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ARCTIC AEROMEDICAL Laboratory

ADAPTIVE CHANGES DURING EXPOSURE TO COLD

PROJECT NUMBER 22-1301-0002

LADD AIR FORCE BASE
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ADAPTIVE CHANGES DURING EXPOSURE TO COLD

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LADD AIR FORCE BASE, ALASKA
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ADAPTIVE CHANGES DURING EXPOSURE TO COLD

A number of adaptive changes upon exposure to cold environments have been demonstrated in homeotherms. Increased caloric intake by man in cold environments has been reported by Johnson et al. (1) and Burton et al. (2). Increased caloric output has been indicated for man by Horvath (3) and Carlson et al. (4) on the basis of oxygen consumption data. A diuresis on exposure to cold has been reported by Burton et al. (2) and Bader et al. (5). Some evidence has accrued that the adrenal gland is activated in the first few days of cold exposure (Bader et al. (5), Freeman et al (6)). Conclusive evidence of significant alteration in thyroid function in man is lacking. The increased metabolic rate in Eskimos (Hoygard (7), Brown (8)) seems related to their diet (Heinbecker (9), Rodahl (10)) rather than to hyperthyroid activit

Firm evidence that man adapts or acclimatizes to cold environments is lacking although considerable evidence that animals do adapt to cold is at hand. Blair (11) demonstrated changes in rats and rabbits which made them more resistant to frostbite, better able to maintain body temperature in severe cold stress and better able to sur vive in cold stress. Sellers et al. (12) advanced similar evidence. Scholander et al. (13) have described the nature of adaptive changes in Arctic animals. Dugal et a (14) and Long (15) have shown that the adrenal gland is activated during exposure to cold and remains in a continuously highly active state. Indications of increased thyroid activity in animals exposed to cold are numerous (Ring (16), Uotila (17) and Dempsey et al. (18)).

In 1949 Carlson et al. (4), on the basis of field studies, formulated an hypothesis concerning adaptation of man to cold environments. This hypothesis was derived from an analysis of simultaneous measurements of rectal and skin temperatures, oxygen consumption and calorimetry by a thermal gradient principle. Average temperature of

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the skin over the body was used as the independent variable since it is one of th body's signals for response to cold. Compared at the same average skin temperatu the adapted person produced less metabolic heat (as determined by oxygen consumpt (Fig. 1a). Metabolism supplies less of the total heat lost (direct calorimetry) the adapted than in the non-adapted individual (Fig. 1b). The extent to which co ing of body tissues supplied heat was calculated from skin temperature changes an the resultant curves (Fig. 1c) again indicated a difference between the adapted a non-adapted individuals.

The hypothesis formulated by these workers then states that adaptation in hu involves a change in bodily economy whereby the individual maintains a relatively lower level of metabolism for a given heat loss and utilizes a larger portion of body weight to supply the heat lost by cooling. Further, on the basis of finger temperatures and finger plethysmography and with reference to the work of Balke et (19), these investigators indicated that it is a readjustment in peripheral circul tion which keeps the extremities warmer.

In attempting to verify this hypothesis, experiments were conducted in the wi of 1951 during which 16-18 hours daily exposure to cold continued for fourteen day The rate of cooling and final temperatures of the skin of the exposed hand were me ured throughout the period. To estimate the extent of the shell and core, deep mu temperatures in the arm and leg, and rectal temperatures were recorded.

METHODS

Skin temperatures on the hand were determined with copper constantan thermoco mounted in silver switch contact buttons fastened into a rayon glove (Glove Rayon, USAF Spec. No. 3145). Body skin temperatures were determined by similar thermocou snapped into the underwear worn. Thermocouples were compared with a 0° C. referen junction and were recorded on a Brown potentiometer. Deep muscle temperatures were

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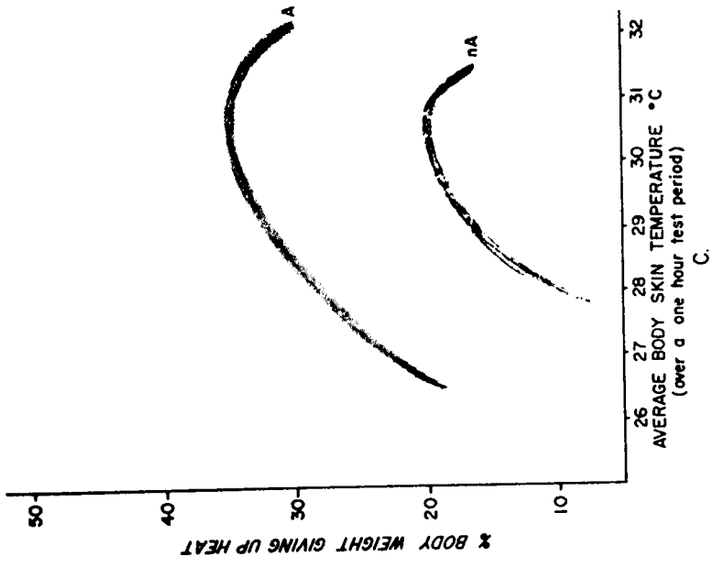

