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THE EFFECTS OF COOLING AND OF VARIOUS MEANS OF WARMING ON THE SKIN AND BODY TEMPERATURE OF MEN

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A series of experiments by Uprus, Gaylor & Carmichael (1935, 1936) and Uprus, Gaylor, Williams & Carmichael (1935) has shown that there is little uniformity in the way in which the human body warms up after cooling. These authors also suggested (1936) that warming by air which was at a higher temperature than that of the body was insufficient to raise the rectal temperature of men who had been previously cooled, and a similar view was reached in wartime experiments reported by Alexander (1945) and again by Adolph & Molnar (1946). Uprus and his colleagues have also shown that an adequate rise of the rectal temperature can be obtained after moderate cooling if part of the body is immersed in hot water, and the experiments reported by Alexander (1945) have shown that death from extreme cooling is best prevented in both animals and men by rapid immersion of the whole body in hot water at about 50° C.

People, however, frequently get cold, and they seem to warm up quite well without taking a hot bath, merely by sitting in a warm place, by exercise, or by taking hot food and drinks. It seemed worth while to study these apparent contradictions both from their practical and physiological aspects, and it was decided to investigate how men whose rectal temperature had fallen by about 1° C. would warm up under the following conditions:

(*a*) Rest at room temperature.
(*b*) A drink of hot sweet cocoa, followed by rest at room temperature.
(*c*) Alternate periods of exercise and rest at room temperature.
(*d*) Rest at about 30° C.

METHODS

Subjects. Eight intelligent and healthy sailors aged 19–25 years were selected, but one of them had to be excluded after 2 days on account of a feverish upper respiratory infection. The area of their body surfaces varied from 1·76 to 1·88 sq.m. Two of the subjects had been working in hot humid air for 3 hr. a day for 5 weeks before the present investigation began, and they must be considered to have been acclimatized to heat (Robinson, Turrell, Belding & Horvath ,1943; Bean

& Eichna, 1943). Four subjects had come straight from a cold naval base where they had been doing outdoor duties and sleeping in unheated huts, while two subjects had not been exposed to any extremes of temperature during the last months before this experiment.

Procedure. The subjects were tested in two groups of four, the first while outdoor temperatures were 4–9° C., the second at outdoor temperatures of −3 to +4° C. After 2 days the first group was reduced to three by the indisposition of one subject. Each group was tested on four successive mornings, but the experiments on the second group were carried out some weeks after those on the first. The subjects wore cotton vests and pants, woollen jerseys, worsted trousers, woollen socks, and leather shoes. They lived together. They got up and had breakfast at the same time every day, each man eating the same type of breakfast and roughly the same amount of food on each day of the experiment. About 30 min. after breakfast they walked about ¾ mile to the laboratory where the tests were being performed. They sat still at 17° C. (±2° C.) for 15 min., and then their skin and rectal temperatures were measured. Simultaneous mouth temperature measurements were made on two subjects in each group. For the following 1½ hr. they sat in a cold room at 0° C. (±1° C.). After that one subject sat still in a room at 29° C. (±1½° C.) and about 50% saturation with moisture, and the other three in a room at 17° C. (±2° C.). Two of the latter sat still all the time, but one of them drank one pint of hot sweet cocoa as soon as he left the cold room; the last man stepped up and down on to a chair 30 times in 60 sec. every 15 min. The cocoa was drunk at a temperature of 45–50° C.; the sugar and cocoa powder in it were equivalent to about 200 cal. (McCance & Widdowson, 1946). Skin, rectal, and in four subjects also mouth temperatures were measured at 15 min. intervals throughout each test beginning 15 min. after entering the cold room. (Allowance was made for the 2–3 min. spent walking between the cold room and the laboratory or the hot room). Exercise, if taken, followed immediately after the measurements, so that the latter were always made in the sitting posture after a period of rest. Each subject was warmed in a different way on each day of the experiment; complete 'crossing over' was thus achieved within each group.

