had duty assignments as clerical workers and the remaining were outdoors for an hour or two daily as part of their duty assignment. The men had no physical abnormalities and were in good health throughout the duration of the experiment. The physical characteristics of the subjects are summarized in table I. With the exception of subject

TABLE I

PHYSICAL MEASUREMENTS OF SUBJECTS BEFORE AND AFTER BIVOUAC

	Age	Height (cm.)	Weight (Kg.)		Surface Area (M^2)	
			Pre-bivouac	Post-bivouac	Pre-bivouac	Post-bivouac
Mean	25	175	69.5	69.6	1.83	1.83
Range	18-37	170-183	52.3-80.9	54.5-80.7		

B, who was an extremely thin individual, there were no outstanding features that distinguished these men from average.

Field Exposure

The field site was situated approximately 20 miles north of Fairbanks, Alaska, at an elevation of 2,100 feet and a distance of 3 miles from the nearest highway. Access to the site was by ski or snowshoe. The subjects stayed within a 5-mile radius of this site from 6 January through 30 January 1956, during which time the ambient air temperature, wind velocity, and percent cloud cover in the vicinity of the campsite were recorded at 4-hour intervals. The meteorological data are summarized in figure 1. The subjects improvised shelters of snowblocks, spruce boughs, and parachute cloth

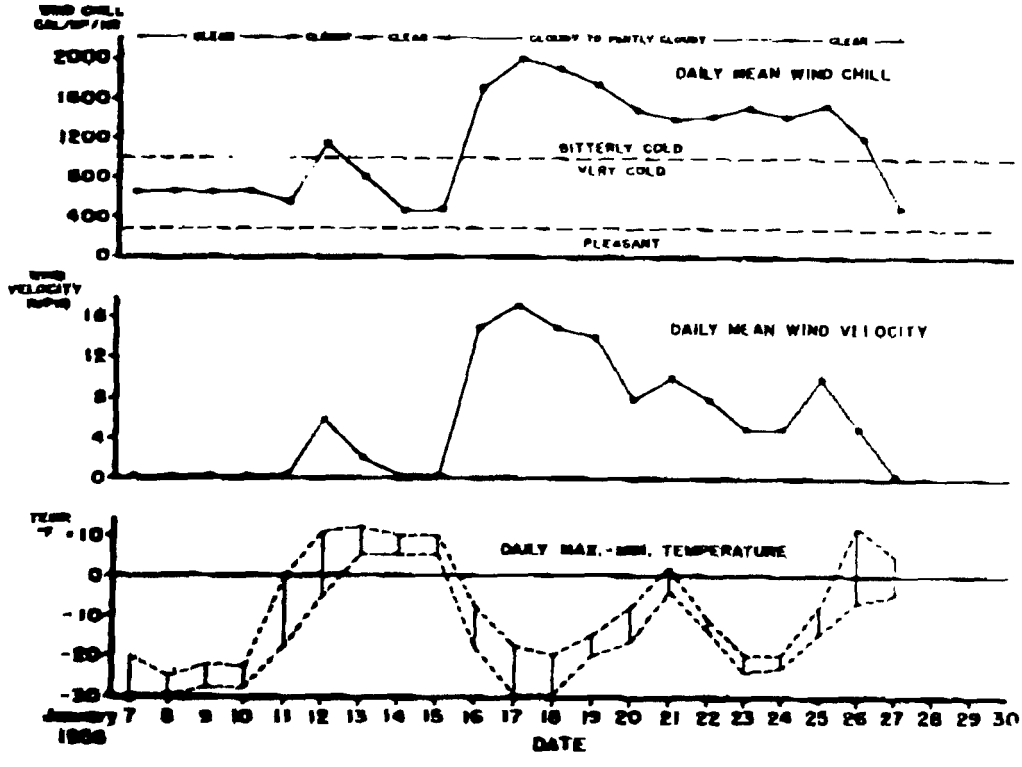

FIGURE 1

Ambient air temperature, wind velocity, wind chill, and the percent cloud cover in the vicinity of the campsite during the field bivouac.

for sleeping and for the storage of personal equipment. No heat was permitted within these shelters. A cook shack of spruce logs and snowblocks was constructed by the subjects, and they were permitted inside this structure for a total of three 45-minute periods daily while eating. Within this cook shack, the mean temperature throughout the period of this bivouac was 0° F. (range, +11° to -25° F.; SD, 8° F.).

Daily activity, which consisted of supervised skiing, snowshoeing, gathering wood for the cook stove, participation in controlled field experiments and general camp chores, commenced at 0730 hours and ceased at 1800 hours. By 2000 hours, the men were generally in their sleeping bags. Clothing was standard Air Force arctic issue.

In order to gain some idea of the over-all energy balance of the men while on this bivouac, the caloric intake was measured by weighing food portions on 11 days selected at random throughout the bivouac; and the nude weights of the men were measured in the observation shack before breakfast on 9 days also selected at random. The daily weights and caloric intakes are summarized graphically in figure 2. Note that on a mean caloric intake of 3,946 calories per day the men lost an average of -2.6 kg. in 24 days.