FIGURE 1C

Relative fraction of the body weight supplying heat calculated from skin temperature changes as related to average body skin temperatures.

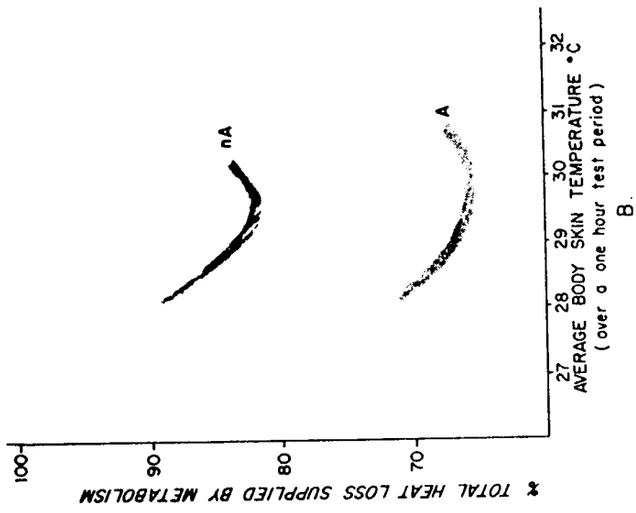

FIGURE 1B

Relative level of metabolism per unit area at different average body skin temperatures.

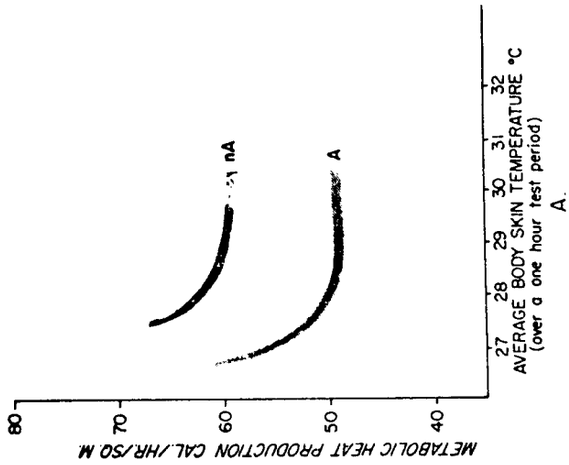

FIGURE 1A

Heat loss supplied by metabolism related to average temperatures over the trunk.

nA – non-adapted
A – adapted

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recorded with copper constantan thermocouples mounted in No. 23 hypodermic needles mounted on plastic blocks. Rectal temperature was recorded at a depth of 10 centimeters These thermocouple e.m.f.'s were compared with a 0° C. reference and read from a Leeds and Northrup Double Range Portable Precision Potentiometer, range 0 - 80.5 Mv. All thermocouple installations were made in a warm room where the subject dressed before going outside for exposure periods of one hour or more.

Five young, healthy adult male subjects lived out of doors for fourteen days of the experiment, spending four to six hours indoors each day to handle equipment and data. Two additional subjects were infantrymen who had been on field maneuvers prior to these experiments which were conducted in November and December of 1951. Outside air temperature varied from - 5° C. to - 17° C. during the periods in which measurements were taken.

RESULTS

The hypothesis toward which this work was directed postulates a readjustment of circulation which tends to give warmer extremities and allows for greater use of the body shell as a heat source. In these experiments special attention was devoted to the rate of drop in the temperature of the exposed fingers and hand and of deep muscle.

Twenty-four experiments were conducted on seven subjects. Typical temperature curves are shown in Figure 2. In this figure two experiments conducted on one subject (C-16, C-27) at the same outside temperature of - 15° C. show the characteristic changes noted in all the five subjects who camped out for the fourteen days. The temperature curves obtained on the two infantrymen (Fig. 2, Co-19) were comparable to those observed in the test subjects after fourteen days of cold exposure. When compared with the tests conducted on the first two days, those performed at the end of the study show a slower initial rate of fall in temperature of the hand with the hand being maintained at a higher temperature during the exposure. The cycling or alternating rise and fall in temperature was large in the early observations and tended to

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lessen in amplitude in the later ones. The maintenance of the hand temperatures seemed to be dependent on the total heat load since the hand temperature was observed to drop markedly when the upper body was exposed by removal of the jacket. The extent to which the hand temperature dropped when the upper body was exposed is shown by comparison of the initial study C-16 with C-27 and with the infantryman Co-19 in Figure 2.