The first set of measurements was always taken about 1 hr. after a meal, but this need not have had any effect on the initial readings, for vasomotor responses to food appear to be slight at temperatures below 20° C. (Richards, 1946). The subjects, furthermore, walked to the experiment each morning, and they walked about 200 yd. across the grounds to and from the cold room, but the influence of all these possible sources of irregularities was excluded by their constancy from day to day.

Skin temperature measurements. The skin temperature was measured in the centre of the forehead and over the ball of the left thumb. When the subjects sat still, they always rested their left hand and forearm in a horizontal position with the thumb uppermost. The face varies its temperature over a narrower range than the limbs (Bedford, 1935), but it reacts more rapidly (Loewy & Dorno, 1925); the hand, moreover, reacts to changes of temperature more readily than the foot (Pickering & Hess, 1933). Thus, if a general pattern of vasomotor reactions is sought, this can be shown by two carefully chosen points, one on the face and one on a limb.

Difficulties in measuring skin temperatures can be caused by the fact that thermometers are either held in position by some insulating material or protrude freely (Bedford & Warner, 1934). Ordinary skin thermometers can also prevent or enhance the evaporation of moisture from the skin. Radiation thermopiles have been alleged to be free from these disadvantages (Bedford & Warner, 1934; Hardy, 1934; Stoll & Hardy, 1948), but under experimental conditions they can become cumbersome and inaccurate tools (Tobias, Loomis, & Lawrence, 1947). It appeared however, that these difficulties could be overcome if very thin wires were used to make up a thermocouple and if those wires were in close apposition to the skin over a sufficient distance to ensure that their junction completely took up the temperature of the body surface without changing it and without being itself influenced by the environment. This purpose was achieved by placing the junction and its leads loosely across the arms of a glass Y tube (Fig. 1). Estimations of the skin temperature could then be made in such a way that the junction lay over the exact spot to be measured while the arms of the glass Y piece were at a distance from it. At the same time it was possible to make the junction and its wires fit over a straight or curved portion of the skin simply by pulling or relaxing the loose leads at the other end of the Y piece. A very thin wire in close contact with the skin cannot affect the temperature of the underlying skin and it can neither enhance the evaporation of sweat nor interfere with it; heat rays and air currents cannot significantly alter the temperature of the wires without at the same time altering that of the underlying skin; and tests have shown that conduction of heat along that portion of the leads which was inside the glass Y piece did not occur.

The electrode was made up in the following manner. Two thin glass tubes about 10 cm. long were each bent to an angle of 30° about 1·5 cm. from one end, and the tubes were stuck together along their arms by means of sticking plaster. Copper and constantan wires (s.w.g. 36) were soldered together end to end in such a way that the junction was scarcely thicker than the wires and then pulled through the glass tube till the junction lay midway between the open arms of the glass Y piece (Fig. 1). The junction was painted over with a very fine layer of heat-conducting varnish and the wires leading loosely away from the Y piece were encased in polythene tubing. The e.m.f. was read on a portable potentiometer designed for this type of work. The cold junction was embedded in melting ice in an insulated container. The potentiometer was always kept at room temperature and only carried into the cold room or warm room when measurements were made; these never lasted more than a few minutes, and the insulating effect of the box was sufficient to prevent errors caused by temperature changes in the standard cell.

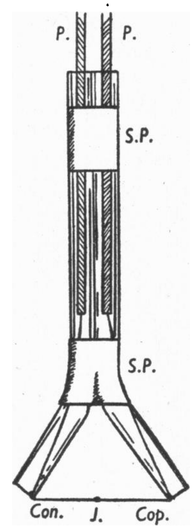

Fig. 1. The thermocouple element, two-thirds natural size. *Con.* = constantan wire; *Cop.* = copper wire; *J.* = junction of wires; *P.* = polythene tubing; *S.P.* = sticking plaster.

Rectal and mouth temperatures. Rectal and mouth temperatures were measured with mercury thermometers over 5 min. to the nearest 0·05° C. The subjects had been taught to insert the rectal thermometers with their right hand through the front flap of their trousers while sitting, and to insert it always to the same distance.