Unfortunately, very little data were obtained on the thermal balance of these subjects during daytime activity. However, observations were made on the men during the evening hours while they slept or rested in their sleeping bags. Rectal temperature and 15 separate skin temperatures were measured by means of thermocouples and a portable potentiometer at 2-hour intervals on each of three subjects for a total of 7 nights. During the same evenings, the resting metabolism was sampled several times by gently arousing the subject, collecting a measured volume of expired air in a Douglas bag, analyzing for oxygen and calculating the metabolism from the

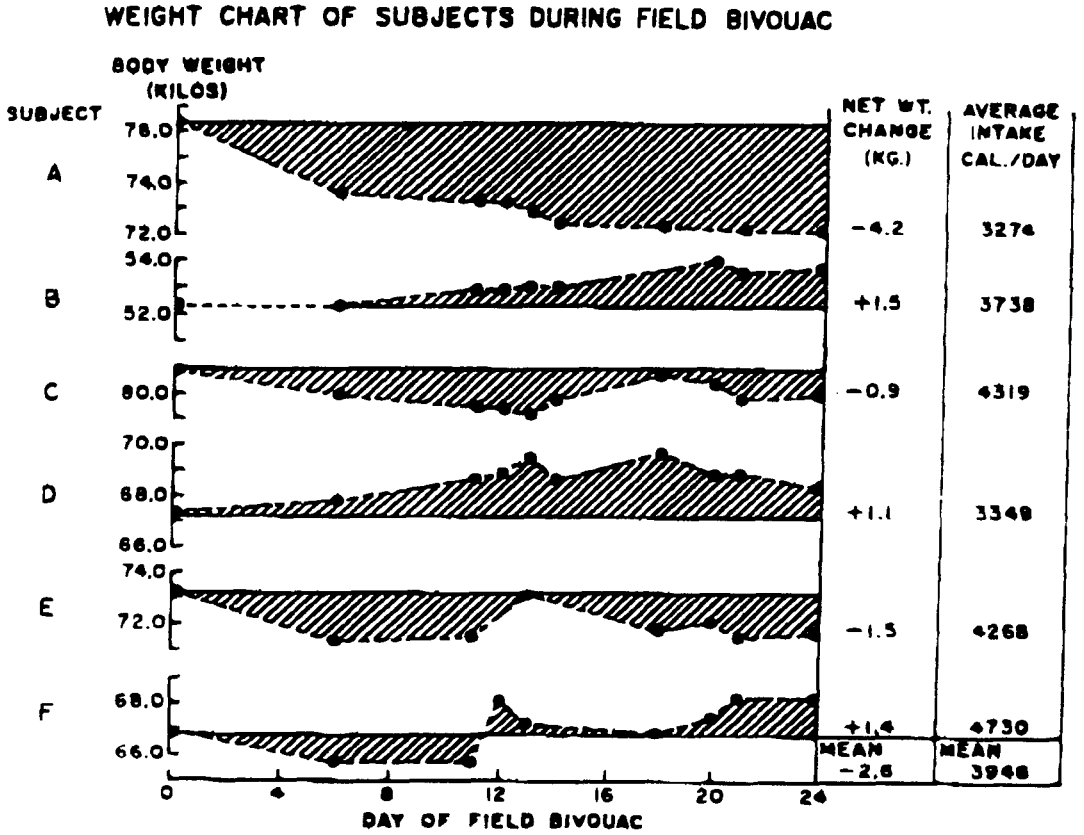

FIGURE 2

Nude body weight, net change in body weight and average daily caloric intake for each subject during the field bivouac.

formula proposed by Weir (36). Evaporative heat loss was estimated by measuring the weight loss of the subjects on a platform balance sensitive to 5 grams. From these data, a thermal balance sheet was constructed and summarized in table II. We deduce from these results that the men were under no great cold stress during at least one-third of the time they were in the field despite the rigorous external environment. Outside of their shelters, however, they experienced considerable discomfort from the face, hands, and feet unless they kept active.

Thyroid Activity Tests

Basal metabolisms of the subjects were determined between the hours of 0730 and 0930 hours for the 2 days before and the 4 days following the field

TABLE II

THERMAL BALANCE DURING SLEEP WHILE ON BIVOUAC

Mean metabolic rate . . . . . (21 observations)	41 ± 5* kg.-cal./M^2/hr.
Mean body heat debt . . . . . (7 observations)	0; range, + 2.5 to -3.5 kg.-cal./M^2/hr.
Mean evaporative heat loss	14 ± 3 kg.-cal./M^2/hr.
Nonevaporative heat loss	27 kg.-cal./M^2/hr.

*Standard deviation

exercise. Duplicate determinations were performed on each subject using open circuit indirect calorimetry. A 10-minute expired air sample was collected in a 120 liter spirometer and an aliquot analyzed for its oxygen content in a Beckman Oxygen Analyzer. Heat production was calculated according to the method described by Weir (36). The caloric equivalent of a liter of expired air was taken as $1.046 - 0.05\ O_E$ where O_E is the percent oxygen in expired air.

Thyroidal uptake of I^{131} was determined in the conventional manner 6, 12, 24, and 48 hours after ingestion of the radioiodine. A scintillation counter was positioned 15 inches in front of the gland for this purpose. The dosage was 15 microcuries of carrier-free I^{131} in capsule form before breakfast initially and 10 microcuries following the field exercise. Urinary elimination of the I^{131} sample was determined at the same time intervals as the thyroidal uptake by comparing the activity of a suitably prepared urine sample with a standard solution of I^{131} in a well-type scintillation counter. In addition, the protein-bound I^{131} was

determined, using a venous blood sample drawn 24 hours after ingestion of the I^{131}.

Cold Room Exposure

The cold room in which the subjects were exposed was kept at a temperature of 50° F. ± 2° F. throughout the experiment and was not permitted to warm above this temperature when not in use so that the wall temperature remained the same as air temperature. Air movement within the room was kept constant and at a low velocity by the use of a small, baffled fan; however, no measurement was made of the cooling power of the air.

