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Heat exchanges of men during caloric restriction in the cold

P. F. IAMPIETRO[1] AND DAVID E. BASS[2] (With the Technical Assistance of Edward B. Green[2] and John A. Vaughan[1])
Environmental Protection Research Division, Quartermaster Research and Engineering Command, U. S. Army, Quartermaster Research and Engineering Center, Natick, Massachusetts

IAMPIETRO, P. F., AND DAVID E. BASS. *Heat exchanges of men during caloric restriction in the cold.* J. Appl. Physiol. 17(6): 947–949. 1962.—The ability of men to maintain thermal balance during continuous cold exposure (14 days at 15.6 C, sedentary while nude) was assessed under four regimens of caloric intake: *a*) adequate, 2,800 kcal/day; *b*) moderate restriction, i.e., sufficient to maintain weight in a warm environment but without the added calories to support shivering, 2,600 kcal/day; *c*) marked restriction, 600 kcal/day; and *d*) complete starvation, 0 kcal/day. Respective weight losses for *b*, *c*, and *d* were 1.8, 8.2, and 12.2% body wt. With 600 and 0 kcal/day there was an impaired ability to maintain rectal temperature; under these conditions the men exhibited rectal temperatures 0.7 C lower than when they were on adequate or nearly adequate caloric intake. The men on complete starvation had the lowest heat production of all groups during later days in the cold; however, the data were too variable to demonstrate a close relationship between depressed core temperature and decreased heat production. It is concluded that marked restriction of calories is associated with depressed core temperatures during prolonged cold exposure, due in part to absence of specific dynamic action.

PROLONGED EXPOSURE TO COLD induces elevated oxygen consumption, enhanced appetite, and increased food intake (1, 2). The increased food intake is sufficient to prevent loss of weight in spite of the increased energy cost due to the cold (2). Nude men living for 2 weeks at 60 F (15.6 C) follow the above pattern with ad libitum access to food. Under these conditions they maintain deep body temperatures very efficiently. It is not known whether restriction of caloric intake would impair thermoregulation under similar conditions. This paper reports the effects of three levels of caloric restriction on the ability of nude men to maintain heat balance during 2 weeks of exposure to a cool environment.

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[1] Present address: Civil Aeromedical Research Institute, Oklahoma City, Okla.

[2] Present address: U. S. Army Research Institute of Environmental Medicine, Natick, Mass.

EXPERIMENTAL DESIGN AND METHODS

The ability of healthy young men to maintain thermal balance during continuous cold exposure was assessed under four regimens of caloric intake: *study I*—2,800 kcal/day; *study II*—2,600 kcal/day; *study III*—600 kcal/day; *study IV*—no calories. These regimens were designed to provide, respectively, *a*) adequate calories for maintenance of the extra requirements for shivering; *b*) moderate restriction, sufficient to maintain body weight in a warm environment, but without the added calories to support shivering; *c*) marked restriction, inadequate to maintain body weight in any circumstances; *d*) complete starvation.

A total of 22 subjects was used, 5 each in *studies I* and *II* and 6 each in *studies III* and *IV*. During all studies the men lived in a chamber maintained at 60 F (15.6 C) for 2 weeks. Air movement was approximately 40 ft/min; relative humidity was 50%. During this period they were nude except for cotton shorts and socks and were engaged only in minimal, sedentary activity, e.g., card-playing, reading, writing, watching TV. Each subject was permitted one Army woolen blanket during the night (10:00 PM–7:00 AM). Caloric intake was in the form of a milk drink served in equal portions three times daily. The composition of this drink was as follows: carbohydrate 41%, protein 17%, fat 42%, caloric density 1.2 kcal/g. The milk drink was supplemented in *studies I* and *II* with toast and butter. Water was allowed ad libitum and black coffee was allowed four times a day in all studies. The experimental period was preceded by 2 weeks at 80 F (26.7 C) during which time sufficient calories in the form of the above-mentioned milk drink, toast, and butter were provided to maintain body weight constant.

Rectal temperature was measured with calibrated clinical thermometers, *study I*, or thermistors, *studies II, III, IV*. Skin temperatures were measured with the Hardy radiometer in *studies II, III*, and *IV* only. Skin sites measured were toes, calf, chest, upper arm, and fingers. Mean weighted skin temperature was calculated as