Calibration. The potentiometer was calibrated against three mercury thermometers to the nearest 0·1° C. All mercury thermometers and thermocouples used in this experiment were tested against each other in a stirred water-bath and found to agree to less than 0·1° C. Quick consecutive readings from the same spot of skin agreed to within 0·2° C., even if read by two independent observers. If a thermocouple was held against the sublingual mucosa it gave readings which agreed to the nearest 0·1° C. with those taken by a mercury thermometer.

RESULTS

Only the results obtained from the seven men who took part in the whole experiment are given here.

Cooling

Average results are given in Fig. 2*a*.

Although there were individual variations and day to day differences, cooling generally followed the same pattern. In four out of twenty-eight observations the rectal temperature rose by 0·1–0·4° C. during the first 15 min. Usually it fell slowly at first and more quickly after about 30 min. The average fall of rectal temperature was 0·9° C. during 1½ hr. at 0° C.; (in twenty-three out of twenty-eight observations the fall in rectal temperature was 0·65–1·35° C., but the total scatter was 0·25–1·9° C.). When the mouth temperature was measured it was found to follow the rectal temperature, except that sometimes the former had fallen less than the latter at the end of cooling.

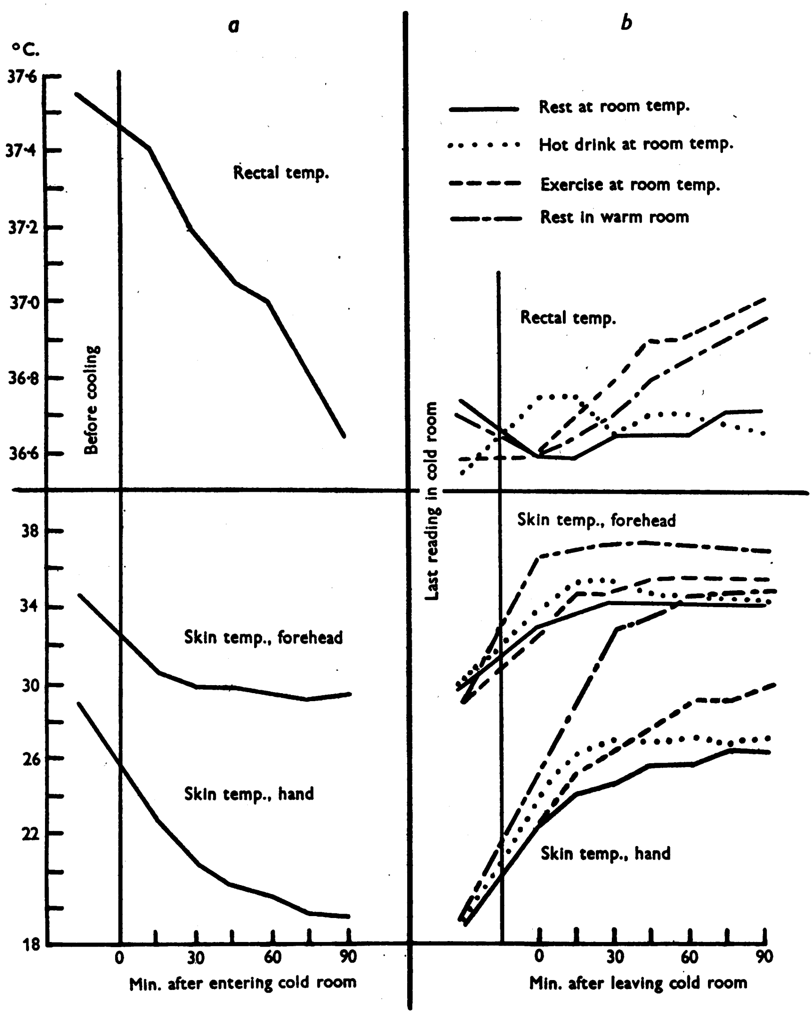

Fig. 2. (*a*) *Cooling* at 0° C. Average of twenty-eight observations on seven subjects. (*b*) *Warming* by different methods. Each line represents the average of seven observations, one on each subject.