A canvas cot covered with a wool blanket supported the supine subject. This was comfortable for the duration of the experiment, but it did not permit free circulation of air over the back of the subject. Arm boards kept the subjects' arms extended at an angle of approximately 30° from their bodies.

Each subject, clothed only in cotton shorts, was placed on the cot outside the cold room and all preliminary preparations were completed at a comfortable air temperature. The subjects were then covered with the liner of a down sleeping bag, and the entire ensemble was carried into the cold room where the subjects rested for an additional 45 minutes. The purpose of these preliminary rest periods was to attain thermal equilibrium. During the last 30 minutes prior to removal of the liner, control measurements of body temperature and metabolism were taken. The liner then was removed and the 100-minute cold air exposure commenced.

Body Temperature Measurement

To measure skin temperature, 30-gauge copper-constantan thermocouples were taped to the skin locations indicated in table III and connected into recording Brown-Honeywell potentiometers having internal zero reference

junctions. Rectal thermocouples were constructed from #10 urethral catheters fitted with silver tips into which were soldered the thermocouple junctions. Rectal temperature was recorded at a depth of 10 centimeters. The thermocouple-potentiometer unit was accurate to $\pm 0.01^{\circ}$ C. over the physiologic temperature range.

Mean skin temperature was calculated according to the method described by Hardy and Dubois (21) using the weighting factors indicated in table III. Digital temperatures were recorded from the finger pads of two fingers and the dorsum of two toes.

Metabolism

The body heat production during the cold exposure was measured by open circuit indirect calorimetry using the formula proposed by Weir (36). Expired air volume was measured continuously with a dry gas meter and recorded every 5 minutes. An aliquot of expired air (150 cc./min.) was

TABLE III

THERMOCOUPLE LOCATION AND WEIGHTING FACTOR FOR EACH SITE

Body Site	Number of Thermocouples	Percent of Total Skin Area Sampled
Head (face)	1	7
Trunk	7	35
Arm	2	14
Leg	4	32
Hand	1	5
Foot	1	7
Total	16	Total 100

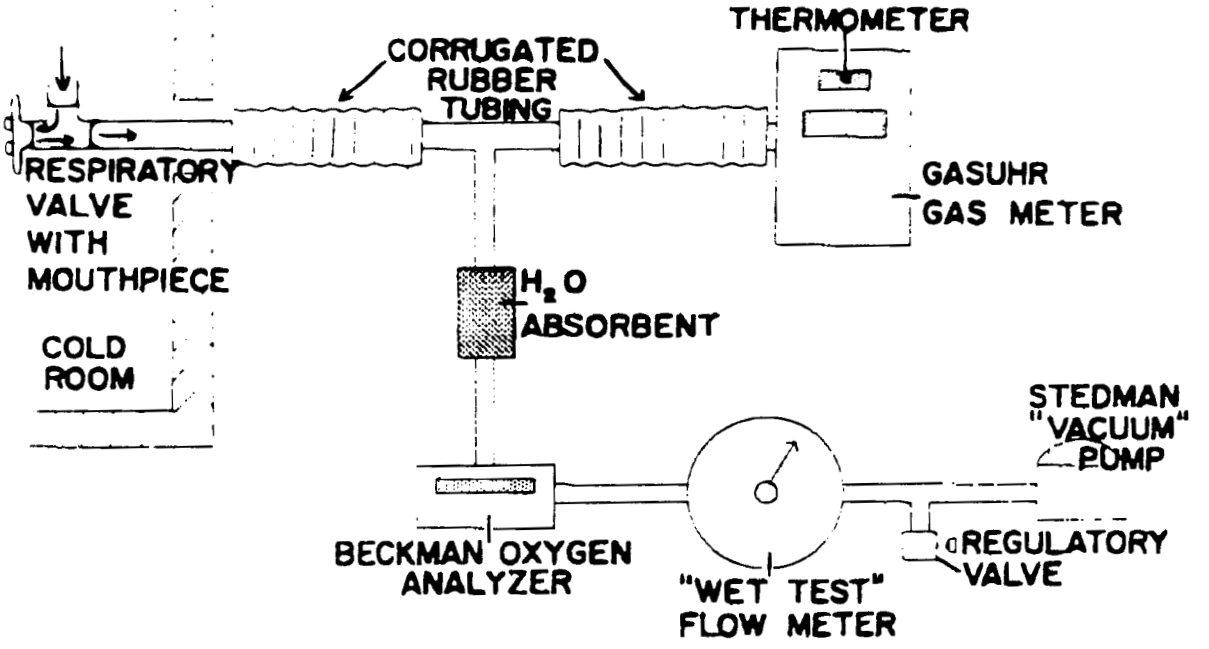

FIGURE 3

Schematic diagram illustrating arrangement of apparatus used in determination of metabolic rates.

TABLE IV

BASAL METABOLISM BEFORE AND AFTER BIVOUAC

	Pre-bivouac	Post-bivouac
Basal metabolism (kg.-cal./M^2/hr.)	43 ± 5*	44 ± 3

*Standard deviation

diverted continuously through a Beckman Oxygen Analyzer, and recordings of the oxygen tension were made every minute and averaged for each 5-minute interval (figure 3).

Statistical Treatment of Data

The significance of the mean difference in basal metabolism thyroidal uptake of I^{131} and urinary elimination of I^{131} was tested by Lord's "t"

test. The body temperature data and the metabolism data for the group of subjects before and following the field bivouac were compared using an analysis of variance.

