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ACCLIMATIZATION TO HEAT AND COLD

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A fall of the rectal temperature, the skin temperature and the pulse rate can be detected in human subjects after a few days, or even a number of hours, in a hot environment, and this was considered to be a sign of acclimatization to heat (Bean & Eichna, 1943; Robinson, Turrell, Belding & Horvath, 1943; Eichna, Bean, Ashe & Nelson, 1945), but definite signs of acclimatization to cold were not obtained after repeated or continued experimental exposures to low environmental temperatures (Adolph & Molnar, 1946; Horvath, Freedman & Golden, 1947; Stein, Eliot & Bader, 1949), although a few authors have described minor signs of adaptation (Scott, Bazett & Mackie, 1940; Glickman, Keeton, Mitchell & Fahnenstock, 1946). The present investigation was planned to show whether acclimatization to cold did exist, and it also offered an opportunity of studying two further problems. (1) How were the movements of blood between the inside of the body and the extremities which were shown to accompany changes of the environmental temperature (Glaser, 1949*b*) affected by continued exposures to heat and cold? (2) Was acclimatization to heat and, if its existence could be demonstrated, acclimatization to cold modified by frequent changes of environmental temperature?

PROCEDURE

Six intelligent and healthy sailors aged 19–20 years had volunteered for the experiment. All had been experimental subjects before, but none of them had been exposed to any extremes of climate for 2 months before the present investigation began. In the cold-room they wore thin woollen underwear, flannel shirts, sleeveless woollen pullovers, serge or flannel trousers, tweed or leather jackets, woollen socks, and leather slippers or shoes. In the hot-room they wore canvas shoes and linen shorts. At night they slept in flannel pyjamas on beds with horsehair mattresses. They used 4 woollen blankets in the cold-room.

The subjects were tested in two groups of three. Each group spent three successive 72 hr. periods alternately in a hot and cold environment, group I starting in the cold-room and group II in the hot-room. Each period began and ended at 10 a.m. Measurements were taken at 3 p.m., 8 p.m. and 8 a.m. and took about 1 hr. The former were taken 2 hr. after the end of a meal, the latter before breakfast. The subjects sat still for ½ hr. before each set of measurements with their left arm supported horizontally. Measurements were always taken in the same order with the subjects sitting still. The subjects only left the air-conditioned rooms twice daily, for 15 min. after breakfast, and for a few minutes before turning in at night. They emptied their bowels and washed at these times. It was intended to keep them fit during the tests without exercising them too hard, and they were, therefore, encouraged to move about as much as possible (except before measurements), and to do gymnastic exercises for 30–45 min. daily. They were given as much food and water as they liked.

The rectal temperature, the skin temperature, the volume of the left forearm and hand, and the vital capacity were measured as previously described (Glaser, 1949*a*, *b*). The skin temperature was measured in seven marked points: over the forehead, the manubrium sterni, the left forearm, the ball of the left thumb, the tip of the left middle finger, the middle of the left thigh, and the middle of the left leg near the anterior edge of the tibia. Since this investigation did not set out to measure the true average surface temperature, representative areas likely to show varying degrees of fluctuation were selected. In the cold-room part of the skin was covered, but it seemed right to measure the temperature both of clothed and exposed areas, which conforms with the principle adopted by Gagge, Winslow & Herrington (1938). The blood pressure was measured with a mercury manometer by auscultation of the brachial artery. The latter was palpated and marked. This and other markings, notably the line used in measurements of the forearm and hand volume (Glaser, 1949*b*), and those used in skin temperature measurements, were kept clear and sharp. The pulse-rate was counted over 30 sec. The urine was collected under toluene in large bottles. While the subjects were in the hot-room the urinary chloride output was estimated every 24 hr. to make sure that the intake of NaCl was adequate to cover all the body's requirements.

The cold-room was adjusted to maintain a temperature of $-1°$ C., but its refrigerating capacity was insufficient and its temperature rose slowly during the day, reaching $+3°$ C., or exceptionally even $+4°$ C., in the evenings. During the night it cooled down again to $-1°$ C. Air movement in the cold-room was negligible. During the first part of the experiment the hot-room was at 40·5° C. (dry bulb) and 35° C. (wet bulb) with an air-movement of 100 ft./min. This corresponds to an 'effective temperature' of 35·5° C. (Bedford, 1946). The plant did not stand up well to continuous running at such a high temperature and during the second part of the experiment, while group II was being tested, the hot-room was kept at 35° C. (dry bulb) and 29° C. (wet bulb) with an air movement of 100 ft./min. This corresponds to an 'effective temperature' of 30° C. In spite of this lowering of the hot-room temperature there was a short breakdown on the second morning of group II's second period in the hot-room; the subjects were kept warm by blankets, but one set of measurements was thus missed. At night the air movement in the hot-room was stepped up to 300 ft./min.