The skin temperature of the forehead and hands fell most during the first 15 min. of cooling. In most cases the forehead ceased to cool down after about 30 min. and subsequently its temperature sometimes even rose slightly, but the hand temperature usually continued to fall until the subjects left the cold room.

Average forehead temperatures fell by 4·0° C. (extremes 2·4 and 7·3° C.) in $1\frac{1}{2}$ hr. and hand temperatures by 11·5° C. (extremes 4·8 and 16·9° C.).

Shivering often began after $\frac{3}{4}$–1 hr. It did not appear to depend on a fall of the rectal or skin temperature to any particular level, although it was often followed by a slowing down of the fall in rectal temperature or even a slight temporary rise. Some subjects shivered more than others, and some did not noticeably shiver at all on certain days, although their rectal temperature had fallen by up to 1·2° C. and was as low as 35·8° C. Some subjects began to shiver when their rectal temperature was 37·0–37·3° C. and after it had fallen by only about 0·2–0·3° C.

Warming

Average results are given in Fig. 2*b*.

At rest in a hot medium the rectal temperature of one subject was unchanged and that of six subjects had fallen by 0·05–0·35° C. 15 min. after leaving the cold, but it invariably rose later. After $1\frac{3}{4}$ hr. it equalled the last reading in the cold room in one subject and had risen above it by up to 0·6° C. in the other six; in all subjects, however, it remained 0·45–0·85° C. lower than it had been before cooling.

When exercise was taken at room temperature the rectal temperature of three subjects rose after 15 min. while that of four subjects fell by 0·05–0·35° C. during the first 15 or 30 min. In these again, it invariably rose later, finally surpassing the last reading in the cold room by up to 0·9° C. in five subjects and equalling it in two. It remained, however, 0·45–0·7° C. below the initial level in all subjects.

Following a hot drink at rest at room temperature, the rectal temperature of one subject fell by 0·25° C. and that of the other six rose by up to 0·85° C. during the first 15–30 min. after leaving the cold. Subsequently, however, it fell in all six subjects in whom it had risen first. At the end of $1\frac{3}{4}$ hr., it was 0·15–0·3° C. below the last reading in the cold room in five of these and 0·45–0·85° C. above it in the other two. In all subjects, furthermore, it remained 0·55–1·05° C. below the initial level.

At rest at room temperature without a hot drink the rectal temperature of one subject showed no change at first, that of one subject rose slightly during the first 15 min. and that of five subjects fell by 0·05–0·7° C. Subsequently, the rectal temperature of all subjects rose, but after $1\frac{1}{4}$ hr. it was still 0·2–0·4° C. lower than at the end of cooling in three subjects, and 0·45–1·2° C. below the initial level in all subjects.

Although none of the subjects came nearer his initial level of rectal temperature than 0·4° C. in any test, all felt comfortable within at most 30 min. from leaving the cold. Often they had no sensations of cold, even when their rectal temperature was similar to or lower than that at which they had shivered and felt cold before. In all tests the rectal temperature settled down to a steady level about 1–1¼ hr. after leaving the cold, and the greatest fluctuation recorded in any one subject during the last 30 min. of any one test was 0·15° C. Every subject had a higher final level of rectal temperature after exercise and after sitting in a warm room than in the other two tests.

When the mouth temperature was taken it followed roughly the same pattern as the rectal temperature, but the former tended to rise more rapidly and settle nearer its initial level than the latter, especially in the warm room. The mouth temperature rose above the rectal temperature after a hot drink, and it also did so in the warm room (Fig. 3).

The skin temperature of the forehead and hand always rose fastest and highest in the warm room and settled at levels which were distinctly above those of the first observations in the same subject on that day. With the other methods the forehead temperature settled near its initial level after about 30–45 min. At rest at room temperature, with or without a hot drink, the hand temperature settled near or just below its initial level after about 1 hr., but it tended to rise a little longer when exercise was taken and to settle at a slightly higher level. After a hot drink the skin temperature of both points always rose faster, though not higher, than at rest or after exercise at room temperature. During the last 30 min. of exposure to a warmer medium, the skin temperature of the hand and forehead fluctuated by less than 0·6° C. in the majority of tests, and only exceptionally by more than 1·0° C.