RESULTS

Thyroid Activity

The basal metabolic rates are summarized in table IV. The group means of the pre- and post-bivouac determinations were 43 and 44 Cal./M^2/Hr. This is not a significant difference.

The thyroidal I^{131} uptake, urinary elimination, and protein-bound I^{131} are summarized in table V. These data are all within the normal range and do not indicate any change in thyroid function as a consequence of the field exercise.

The body temperatures and the heat production of all subjects were determined for a half-hour period prior to the onset of the cold air exposure. These measurements are summarized in table VI and give an indication of the body heat content at the beginning of the test periods. The rectal temperatures of the subjects, when compared for the pre- and post-bivouac control tests, were not significantly different. The rate of body heat production was more variable between the two control periods, and the group mean of the pre-bivouac control (47 Cal./M^2/Hr.) was somewhat lower than that following the field exercise (52 Cal./M^2/Hr.); however, this difference is not significant ($P > 0.05$). The average skin temperatures of the subjects were slightly but significantly higher during the post-bivouac control period ($P < 0.05$).

During the cold test, the rectal temperatures rose a few tenths of a degree centigrade and never fell below the control temperatures; this is

TABLE V

THYROIDAL UPTAKE AND URINARY EXCRETION OF I^{131} BEFORE AND AFTER THE FIELD BIVOUAC

	I^{131} Thyroid Uptake (% of Dose)				I^{131} Urinary Excretion (% of Dose)				Recovery I^{131} (Thyroid Uptake + Urinary Excretion)		PBI^{131} (% of Dose)	PBI (Micrograms %)
	6 Hour	12 Hour	24 Hour	48 Hour	6 Hour	12 Hour	24 Hour	48 Hour	24 Hour	48 Hour	24 Hour	24 Hour
Before Bivouac	13.1	16.8	19.2	21.2	28.4	23.7	12.2	7.8	83.4	93.3	0.9	5.0
After Bivouac	12.7	16.2	18.9	20.8	20.3	20.9	14.8	5.9	74.9	8.6	0.9	5.3

TABLE VI

BODY TEMPERATURES AND METABOLIC RATES DURING THE TEST CONTROL PERIODS

	Pre-bivouac	Post-bivouac	P*
Rectal temperature (° C.)	37.1	37.1	> 0.05
Average skin temperature (° C.)	34.7	35.3	< 0.05
Metabolic rate (kg.-cal./M^2/hr.)	47.0	52.0	> 0.05

*Determined by an analysis of variance.

presented graphically in figure 4. There was no difference in the pattern of the rectal temperature between the pre- and post-bivouac tests except for a tendency of the nonacclimatized subjects to maintain a more elevated temperature near the completion of the cold test.

Average skin temperatures fell rapidly during the first 30-40 minutes of cold exposure and then began to approach an asymptote. This is depicted in figure 4. At the completion of the cold tests, the skin temperatures were still falling at a slow rate and those of the acclimatized subjects

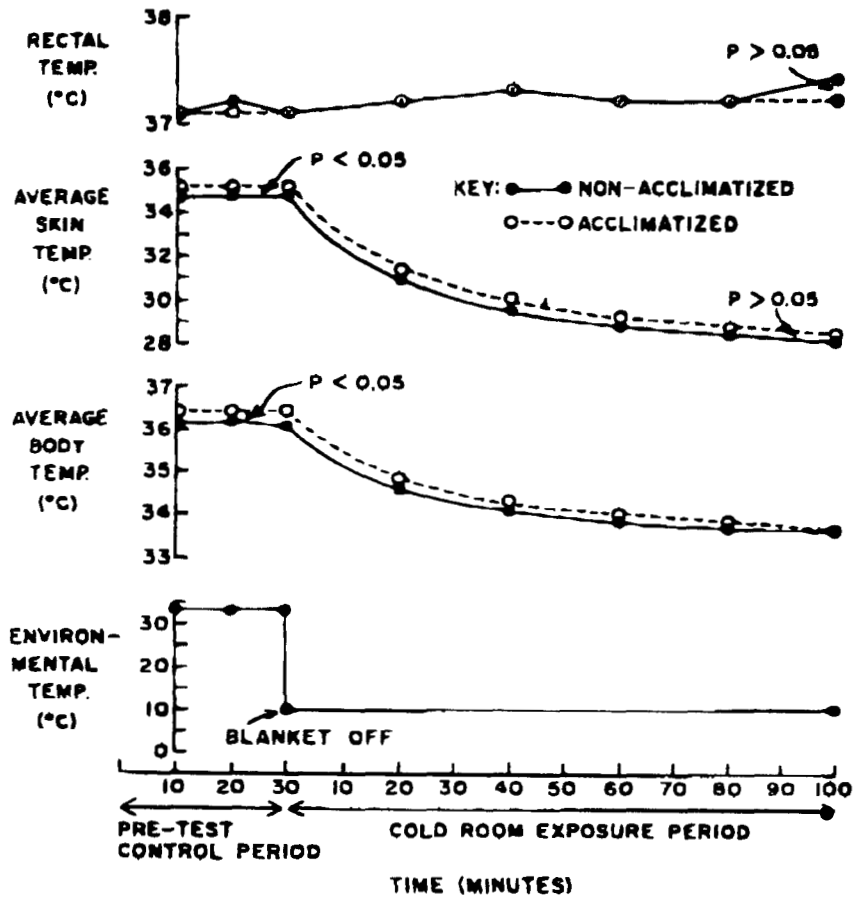

FIGURE 4

The course of rectal temperature, average skin temperature and average body temperature ($0.6T_R + 0.4T_S$) for the average subject during the cold test before and following the field bivouac.

were 0.4° C. higher than before the field exercise. This difference was not significant statistically ($P > 0.05$).