An observation on the effect of exercise is recorded in Figure 2 (C-27). The walk was at a rate of 2 miles per hour. Note the rise in hand temperatures, the fall in arm skin temperatures and in deep arm temperatures. Body and leg skin temperatures tend to rise. Deep back temperature rose above rectal and deep leg temperature also rose.

The time course of events during adaptation as shown by skin temperature of the hand is schematically presented in Figure 3. In the non-adapted individual the temperature of the exposed hand drops rapidly and approaches freezing temperatures. A cycling in temperature may occur at this point and will be large in magnitude. As adaptation progresses, the temperature drop is interrupted by cycling at higher temperatures and eventually the amplitude of the cycle decreases. It may be that these reactions in the hand will differ in degree among adapted as well as non-adapted individuals. It is interesting that Yoshimura and Toshiyaki (20) make use of this phenomenon in the determination of a resistance index to frostbite.

Differences between rectal temperature and arm or leg temperatures at 20 mm. depth were taken as indices of the core to shell relationship. Skin temperature on the arm or leg compared to the muscle temperature at 20 mm. depth was used as an indication of the gradient. Figure 4 shows the average of these measurements made on three subjects. Experiments conducted in the laboratory are compared with the initial and final tests in the field. It would seem from these data that the core tends to withdraw as adaptation proceeds.

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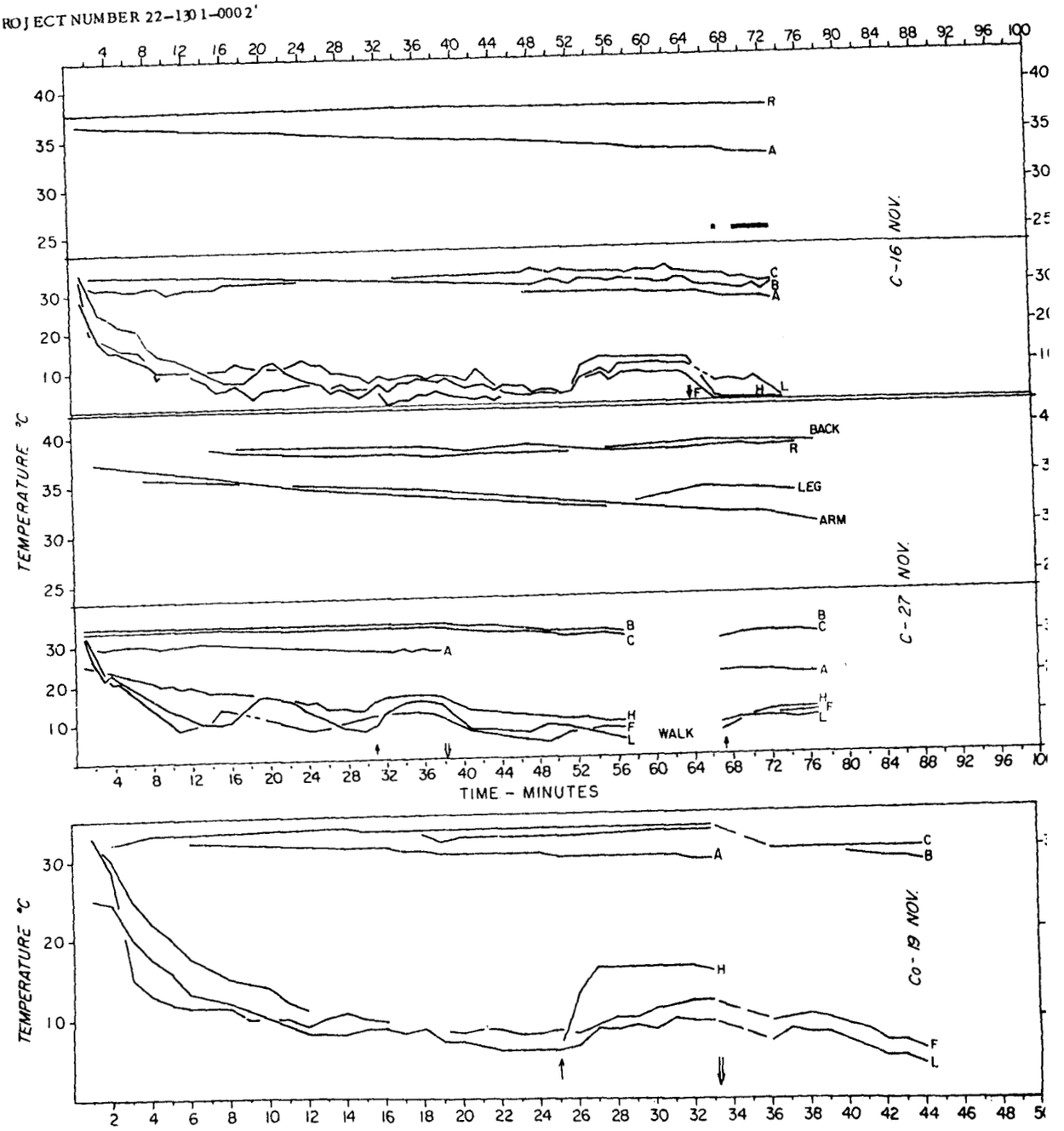