On the days when the eighth subject took part in the experiment he produced no results which contradict what has been said above.

Acclimatization

No difference was noticed between the two groups of men or between those who were acclimatized to heat and those who had lived under cold conditions. Day to day changes in cooling did not suggest that acclimatization to cold was achieved during this experiment.

The relationship between mouth, rectal, and skin temperature on warming in a hot medium

As has been stated above, the mouth temperatures rose above the rectal temperature when the subjects went straight from the cold room to the warm room. In all subjects except one, the skin temperature of the forehead also rose above that of the rectum and, when the mouth temperature was recorded, above the latter. Simultaneous readings of the skin temperature of the hand and of random points on the limbs were always below the rectal and mouth temperature. If the thermocouple was held in the air near the forehead a lower temperature was invariably recorded, which shows that these findings were not brought about by direct radiation from the heaters. One of the tests in which the eighth subject took part involved warming in the warm room, and he also showed this phenomenon. Since he was tested under similar conditions in all relevant aspects it seems fair to include him in this particular description. A rise of the forehead temperature above that of the rectum was thus recorded in seven out of eight subjects, and its maximum varied from 0·2 to 1·7° C. A typical record is given in Fig. 3. It was chosen, because it includes a record of the mouth temperature and because the maximum rise of the forehead temperature above that of the rectum equals the average of the maximum rise in all seven observations.

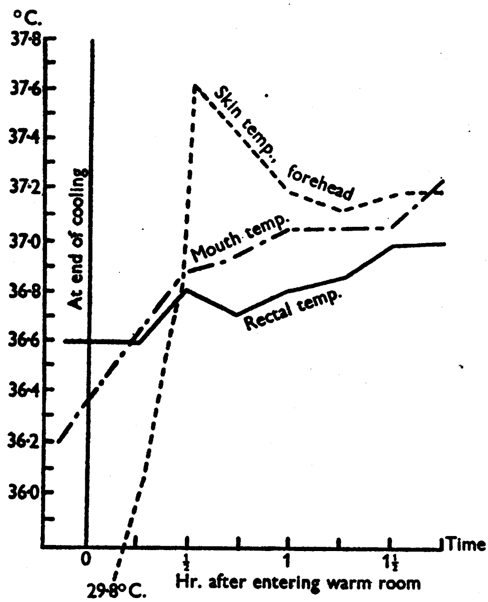

Fig. 3. The relationship between the rectal temperature, the mouth temperature, and the forehead temperature on changing from a cool medium (0° C.) to a warm one (29° C.). Typical record.

Most subjects showed some slight sweating of the forehead about ¾–1 hr. after entering the warm room and then the forehead temperature dropped a little, but it was still above that of the rectum at the end of the test in five subjects. This mild sweating always occurred at rectal temperatures which were lower than the initial level on that day and sometimes also lower than that at which the same subject had begun to shiver on the same day.

DISCUSSION

Shivering. Spealman (1945) found that men in moderately cool baths began to shiver when their rectal temperature had fallen to 36° C. Heat production was increased as a result of shivering, and the rectal temperature remained around 36° C. Spealman thought that 36° C. was a critical level of human heat regulation, but this need not be true outside the carefully standardized conditions of his experiment. Uprus, Gaylor & Carmichael (1935) noted shivering only when the rectal temperature of their subjects was falling, but not when the rectal temperature began to rise again. The present investigation, however, suggests that there is no close relationship between the rectal temperature and shivering. Since there is no evidence that the receptors which initiate shivering lie in the rectum such a relationship appears highly improbable.