The decline in mean body temperature, which is plotted also in figure 4, is based on the calculation of mean body temperature from the formula (4):

$$T_B = 0.6T_R + 0.4T_S$$

where T_R and T_S are rectal and average skin temperatures, respectively. The initial mean body temperature was higher by 0.3° C. ($P < 0.05$) in the acclimatized subjects due to the effect of the higher skin temperature. The body temperature at the completion of the cold test, however, was identical for both test periods (33.6° C.), indicating that a slightly greater loss of stored body heat occurred in the acclimatized subjects. The magnitude of this increased heat loss was approximately 5 Cal./M^2, assuming that body heat content is the product of body mass, body temperature, and body specific heat (0.83).

The changes in regional skin temperatures during the cold tests are illustrated in figure 5. The skin temperature of the trunk area and upper leg declined at the same rate and to the same extent during the pre- and post-bivouac tests. The arms and hands, as illustrated in figure 5, did not cool as quickly during the post-bivouac tests and at the completion of the cold test were significantly warmer in the acclimatized men.

The metabolic changes during the cold tests are illustrated in figure 6. Metabolism in all test periods rose with the onset of cold exposure and continued to rise throughout the duration of the tests with some waxing and waning depending upon the degree of shivering. The magnitude of the response was identical for the pre- and post-bivouac tests although

the subjects felt more comfortable and did not appear to observers to be shivering as violently during the post-bivouac tests.

DISCUSSION

The over-all heat balance of the subjects was almost identical for each test series. In order to analyze it, the "average subject" was used; that is, the mean of the 12 pre-bivouac runs was compared with the mean of the post-bivouac runs. Any obvious differences between these two values were further tested for statistical significance by an analysis of variance.

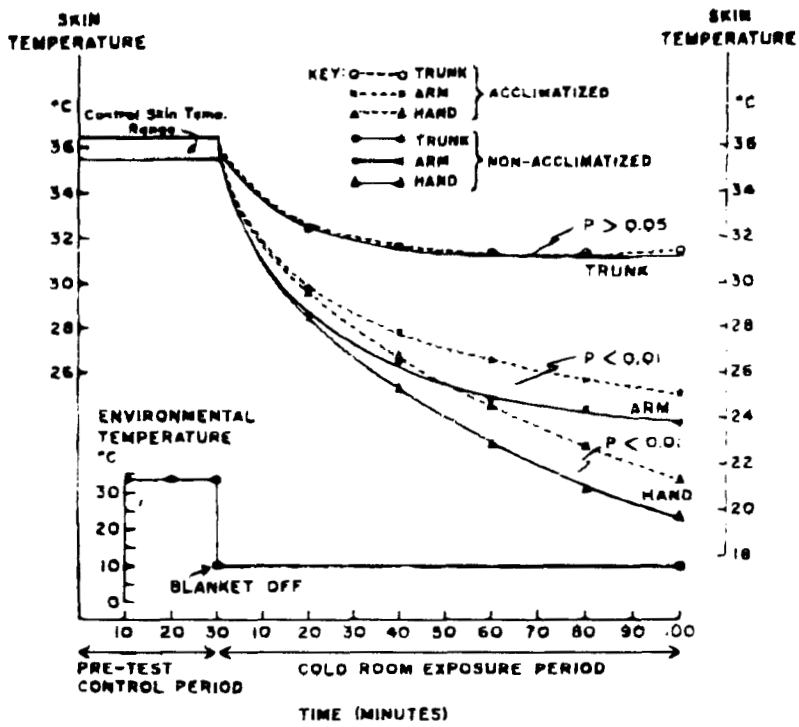

FIGURE 5

Changes in regional skin temperatures (trunk, arm, and hand) of the average subject during cold test before and following field bivouac.

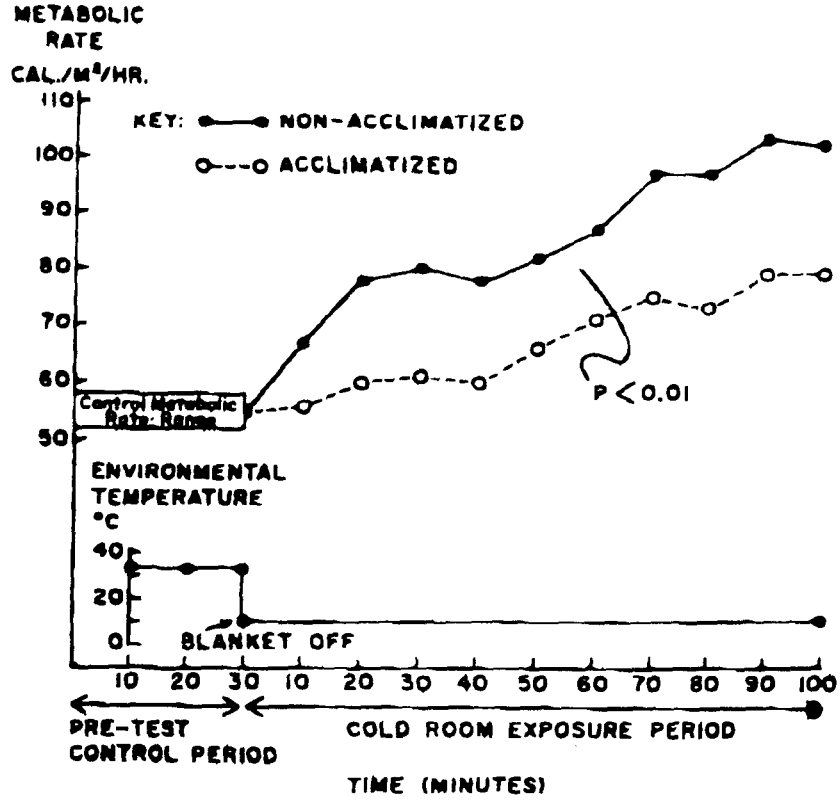

FIGURE 6

Metabolic rates of the average subject during cold test before and following field bivouac.