FIGURE 2

Skin temperature recorded during exposure to outside air, subject standing. At one minute on each graph, one hand was ungloved and exposed with only the rayon glove covering the hand. At the arrow the glove assembly was put on. At the double arrow the outer jacket and gloves were removed; otherwise the clothing was kept the same. Subject C arrived in Alaska on 15 November and lived outdoors during a 14 day test. Subject Co was an enlisted man who had been on extensive field training prior to the test. Skin areas sampled by thermocouples are indicated as:

H – back of hand; F – forefinger tip; L – little finger tip; C – chest; A – forearm; B – back; LL – lower leg

R indicated rectal temperature. Deep thermocouples are indicated as: back, leg, arm. Mean temperature during experiments C – 16 and C – 27 was –15° C. and during experiment Co – 19 was – 16° C. Solid bar denotes shivering.

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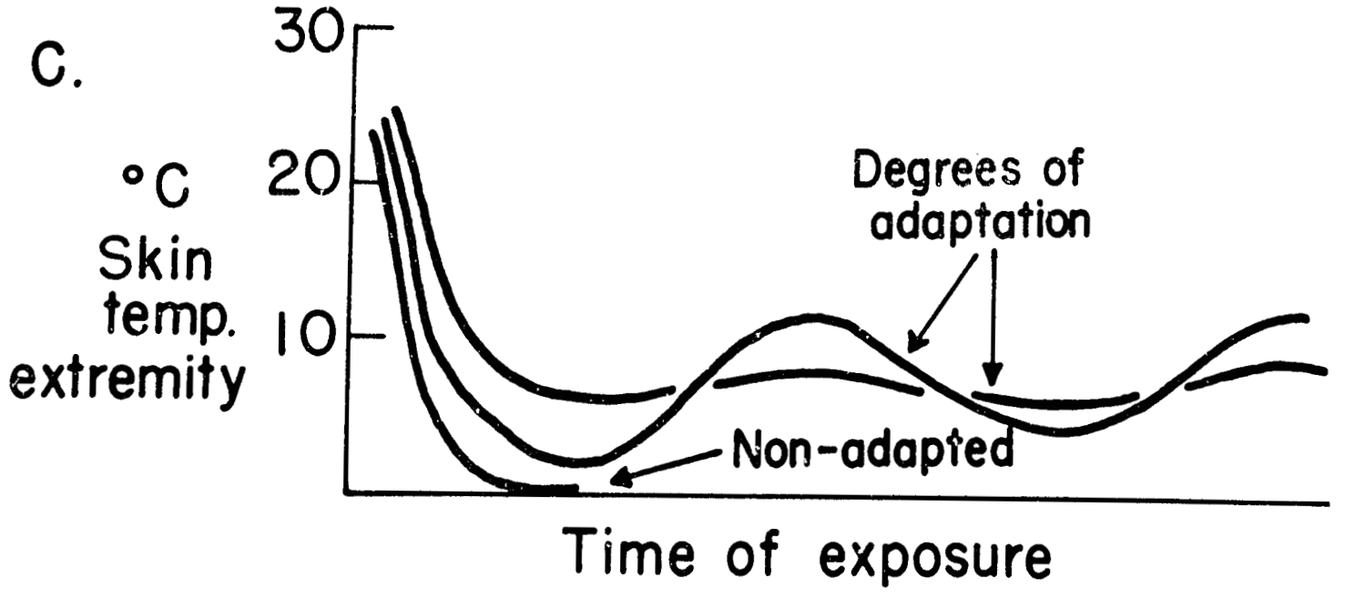

FIGURE 3

Schematic representation of the changes in skin temperature of the hand with exposure to cold.