The paradoxical behaviour of the rectal temperature at the beginning of cooling and warming. A slight temporary rise of rectal temperature on cooling or a slight temporary fall on warming has been recorded by Barcroft & Verzár (1931), Uprus *et al.* (1936), Alexander (1945), Adolph & Molnar (1946), and Aschoff (1947). Tholozan & Brown-Séquard (1858) noticed that the mouth temperature sometimes rose when a hand was immersed in cold water, while Cooper & Kerslake (1948) noted an initial fall of the mouth temperature on warming human subjects under a cradle. Freeman & Nickerson (1938) actually thought that there was some negative correlation between the temperature of the skin and the rectum. This statement would imply that the rectal temperature is lowest when the skin is warmest and highest when the skin is coolest, but the present investigation and a study of the observations mentioned above suggests nothing more than that the rectal temperature and the skin temperature can sometimes move in opposite directions.

Uprus *et al.* (1936) have briefly touched upon the possible mechanism of such an occasional and temporary rise of rectal temperature when the body is cooled, and this was expanded by Aschoff (1944, 1947). The latter found that dissipation of heat through the hand was greatly reduced when the hand was cooled, sometimes more so than the extent of cooling would warrant, and he thought that such a reduction of heat loss through the hand might at times 'over-compensate' the requirements of the body. This hypothesis may also help to explain why the rectal and mouth temperature occasionally fall on exposing the body surface to heat, for reflex vasodilatation may result in dissipating more heat than necessary, provided the environmental temperature is lower than the skin temperature. In the present investigation this paradoxical fall of the rectal temperature was most consistently noted on entering the warm room when there was a considerable stimulus for superficial vasodilatation.

There appears, however, to be another mechanism. Cooling of the skin results in cooling of the underlying muscles (Bing, Carlsten & Christiansen, 1945) and warming of a limb increases the blood flow through the skin and muscles (Barcroft & Edholm, 1943). Thus, when a chilled person is rapidly warmed, it is probable that a large amount of blood flows through a cold limb. It is known that venous blood in the limbs is usually colder than the blood in the adjoining arteries (Davy, 1814; Bazett, 1947), and Lewis (1927) found that the skin above a vein carrying blood from a hand which had been immersed in cold water was up to 9° C. cooler than the surrounding skin. The rectum, therefore, may be cooled by passage of cool blood from the lower limbs through the haemorrhoidal plexus to the mesenteric vein. Warming of the rectum by passage of warm venous blood through the haemorrhoidal plexus is unlikely to occur, for the limbs are as a rule cooler than the rest of the body, and cooling decreases the blood flow. A reduction of the amount of cool blood flowing through the rectum may, however, result in a rise of the rectal temperature, for the latter would depend both on the quantity and the temperature of the blood flowing through the rectal vessels.

Heat exchanges. Fluctuations of the rectal temperature disappeared after about 1 hr. under constant conditions. Barcroft & Verzár (1931) have suggested that the heat production of a resting man may be insufficient to raise his body temperature after cooling, and a rough estimate of the heat exchanges occurring in the present investigation confirms this assumption. Heat losses of lightly clothed and 'semi-reclining' men were estimated to be 40·5 cal./sq.m./hr. at 29° C. and 76 cal./sq.m./hr. at 17° C. (Gagge, Winslow & Herrington, 1938). At rest in the warm room the subjects of this experiment may thus have given off about 70–75 cal./hr. and at rest at room temperature about 135–140 cal./hr. A generous estimate of their resting heat production would be about 100 cal./hr. The subjects of the present investigation were tested under somewhat similar conditions to those of Gagge *et al.* (1938) and it may be concluded that at rest at room temperature their heat production was lower than their heat losses. It follows that warming of the periphery after leaving the cold room was largely achieved at the expense of cooling other parts of the body, and this explains why in eight out of fourteen tests at rest at room temperature the rectal temperature eventually settled down at a level lower than that at which it had been when the subject left the cold room. The direct warming effect of 1 pint of fluid taken at 45–50° C. was negligible (about 6–9 cal.) and was more than counteracted by the increase of heat elimination which sets in after ingestion of hot fluids (Pickering, 1932). That such an increase of heat elimination did occur in the present experiment is demonstrated by the fact that peripheral vasodilatation after a hot drink was always more sudden than in the other tests at room temperature while the rectal temperature eventually fell below the last reading in the cold room five out of eight times. In the warm room heat losses may have been smaller than heat gains, and eventually some warming of the body as a whole may have occurred. Each 1 min. period of stepping may have raised heat production by about 10 cal. (Lusk, 1928). Under those conditions the subjects may have produced some 40 cal./hr. more than at rest, and their bodies may have again gained heat as a whole.