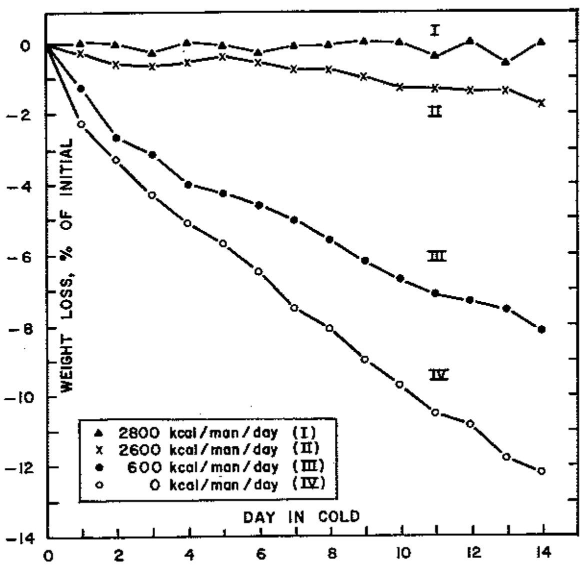

FIG. 1. Mean weight losses during caloric restriction in the cold.

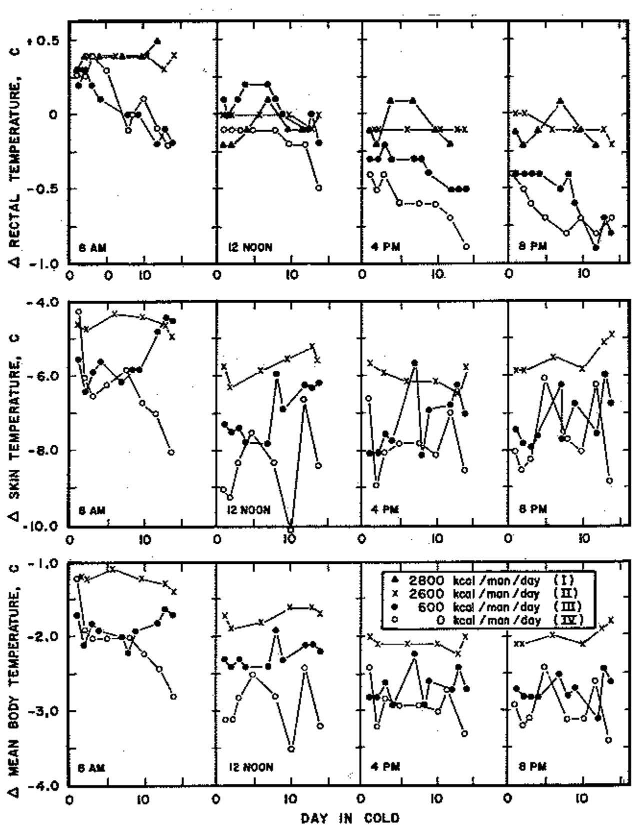

FIG. 2. Body temperatures during caloric restriction in the cold.

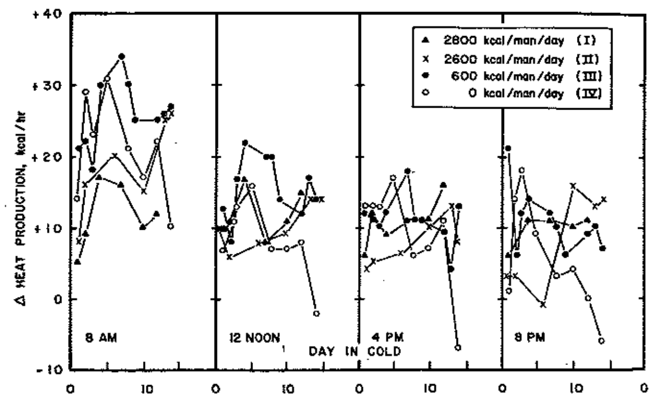

FIG. 3. Heat production during caloric restriction in the cold.

follows: .06 finger temperature + .06 toe temperature + .30 leg temperature + .18 arm temperature + .40 chest temperature. Mean body temperature (T_{MB}) was calculated from mean weighted skin temperature (T_S) and rectal temperature (T_R) according to the following weightings: .33 T_S + .67 T_R (3). Oxygen consumption was measured with the Sanborn Waterless Metabulator, *study I*, or by collecting expired air in a spirometer and analyzing for oxygen with a Beckman oxygen analyzer in *studies II, III, IV*. Heat production was calculated according to the method of Weir (4). All measurements were made four times during the day: 8:00 AM, prebreakfast; 12:00 noon, prelunch; 4:00 PM, presupper; and 8:00 PM. At least ½ hr of bed rest, supine position, preceded these measurements. Nude body weights were measured at 7:00 AM after the subject had voided.