The extent of the body heat debt, D, may be calculated from the fall in average body temperature, $T_{B_1} - T_{B_2}$, which occurred during the cold test (figure 4). We may express the heat debt for this interval as follows:[1]

$$D = \frac{(T_{B_1} - T_{B_2}) \times 0.83 \times \underline{m}}{S} \quad \text{kg.-cal./M}^2$$

where T_{B_1} and T_{B_2} are the control and final body temperatures, 0.83 is the specific heat of body tissues, $\underline{m}$ is the body mass and S is the surface area.

[1]This and subsequent formulae are taken with very little modification from the discussions of Burton (9, 10, and 11).

According to this calculation, the mean body heat debt incurred by these subjects during the pre-bivouac tests was 81 kg.-cal./M^2; during the post-bivouac tests, 86 kg.-cal./M^2. This is not a statistically significant difference.

The total body heat loss during the interval of these cold tests may be approximated by adding the total heat produced to the mean heat debt:

$$H = M + D$$

where M represents metabolic heat and D is considered positive during a time when heat loss exceeds heat production, as was the case in the present tests.

For the time interval of these tests, the total body heat loss during the pre-bivouac runs was 191 kg.-cal./M^2; during the post-bivouac runs, 198 kg.-cal./M^2. Again there is no significant difference between these two values.

We conclude that the field exposure had no discernible effect on over-all body heat economy during the rather brief interval of these cold tests. There is reason to suspect that the slightly greater heat debt and total body heat loss of the post-bivouac tests would have become significant had the exposure been of longer duration. The reason for postulating this will become evident during the discussion of tissue insulation.

The effective over-all tissue and environmental insulations of the subjects can be estimated for the final few minutes of the exposure when the rate of change of body temperature and metabolism is minimal (figures 4 and 6). The assumption will be made that during the final minutes heat loss equals heat production; that is, mean body temperature is stabilized. As a matter of fact, there is a mean decline in body heat content of only

[illegible] kg.-cal./M^2 (corresponding to a drop in body temperature of [illegible]$^\circ$ C.) during the final 10 minutes. Body insulation can be approximated according to the formula:

$$I_B = \frac{T_R - T_S}{\dot{H}} \quad {}^\circ \text{ C./kg.-cal./M}^2\text{/hr.}$$

where I_B is the effective body insulation, T_R and T_S are rectal and average skin temperatures, respectively, and $\dot{H}$ is the heat flux to the skin in kg.-cal./M^2/hr. (assumed to equal the metabolism in the present case). Substituting the appropriate numerical values for the average subject:

Pre-bivouac: $I_B = \frac{37.4 - 28.0}{82} = 0.115^\circ$ C./kg.-cal./M^2/hr. (0.64 clo units)

Post-bivouac: $I_B = \frac{37.2 - 28.4}{77} = 0.114^\circ$ C./kg.-cal./M^2/hr. (0.64 clo units)

No change in over-all body insulation was effected by the field exposure.

Environmental insulation depends on the same assumptions as body insulation, except that nonevaporative heat loss is the heat flux to be considered.

$$I_E = \frac{T_S - T_A}{\dot{H} - 0.24\,\bar{H}}$$

where T_A is room air temperature and $0.24\,\bar{H}$ is the fraction of resting metabolism lost by evaporation (assumed to equal 12 kg.-cal./M^2/hr.). Substituting as before:

Pre-bivouac: $I_E = \frac{28.0 - 10}{70} = 0.26^\circ$ C./kg.-cal./M^2/hr. (1.4 clo units)

Post-bivouac: $I_E = \frac{28.4 - 10}{65} = 0.28^\circ$ C./kg.-cal./M^2/hr. (1.5 clo units)

These values are somewhat higher than those commonly given for still air insulation (11). The fact that the subjects were lying on a woolen blanket probably explains the discrepancy, since this prevented air circulation over that portion of the skin area.

The lack of any change in environmental insulation between test periods simplifies somewhat the interpretation of the warmer distal extremity skin areas during the post-bivouac tests. As illustrated in figure [illegible] for the arm and hand, certain skin regions did not cool as rapidly or as much following the field phase. This suggests an augmented heat flow (blood flow) to these regions. Burton (9) has emphasized that the absolute level of skin temperature alone is not adequate information for estimating the magnitude of skin blood flow. The ratio of heat delivered to a skin area to that carried away from a skin area gives a more accurate picture of the relative skin blood flow, and this Burton has called the thermal circulation index. It is expressed:

$$TCI = \frac{T_S - T_A}{T_R - T_S}$$

where the symbols have the same meaning as used previously. In the absence of changes in environmental insulation, the thermal circulation index may be related to changes in tissue blood flow and tissue insulation.