It can be seen from what has been said above, that the means of warming employed in the present investigation would not normally raise the rectal temperature of healthy men to any significant extent. It might have been expected that people with a lowered overall temperature would have maintained peripheral vasoconstriction until their loss of heat had been made good. In fact, however, their skin temperature rose fast while their rectal temperature remained low, and such a persistent lowering of the rectal temperature could not have been a result of cooling by venous blood. During the last 30 min. of these tests both the skin and rectal temperature remained remarkably steady, even though the forehead was sometimes warmer than the rectum (Fig. 3), which suggests that a balance had been struck between heat production and heat loss at a temperature lower than the initial one. The results published by Freeman & Nickerson (1938), Gagge (1941, table 1), Robinson, Turrell & Gerking (1945), Spealman (1945), and Robinson & Gerking (1947) confirm the view that such a balance can be maintained at various levels of rectal temperature. It appears, furthermore, that *within certain limits* the establishment of thermal balance takes precedence over the temperature of any part of the body (or at any rate the rectum, the mouth and the skin). This view is borne out by a report of Rapaport, Fletcher & Hall (1948), who found that in a cold environment the hand and foot temperature of their subjects could be made primarily dependent on the state of thermal balance of the body and almost independent of the environment. It may be concluded that the methods of warming employed in the present investigation failed to achieve a return of the rectal temperature to its initial level, but that they were sufficient to restore comfort and approximate thermal balance; it does not follow, therefore, that these methods were inadequate.

The meaning of 'adequate warming'. It is evident from what has been said above that a definition of a normal state of body temperature is required, especially under conditions of thermal stress. A definition based on the rectal temperature would be unsatisfactory because, as has been suggested above, heat exchanges can be in equilibrium over a range of rectal temperatures, because the rectal temperature varies from man to man, and because it may be influenced by changes of temperature in the lower limbs. It is necessary, furthermore, to differentiate between a feeling of warmth, depending largely on the skin temperature, and the total amount of heat in the body. In the present investigation the subjects often felt warm after leaving the cold room while their skin temperature was rising and their rectal temperature falling, but such a fall of rectal temperature, coupled with a rise of skin temperature, suggests that the body is losing heat as a whole. One cannot say, therefore, that people are warm when they feel warm, nor can one say that a state of thermal balance represents comfort. The example given above (Spealman, 1945) showed that men might be in thermal balance while shivering with rectal temperatures of about 36·0° C. The table already quoted (Gagge, 1941) shows that naked men were actually giving off a small amount of heat in a hot dry medium when their rectal temperatures averaged 37·56° C., and Robinson & Gerking (1947) have shown that men working in a hot humid medium could be near thermal balance at rectal temperatures around 38·5° C. All these subjects may have felt uncomfortable, and a definition which disregards subjective feelings or the efforts of the body to maintain thermal equilibrium does not seem satisfactory. One must say, therefore, that a satisfactory state of body temperature implies: (*a*) a state of balance or near-balance between heat production, and heat loss, and (*b*) a range of skin temperature which is subjectively comfortable. The latter implies the absence of shivering, sweating or panting.

The mutual relationship of the rectal, mouth and forehead temperature after rapid warming. The finding that the rectal temperature was lower than the mouth and forehead temperature when the subjects were resting in the hot room may have been a result of cold blood flowing through the haemorrhoidal veins (see above), while warm blood from the inner organs was being pumped into the head. The findings, though not the conclusions, of Haldane (1905) suggest that such a flow of warm arterial blood to the head may occur when men are suddenly exposed to a much hotter environment than the one they had been in before. The forehead temperature, however, could have risen above that of the mouth only if there was extreme vasodilatation in the former, and extreme vasoconstriction, coupled with previous cooling, in the latter.