RESULTS

Average results are given to the nearest significant decimal. A difference between two means was considered significant if it amounted to more than twice the standard error of the difference (Bradford Hill, 1942).

Subjective effects

There was some uniformity in the personal impressions recorded in the subjects' diaries. The last day of each period of exposure always seemed to be the least unpleasant, which appears to be evidence of acclimatization to both heat and cold. Moreover, the second exposure to either environmental extreme was always tolerated better than the first. During the last 2 days of the experiment none of the subjects in group I ever shivered or felt uncomfortably cold; and none of the subjects in group II sweated while sitting still, or felt uncomfortably hot.

General results

Table I shows that the average vital capacity and the average forearm and hand volume of both groups were significantly smaller in the cold-room than

TABLE 1. Mean values of all observations in the cold-room and hot-room

		All observations in the cold-room				All observations in the hot-room					
	Group	No.	Mean	S.D.	Error of mean	No.	Mean	S.D.	Error of mean	Difference between the means	S.E. of the difference
Vital capacity (l.)	1	162	4·70	0·565	0·044	81	4·86	0·592	0·064	0·16	0·0793
	2	81	5·12	0·322	0·036	153	5·36	0·366	0·030	0·24	0·0464
Forearm and hand volume (l.)	1	54	1·46	0·020	0·0027	27	1·55	0·089	0·0173	0·09	0·0171
	2	27	1·56	0·115	0·0222	51	1·63	0·095	0·0133	0·07	0·0258
Skin temp. (° C.)	1	378	25·7	6·295	0·324	189	36·2	2·057	0·15	10·5	0·356
	2	189	26·7	7·231	0·530	357	34·7	2·056	0·11	8·0	0·537
Rectal temp. (° C.)	1	54	37·2	0·549	0·075	27	37·8	0·600	0·115	0·6	0·138
	2	27	37·0	0·386	0·074	51	37·6	0·371	0·052	0·6	0·090
Pulse rate	1	54	59	9·05	1·23	27	96	20·54	3·96	37	4·14
	2	27	70	9·64	1·85	50	78	9·59	1·35	8	2·30
Syst. B.P. (mm. Hg)	1	42	127	8·06	1·24	27	117	6·00	1·17	10	1·69
	2	27	133	16·30	3·14	51	117	7·94	1·11	16	3·32
Diast. B.P. (mm. Hg)	1	42	66	11·66	1·80	27	50	17·37	3·34	16	3·80
	2	27	60	14·79	2·85	51	52	19·89	2·76	8	3·98

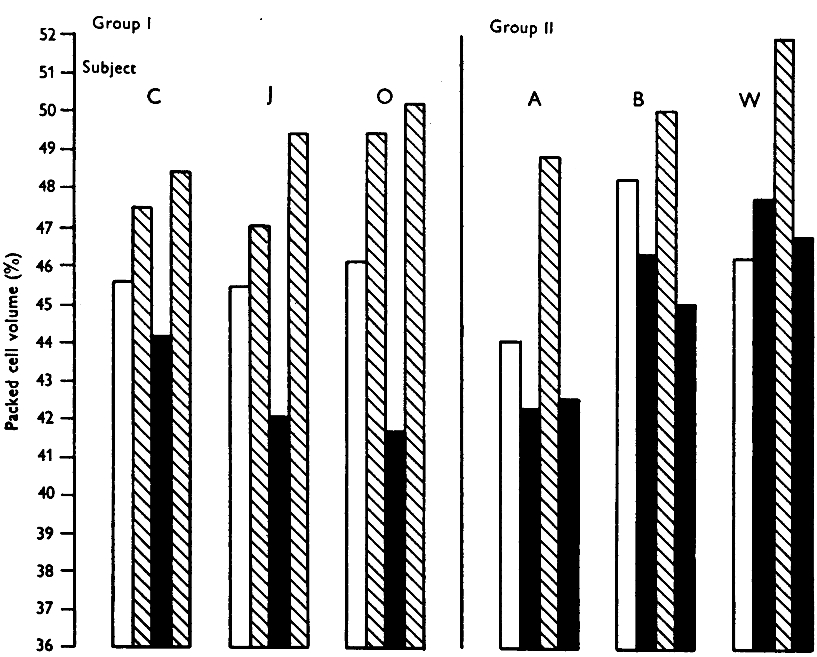

Fig. 1. The packed cell volume before the tests and at the end of each exposure to heat and cold. Initial level. After 72 hr. in cold. After 72 hr. in heat.

in the hot-room, and this conforms with the results obtained during shorter exposures to heat and cold (Glaser, 1949*b*). Table 1 also shows that the skin temperature, the rectal temperature, and the pulse rate were significantly lower, whereas the systolic and diastolic blood pressure was significantly higher in the cold-room. Fig. 1 shows that all subjects showed an increase of the packed cell volume (haematocrit ratio) during each period of cooling and a decrease during each period of warming. The erythrocyte count and haemoglobin level behaved similarly, but estimations of the white blood cell count and differential blood-counts produced no relevant data.