In table VII are summarized the skin temperatures and corresponding thermal circulation indexes for the major skin areas at the completion of the cold tests. These are not final "equilibrium" values, particularly for the distal extremities; it is apparent from figure 5 that the skin temperatures still are falling in some of these regions. However, results clearly indicate an augmented heat flux to the skin areas of the foot, hand, and

TABLE VII

REGIONAL SKIN TEMPERATURES AND THERMAL CIRCULATION INDEXES AT THE COMPLETION OF THE COLD TESTS

Skin Area	Skin Temperature (° C.) Pre-bivouac	Skin Temperature (° C.) Post-bivouac	Thermal Circulation Index Pre-bivouac	Thermal Circulation Index Post-bivouac
Trunk	31.2	31.4	3.48	3.64
	($P > 0.05$)*			
Head	29.4	28.8	2.46	2.50
	($P > 0.05$)			
Thigh	26.4	26.3	1.50	1.48
	($P > 0.05$)			
Calf	24.0	24.5	1.05	1.13
	($P = 0.05$)			
Foot	20.1	21.3	0.60	0.71
	($P < 0.05$)			
Arm	23.7	25.0	1.00	1.21
	($P < 0.01$)			
Hand	19.6	21.3	0.55	0.73
	($P < 0.01$)			
Fingers	13.6	15.2	0.15	0.23
	($P = 0.05$)			

*Determined by analysis of variance.

arm and an equivocal increase in heat flux to the skin of the calf and fingers of the post-bivouac subjects. We do not know the mass of tissue involved in this elevated temperature; hence, we cannot estimate the amount of heat that would be required to account for the results. As a very rough approximation, assume that the area involved is about 30 percent of the body surface or 0.5 M^2 and has a thickness of 10 mm. To cause a temperature difference of 1° C. in a mass of tissue of this dimension would require an additional heat content of only about 5 kg.-calories. Our thermometric tech-

niques probably could not detect the small differences in body tissue temperature required to supply this amount of heat. Carlson et al. (13) have described an increased rectal-subcutaneous temperature gradient in the limbs of cold acclimatized men, which suggests that the heat source may lie in the body shell during conditions such as these. The increase in the blood supply that would be required to supply this additional heat should be considerable and amenable to measurement. The fundamental changes that occur to effect heat distribution such as we have observed must involve complicated alterations in vascular reactivity and blood content of the limbs.

Our results suggest that local acclimatization changes may be the only important physiologic ones when men are chronically exposed to severe cold but are able to clothe and shelter themselves, maintain good nutrition, and keep up a high level of physical activity. If this is indeed the case, further study of cold acclimatization in man would most profitably be directed toward the peripheral vascular mechanisms involved.

SUMMARY AND CONCLUSIONS

The metabolism and body temperatures of six subjects were recorded during a standardized cold test before and following a 24-day arctic winter bivouac in order to determine if any changes took place which might be ascribed to living in a cold environment. The body heat debt, total body heat loss, tissue and environmental insulation and vascular reactivity of certain skin areas were estimated from these data. Basal metabolism and thyroid function using I^{131} uptake were also measured in each subject before and following the bivouac.

No change in basal metabolism or I^{131} uptake was noted in any subject following the field exposure.

There was no significant difference in the over-all thermal balance of these men between the pre- and post-bivouac tests; that is, average body temperatures and heat production were almost identical. The effective environmental insulation was unchanged between the two test series.

There was a significantly higher skin temperature of the arms, hands, and feet at the completion of the post-bivouac tests ($P < 0.01$). The temperature of other skin areas and the rectal temperatures were identical from one test period to another. The warmer extremity temperatures are interpreted as indicating a relatively reduced vascular constriction in response to cold stress among the acclimatized subjects, and this local acclimatization was the only detectible effect of the field exposure.

ACKNOWLEDGMENTS

The splendid cooperation and willing service of M/Sgt. Milton Wills, S/Sgt. Arnold Engel, S/Sgt. James Jatras, A/1C James Halderson, A/1C James Moore, and A/1C Rodney England, who served as experimental subjects, are gratefully acknowledged.

We wish to thank T/Sgt. Ben Freeman, T/Sgt. John Carr, S/Sgt. George Sheldon, S/Sgt. John Collins, and A/2C Kenneth Behymer for technical assistance in the field and laboratory.

Dr. Gisle Bang performed the thyroid I^{131} determinations, and we gratefully acknowledge his contribution to this study.

REFERENCES

1. Adolph, E. F. and G. W. Molnar, "Exchanges of heat and tolerance to cold in man exposed to outdoor weather." Am. J. Physiol. 146:507, 1946.

2. Ames, A., III, and D. A. Goldthwait, "Influence of cold climate on basal metabolism." Environmental Protection Section Report No. 136, Quartermaster Research Lab., Lawrence, Mass., 1948.

3. Balke, B., H. D. Cremer, K. Kramer, and H. Reichel, "Untersuchungen zur kälteanpassung." Klin. Wschr. 23:204, 1944.

4. Bazett, H. C. "The regulation of body temperatures." Physiology of Heat Regulation and the Science of Clothing by L. H. Newburgh. Saunders, Philadelphia, 1949.

5. Brown, G. M. and J. Page, "The effects of chronic exposure to cold on temperature and blood flow of the hand." J. Appl. Physiol. 5:221, 1952.

6. Brown, G. M., "Metabolic studies of the Eskimo." Cold Injury. Trans. 3rd Conf. on Cold Injury. Ed. by I. Ferrer. The Josiah Macy Jr. Foundation, New York, 1954.