In a recent publication, which was seen after this paper was written, Bazett, Love, Newton, Eisenberg, Day & Forster (1948) suggested that vascular anastomoses may affect the rectal temperature. In another publication Bazett, Mendelson, Love & Libet (1948) described paradoxical changes of the skin temperature during warming after cooling. The latter findings appear to have been associated with the fact that certain superficial blood vessels carried cool blood from the body surface while others carried warmer blood from deeper tissues. This conception expands the tentative explanation put forward in the present paper for the causes of the rise of skin temperature above that of the mouth and rectum.

Practical implications. The relative merits of the various ways of warming any particular person may have to be determined for each and every practical set-up, and they will depend on the extent of previous cooling, the available facilities, and the condition of the subjects. It must be understood that the body as a whole does not immediately gain heat when it moves from a cold medium to a warmer one and that any stimulus causing peripheral vasodilatation may result in loss of heat for it will cause valuable energy to be expended on warming less important organs at the expense of essential ones. A short period in a warm place, therefore, seems undesirable for those who must return to the cold. A hot drink causes an immediate feeling of warmth, but it increases the heat elimination from the periphery, and it appears that its effect is similar to that of alcohol. Both a short period in a warm place and a hot drink, however, may be beneficial when the heat production of the body is adequate and frost-bite is to be forestalled. Voluntary exercise may be beneficial to men who are not shivering. It must be remembered, however, that fatigue predisposes to exhaustion from cold and that shivering alone can cause fatigue (Adolph & Molnar, 1946). It seems safe to conclude that a combination of all three methods, i.e. hot food and drink coupled with exercise in a warm place, would warm up people more rapidly than any one method. This will have to be confirmed by experiment, although the quick effect of a hot drink, the increase of heat production following upon exercise and food, and the lowering of heat losses in a hot place can be expected to have a cumulative effect.

Thermal balance (that is a steady level of rectal and skin temperature) seems to have been established fairly soon in all tests, but this was achieved at a low level of rectal temperature. It is impossible to say without further experimental evidence whether it would be a disadvantage to begin another period of cooling at such a low level, but this possibility must be considered. Animal experiments (O'Connor, 1919, figs. 3 and 5) suggest that heat elimination from a limb was raised for some time after warming of the animal had stopped. It appears, therefore, that men in cold places ought to be kept warm rather than intermittently warmed. Warming by hot water remains the most efficient single method, especially after severe chilling (Alexander, 1945). Even air which is warmer than the skin temperature is less effective than water, because the heat capacity of air is small and because air in the immediate vicinity of the body adjusts itself to the skin temperature (Loewy & Dorno, 1925).

SUMMARY

1. Seven men were moderately chilled and then warmed over $1\frac{3}{4}$ hr. under the following conditions: (*a*) rest at room temperature, (*b*) a hot drink followed by rest at room temperature, (*c*) alternate periods of rest and exercise at room temperature, (*d*) rest in a warm dry medium.

2. In a warm medium the skin temperature of the forehead and hand always rose above its initial level. In the other tests it settled near its initial level.

3. During warming the rectal temperature always remained 0·4–1·2° C. below its initial level. At rest at room temperature it also tended to settle below the last reading in the cold room, especially if a hot drink was taken.

4. On entering the warm room the forehead temperature of all subjects but one rose by up to 1·7° C. above their rectal temperature. If the mouth temperature was taken at the same time the forehead temperature also rose above the latter.

5. The initial effect of entering a warm room after cooling seems to have been a warming of the surface at the expense of more essential regions. A hot drink appears to have been followed by loss of heat from the body as a whole.

6. It is suggested that venous blood flowing through the haemorrhoidal plexus may cool the rectum.

7. After $1\frac{1}{4}$ hr. in a warmer medium only insignificant fluctuations of the skin and rectal temperature were recorded. It is concluded that thermal balance was achieved, and it is suggested that, within limits, the establishment of such a balance may take precedence over the maintenance of a constant temperature.

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