Effects of prolonged exposures

Tables 2 and 3 give the mean differences between comparable readings taken from the same subject at the same time of the day (and in Table 2 also from the same spot of skin), during the first and third 24 hr. period in the cold-room.

TABLE 2. A comparison of the skin temperature on the first and third day of the first exposure to cold

(Differences between the temperature of identical points on the skin, measured at the same time of the day.)

Subject	Group	No. of obs. each day	Mean difference between corresponding obs. (° C.)	S.D.	S.E. of mean
A	2	21	+0·4	1·90	0·415
B	2	21	+0·4	2·37	0·517
C	1	21	+0·8	1·69	0·369
J	1	21	+0·9	2·57	0·561
O	1	21	+1·0	1·65	0·360
W	2	21	+0·4	2·30	0·502
All subjects		126	+0·65	2·14	0·192

TABLE 3. The difference between comparable measurements of the rectal temperature on the first and third day of the first exposure to cold

Subject	Group	No. of obs. each day	Mean difference between corresponding obs.
A	2	3	+0·2
B	2	3	+0·5
C	1	3	+0·5
J	1	3	+0·6
O	1	3	+0·1
W	2	3	0·0
Total		18	+0·32
		S.D.	0·359
		S.E. of mean	0·0847
			$t=3\cdot782$
			$P<0\cdot01$

Since the subjects of group I spent two 72 hr. periods in the cold, only the first of these exposures was taken into consideration. On the third day in the cold-room all subjects showed a mean increase of the skin temperature and five subjects a mean increase of the rectal temperature. These differences were statistically significant, and it seems reasonable to assume that they were signs of acclimatization to cold. During the third day in the hot-room the average skin temperature of all subjects was 0·9–2·0° C. lower, and the average rectal temperature of five subjects 0·1–1·1° C. lower than on the first day, which conforms with previous observations on acclimatization to heat. While the subjects remained in the same air-conditioned room, the vital capacity and the volume of the forearm and hand did not fluctuate much from day to day, and the pulse-rate and blood pressure behaved inconsistently.

Effects of alternating exposures

Those adaptations which could be detected towards the end of the first period of cooling or warming generally became more obvious during the second period of exposure to the same medium. Thus the mean skin temperature of all subjects in group I was significantly higher during the second than during the first period in the cold-room, and the mean skin temperature of group II was significantly lower during the second than during the first period in the hot-room (Table 4). All subjects in group I had a greater packed cell volume

TABLE 4. A comparison of the skin temperature during the first and second exposure to the same medium

(Differences between the temperature of identical points on the skin, measured at the same time of the day on corresponding days.)

Group 1. Two 72 hr. exposures to cold, with an intervening 72 hr. period in the hot-room.

Subject	No. of obs. during each 72 hr. period in the cold	Mean difference between corresponding obs. (° C.)	S.D.	S.E. of mean
C	63	+1·0	1·99	0·26
J	63	+1·7	2·56	0·32
O	63	+0·6	2·36	0·30
All subjects	189	+1·1	2·29	0·17

Group 2. Two 72 hr. exposures to heat, with an intervening 72 hr. period in the cold-room.

Subject	No. of obs. during each 72 hr. period in the heat	Mean difference between corresponding obs. (° C.)	S.D.	S.E. of mean
A	56	−0·5	1·38	0·18
B	56	−0·2	2·25	0·29
W	56	−0·7	1·50	0·22
All subjects	168	−0·5	1·77	0·14

at the end of the second period of cooling, and two subjects in group II had a lower packed cell volume at the end of the second period of warming (Fig. 1). All three subjects of group I also had a higher average rectal temperature by 0·2–0·3° C. during the second period in the cold-room, but this was not statistically significant. Moreover, the average vital capacity of group I was 0·09 l. lower, and the average forearm and hand volume 0·1 l. lower during the second exposure to cold, while the average vital capacity of group II was 0·6 l. higher and the average forearm and hand volume 0·01 l. higher during the second exposure to heat. The latter differences were, again, not statistically significant.