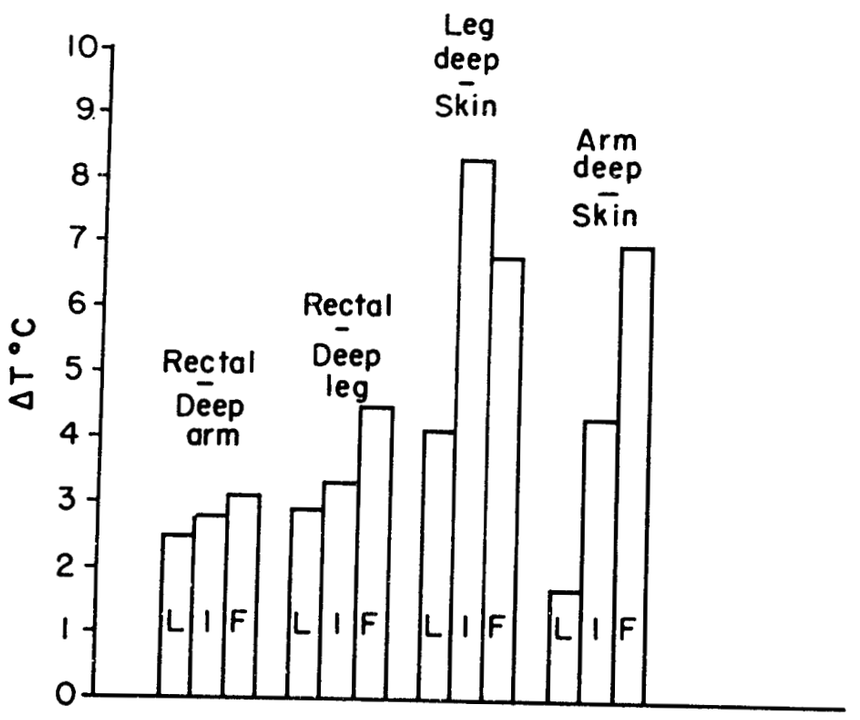

FIGURE 4

Temperature differences between rectal and deep arm or leg (20 mm. depth), and between arm or leg temperatures at 20 mm. depth and skin temperature over the same area. L, in the laboratory in September; I, initial tests on field trial; F, final tests on field trial.

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DISCUSSION

In the hypothesis of Carlson et al. (4) concerning adaptation to the cold the changes during cold exposure are not considered as a steady state. The various physiological mechanisms involved in the response to a negative heat load may play parts in varying degrees during the exposure. The question considered here is the ability to maintain the extremities at temperatures which render them useful as a result of adaptation to cold environments.

The data presented indicate a progressive change in the ability to maintain th temperature of the exposed hand in below freezing environments. Balke et al. (19) have shown a similar effect in experiments on adaptation. In an entirely different manner, this has been shown by Mackworth (21) in his studies on numbness. Mackwort clearly demonstrated that the hands of persons adapted to living at cold temperatur did not become as numb on exposure as the hands of non-adapted persons. Further, i a five week period he demonstrated a progressive decrease in the numbness index in subjects continuously exposed to cold. It would seem that this would indicate that the hands are kept at higher temperatures. Des Marais and Dugal (22) have shown th in rats, "complete adaptation to cold is accompanied by a new rate of peripheral ci culation which is a light vasodilatation."

In animal experiments, Blair (11) has shown in rats and rabbits that previous adaptation will prevent the occurrence of frostbite in the extremities at lower tem peratures. This can only mean that the temperature of the extremity is kept higher Since Blair's adapted animals could also survive longer at low temperatures, the adaptation must involve metabolic changes as well.

SUMMARY

1 . The work reported is on a few subjects carefully studied under similar con ditions. The conclusions drawn are subject to further test to substantiate their validity.

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2 . Skin and body temperature patterns on exposure to cold seem to confirm th hypothesis that an adapted person tends to keep extremities warmer and increase th "shell" participating in heat loss. This allows the adapted person to endure expo to cold with less discomfort and loss in manipulatory efficiency, and, if able to warm periodically, to call less on metabolism in response to cold.

3 . Existing data on man and animals confirm the hypothesis presented.

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