7. Brown, G. M., G. S. Bird, T. J. Boag, L. M. Boag, J. D. Delahaye, J. E. Green, J. D. Hatcher, and J. Page, "The circulation in cold acclimatization." Circulation 9:813, 1954.

8. Brown, G. M., "Cold acclimatization in Eskimo." Arctic 7:343, 1954.

9. Burton, A. C., "The application of the theory of heat flow to the study of energy metabolism." J. Nutrition 7:497, 1934.

10. Burton, A. C. and H. C. Bazett, "A study of the average temperature of the tissues, of the exchange of heat and vasomotor responses in man by means of a bath calorimeter." Am. J. Physiol. 117:36, 1936.

11. Burton, A. C. and O. G. Edholm, Man in a Cold Environment. Edward Arnold Ltd., London, 1955.

12. Carlson, L. D., A. C. Young, H. L. Burns, and W. E. Quinton, "Acclimatization to cold environment; physiologic mechanisms." USAF Technical Report No. 6247. Air Materiel Command, Wright-Patterson AFB, Dayton, Ohio, 1951.

13. Carlson, L. D., H. L. Burns, T. H. Holmes, and P. P. Webb, "Adaptive changes during exposure to cold." J. Appl. Physiol. 5:672, 1952.

14. Daniels, F., Jr., D. C. Fainer, C. L. Bommarito, and D. E. Bass, "Acclimatization to cold in man." Fed. Proc. 10:32, 1951.

15. Elsner, R. W., "Some acclimatizing responses of man to prolonged cold exposure." Project No. 8-7951, Report No. 1, Arctic Aeromedical Laboratory, Ladd AFB, Alaska, November 1955.

16. Fainer, D. C., F. Daniels, Jr., C. L. Bommarito, and D. E. Bass, "The physiological effects of prolonged exposure to cold: Body temperature, energy metabolism and subjective response." Report No. 186, Quartermaster Climatic Research Lab., Lawrence, Mass.

17. Frazier, R. G., "Acclimatization and the effects of cold on the human body as observed at Little America III, on the United States Antarctic Service Expedition 1939-1941." Proc. Amer. Phil. Soc. 89:249, 1945.

18. Glaser, E. M., "Acclimatization to heat and cold." J. Physiol. 110: 330, 1950.

19. Glickman, N., R. W. Keeton, H. H. Mitchell, and M. K. Fahnestock, "Tolerance of man to cold as affected by dietary modifications; high vs. low intake of certain water soluble vitamins." Am. J. Physiol. 146:538, 1946.

20. Goldby, F., C. S. Hicks, W. J. O'Connor, and D. A. Sinclair, "A comparison of the skin temperature and skin circulation of naked whites and Australian aboriginals exposed to similar environmental changes." Australian J. Exper. Biol. & Med. Sc. 16:29, 1938.

21. Hardy, J. D. and E. F. Dubois, "The technique of measuring radiation and convection." J. Nutrition 15:461, 1938.

22. Horvath, S. M., A. Freedman, and H. Golden, "Acclimatization to extreme cold." Am. J. Physiol. 150:99, 1947.

23. Ingbar, S. H., C. R. Kleeman, M. Quinn, and D. E. Bass, "The effect of prolonged exposure to cold on thyroidal function in man." Clin. Res. Proc. 2:86, 1954.

24. LeBlanc, J., "Evidence and meaning of acclimatization to cold in man." J. Appl. Physiol. 9:395, 1956.

25. Mackworth, N. H., "Local cold acclimatization in man." The Polar Record 8:13, 1956.

26. Meehan, J. P., "Body heat production and surface temperatures in response to a cold stimulus." Project No. 7-7951, Report No. 2, Arctic Aeromedical Laboratory, Ladd AFB, Alaska, January 1955.

27. Meehan, J. P., "Racial and individual variations in a vascular response to a cold stimulus." Mil. Med. 116:330, 1955.

28. Newburgh, L. H. and C. R. Spealman, "Acclimatization to cold." Committee on Medical Research Report No. 241, National Research Council. Div. of Med. Sci., 1943.

29. Scholander, P. F., K. L. Andersen, J. Krog, F. V. Lorentzen, and J. Steen, "Critical temperature in Lapps." J. Appl. Physiol. 10:231, 1957.

30. Scholander, P. F., H. T. Hammel, K. Lange Andersen, and Y. Loyning, "Metabolic acclimatization to cold in man." Fed. Proc. 16:114, 1957.

31. Schwiegk, H., "Pathogenesis and treatment of local cold injury." German Aviation Medicine. World War II. Vol. II. U. S. Government Printing Office, Washington, D. C., p. 843, 1950.

32. Spealman, C. R., W. Yamamoto, E. W. Bixby, and M. Newton, "Observations on energy metabolism and water balance of man subjected to warm and cold environment." Am. J. Physiol. 152:233, 1948.

33. Stein, H. J., R. A. Bader, J. W. Eliot, and D. E. Bass, "A study of hormonal alterations in men exposed to heat and cold stress." Environmental Protection Section Report No. 140, Quartermaster Clim. Research Lab., Lawrence, Mass., 1948.

34. Stein, H. J., J. W. Eliot, and R. A. Bader, "Physiologic reactions to cold and their effects on the retention of acclimatization to heat." J. Appl. Physiol. 1:575, 1949.

35. Takahashi, S., "Changes in the circulatory reaction of the human skin to cold by training." Jap. J. Med. Sc., Biophysics 6:122, 1940.

36. Weir, J. B. de V., "New methods for calculating metabolic rate with special reference to protein metabolism." J. Physiol. 109:1, 1949.