DISCUSSION

Although the statistical calculations presented above are only valid for the subjects of the present investigation, they allow conclusions about the adaptive mechanisms which may function following changes of the environmental temperature.

Acclimatization

It was previously suggested that movements of blood between the surface of the body and the inner regions may be an important mechanism of adjustment to changes of environmental temperature (Glaser, 1949*b*). The present investigation suggests that acclimatization perpetuates these movements and that changes of the circulating blood volume play an important part in the latter process.

The findings that the proportion of plasma in the blood was invariably greater in the hot-room than in the cold-room (Fig. 1) conforms with the observations of Barcroft, Meakins, Davies, Scott & Feller (1923), Bazett, Sunderman, Doupe & Scott (1940), Spealman, Newton & Post (1947) and Stein *et al.* (1949) who found that the human body contained a greater volume of blood in a hot environment than in a cool one. In the present investigation the decrease of the total amount of blood after 3 days in the cold-room appears to have been accompanied by a more rapid flow of blood through the body surface, while the amount of blood in the latter remained small. This may explain why the skin temperature of all subjects was higher on the third day of exposure than the first. Conversely, the fall of the skin temperature which was noted after 3 days in the hot-room may have been caused by a slowing down of the blood flow through the small vessels of the skin while these vessels remained well filled, thus bringing about a decrease of the skin temperature. This explanation is at variance with the findings of Scott *et al.* (1940), who noted that the rate of blood flow through the finger continued to increase for several days in a hot-room. It cannot be excluded that changes of the B.M.R. (Burton, Scott, McGlone & Bazett, 1940; Butson, 1949) may have helped to produce some of the effects of acclimatization.

The discrepancy between the results of the present investigation and the findings of Adolph & Molnar, (1946), Horvath *et al.* (1947), and Stein *et al.* (1949) may have been due to the fact that these authors made their subjects work hard or shiver to exhaustion during the exposures to low temperatures. They also stated (Horvath *et al.* 1947; Stein *et al.* 1949) or inferred (Adolph & Molnar, 1946) that such muscular activity was accompanied by a rise of the skin temperature, and it is known that working muscles need more blood than resting ones (Anrep & von Saalfeld, 1935). Exercise was thus accompanied by an increase of the peripheral blood flow which could have been compensated by a decrease of the blood flow through the vascular regions contained inside the body cavities, and it may have caused changes which were the opposite of those following upon exposure to cold but similar to those caused by exposure to heat. Exercise might, therefore, be expected to inhibit acclimatization to cold and facilitate acclimatization to heat. Indeed, the latter effect was demonstrated by Bean & Eichna (1943). This aspect of acclimatization may be a matter of fine balance between the opening up and closing down of vascular pools, changes of the total amount of blood in the body, and the adaptability of vasomotor control.

Alternate exposures

It appears unlikely that the improved ability to withstand low environmental temperatures which was noted in the subjects of group I during the second period in the cold-room was due to a persistence of the effects of the first exposure, because the latter were abolished during the intervening period in the hot-room. Similarly, the improved adaptability to heat shown by the subjects of group II during the second period in the hot-room was probably not an after-effect of the first exposure to heat. It appears more likely that repeated changes of environmental temperature resulted in an improvement of the facility with which the volume and the distribution of the blood could be altered. Previous observations bear out this view. Thus the circulatory response of some men to exercise in a hot medium became more efficient after 1–2 weeks in a cool medium (Henschel, Taylor & Keys, 1943, Table 4), and superficial vasoconstriction in the extremities was found to set in more readily after repeated exposures to cold (Stein *et al.* 1949). Moreover, the Finnish *Sauna* (which consists of very hot and very cold baths), is considered to augment resistence to climatic extremes (Ott, 1948).

Practical conclusions

(1) An appreciable degree of acclimatization to cold can be achieved after 3 days in a moderately cool environment.

(2) Exercise or severe shivering during periods of cooling may inhibit acclimatization to cold.

(3) Frequent changes of temperature may be beneficial to those who must adapt themselves to extreme climatic conditions.

SUMMARY

1. Between the first and third day of exposure to cold there was a statistically significant increase of the skin temperature and the rectal temperature of 6 men. This was accompanied by greater subjective comfort, and it was taken to be a sign of acclimatization to cold.

2. Acclimatization to heat and cold was accompanied by apparent changes in the rate of superficial blood flow and the total blood volume, but it did not alter the distribution of blood in the body.

3. Repeated changes of the environmental temperature enhanced the facility with which the volume and the distribution of the blood could be varied.

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