RESULTS

Body weight changes. Under the conditions of our studies, we found that 2,800 kcal/day was adequate to maintain body weight constant in the cold (*study I*). As would be expected, weight losses were incurred when a caloric deficit was imposed. When the deficit was only 200 kcal/man day (*study II*), 1.8 % of the initial body weight was lost after 14 days (Fig. 1). When caloric intake was 600 kcal/man day, 8.2 % of the body weight was lost; when caloric intake was 0 kcal/man day, 12.2 % was lost. Figure 1 shows that after the first 2 or 3 days of caloric restriction body weight loss was essentially linear. The contribution of body water to the initial sharp drop in body weight and the composition of the weight lost during the experimental period have been discussed in a previous publication (6).

Body temperatures. Body temperatures are depicted in Fig. 2 as the difference between experimental, i.e., cold, values and the mean of corresponding controls at 8:00 AM, noon, 4:00 PM, and 8:00 PM. This treatment of the data permits comparison of all four studies in a manner which takes into account the diurnal increases of body core temperature previously reported for similar ambient conditions (1) and the variability, between studies, of control measurements. Figure 2 clearly demonstrates that when calories were markedly restricted, *studies III* and *IV*, the rectal temperatures were not as well maintained as when calories were adequate, *study I*, or only slightly restricted, *study II*. Thus, the men on 600 and 0 kcal/day had progressively lower rectal temperatures as the cold exposure continued (decrease = 0.7 C), particularly at 4:00 and 8:00 PM, whereas the men on 2,800 and 2,600 kcal/day maintained their rectal temperatures at control levels throughout the study. Skin temperatures were too variable to permit strong inferences, although they were generally lower in *studies III* and *IV* than in *study II* (no measurements were made in *study I*).

As might be expected, mean body temperatures were lower in *studies III* and *IV* than in *study II*; they did not, however, reflect the downward trend of the rectal temperatures as cold exposure continued, presumably because of the highly variable skin temperatures. The decrease in mean body temperature for *study II* was 1 C at 8:00 AM and 2 C the rest of the day for the entire experimental period. Mean body temperatures for *studies III* and *IV* fell about 2 C at 8:00 AM and 2–3 C for the rest of the day. A decrease of 1 C in mean body temperature for a 70-kg man signifies a decrease in body heat content of approximately 60 kcal. Thus, in *study I* the heat debt was about 60 kcal at 8:00 AM and 120 kcal at 12:00 noon, 4:00 PM, and 8:00 PM; in *studies III* and *IV* the heat debt was 120 kcal at 8:00 AM and 120–180 kcal at 12:00 noon, 4:00 PM, and 8:00 PM.

Heat production. Heat production is shown in Fig. 3 as the difference between values in the cold and the mean measurements at corresponding times of day during the control period. Although there were no clearly defined differences attributable to caloric intake, the men on complete starvation, *study IV*, exhibited generally lower heat production during the later days in the cold at noon, 4:00, and 8:00 PM, so that by the 14th day, their heat production was the lowest of all groups.

DISCUSSION

It is apparent from these studies that a threat to thermal equilibrium is imposed when caloric intake is appreciably inadequate during cold exposure (Fig. 2). Cold exposure per se, although causing a drop in skin temperature, seems to have little effect on maintenance of deep body temperature when calories are adequate (1). Heat production under these conditions increased sufficiently to maintain body temperature, i.e., a balance was established between heat production and heat loss. The variability of the data on heat production makes it difficult to correlate the lowered rectal temperatures of *studies III* and *IV* with decreased heat production, although there was some indication that resting metabolism was dropping during the last cold exposure days of these two studies (Fig. 3).

The design of these studies did not allow assessment of the SDA (specific dynamic action) effect of the food eaten. However, it is possible that this extra heat could partly account for the differences in thermal balance seen among the four studies. Our measurements were made 3–4 hr after a meal, at which time the peak heat from SDA had already passed (6). Buskirk, Iampietro, and Welch (6) found an increase in metabolism due to SDA of about 10% after a meal with the peak SDA occurring within 1 hr and decreasing thereafter for several hours. The total daily caloric intake was given in three equal portions during the day. In *study I*, 935 kcal was served at each meal; in *study II*, 870 kcal was given, and in *study III*, 200 kcal was served. Assuming that the SDA was 10%, about 94, 87, and 20 kcal were available, respectively, for maintenance of core temperature in these three studies. Therefore, total heat input (metabolic and SDA) in *studies I* and *II* was just adequate to maintain thermal balance, whereas in *study III* (small SDA) and *study IV* (no SDA) the total heat input was not adequate to maintain thermal balance in the absence of relatively greater increase in shivering or other thermogenesis. In this connection, shivering is an inefficient method of maintaining thermal balance; thus, Horvath et al. (7) estimated that only 11% of the extra heat produced by shivering was utilized in protecting against thermal imbalance. In contrast, all the heat from SDA would be available for maintaining thermal balance.

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