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THE EFFECTS OF SUBCUTANEOUS FAT AND OF PREVIOUS EXPOSURE TO COLD ON THE BODY TEMPERATURE, PERIPHERAL BLOOD FLOW AND METABOLIC RATE OF MEN IN COLD WATER

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Individual fat men have been observed to lose less heat than thin men in cold surroundings (Winslow, Herrington & Gagge, 1937; Pugh & Edholm, 1955; Carlson, Hsieh, Fullington & Elsner, 1958; Keatinge, 1959). It has been reported that men maintained their peripheral blood flow better when exposed to cold sitting still indoors, after a period of physical training in a cold climate, than they did in a similar experimental exposure to cold before this period of training in a cold climate (Brown & Page, 1952–3; Keatinge & Evans, 1958). In the present experiments men with a wide range of fat thickness have been immersed repeatedly for periods of 30 min in water at 15° C, in order to determine whether their falls in deep body temperature during immersion depended mainly on the thickness of their subcutaneous fat or mainly on their peripheral blood flow, and whether these falls were increased by exposure to cold or by exercise earlier in the day.

Reports about the effect of acclimatization to cold on men's metabolic rates in the cold have been conflicting (Burton, 1941; Adolph & Molnar, 1946; Le Blanc, 1956) but it has been found (Keatinge, 1959) that repeated brief immersion in water at 15° C reduced men's over-ventilation and increase in heart rate, as well as their metabolic rate, during such immersion. Metabolic rates have been measured in the present experiments in the hope of throwing light on the mechanism and significance of such changes. The experiments have also provided information about the method by which the metabolic rates of fat and thin men were adjusted to their differing rates of heat loss in the cold.

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METHODS

The subjects were twelve healthy naval ratings, all volunteers, aged between 18 and 28. They came in groups of four and each group was studied over a period of 3 weeks. On the first day their heights and weights were measured, their subcutaneous fat thicknesses were estimated by Harpenden callipers (Edwards, Hammond, Healey, Tanner & Whitehouse, 1955) at the sites used previously (Keatinge, 1959) and they were given practice in wearing the masks used for the immersion experiments.

All immersions were made in an indoor tank, 8 ft. long and 4 ft. (1·22 m) wide and deep, which has already been described (Keatinge, 1959). During the next 3 weeks each man was repeatedly immersed up to his shoulders in this for 30 min at a time. The water was always at $15 \pm 0{\cdot}1^{\circ}$ C and was vigorously stirred mechanically; while immersed in it the man sat on a slatted wooden seat, wearing only very brief cotton bathing trunks, a helmet and a mask. Under these conditions the temperature of the immersed skin was shown to fall in 2 min to within 1° of 15° C (Keatinge, 1959). Before immersion each man sat unclothed for at least 30 min in the room, which was maintained by a thermostat at $29 \pm 1^{\circ}$ C in all except the 'initially hot' and 'initially cool' experiments.

The man's rectal temperature was followed by a thermojunction enclosed in semi-rigid plastic tubing and inserted 11 cm from the anus. The cold junction was in a vacuum flask of ice and water and the e.m.f. was measured by a potentiometer; readings were accurate to the nearest 0·05° C. The air expired during the first 10 and last 20 min of the 30 min immersions was collected separately by masks and either passed into a Max Planck Institute Respirometer or into Douglas bags. Its oxygen deficit was then measured by a Hartmann and Braun automatic analyser. The meter was accurate to ± 1 % and the analyser to ± 2 %. The same meter was used to measure the volume of gas in the Douglas bags when the latter were used. The metabolic rates were then calculated by the method of Weir (1949). These rates, particularly those determined over the first 10 min of immersion, were subject to error, for the men were not in a steady state of oxygen exchange, but this error can only have been small and was presumably consistent for the same individual in different experiments. The oxygen deficit of the expired air was used as an indication of the degree of over-ventilation in relation to oxygen consumption. An electrocardiograph record was obtained from waterproof leads on the wrists for the whole of the first 15–70 sec of immersion, and subsequently for the first 15 sec of every minute. In order to estimate peripheral blood flow during immersion a heat-flow disk (Hatfield, 1949) was stuck by 'Nobecutane' (Evans) to the dorsum of the terminal phalanx of the index finger of the right hand and supported by a rubber band around its base. This finger was immersed in the tank for 10 min before the start of each experiment to permit an estimate of blood flow in the finger to be made just before immersion, when there was no general cooling of the body.

During either their 2nd or their 3rd day each man was immersed twice. Before one of these immersions (initially cool) the room temperature was 24–27° C, and before the other (initially hot) was 38–39° C. The men sat in the room at these temperatures for 30 min before immersion, and at the higher temperature they were always sweating before immersion. Subjects with odd numbers were immersed in the morning with the room hot, and then in the afternoon of the same day with the room cool; those with even numbers were immersed in the opposite order.

During the next 8 days each man was immersed regularly every second day, always in the afternoon between 2.30 and 4 p.m. During the mornings before an immersion, the men either (*a*) sat still, normally clothed, in a warm room at $23 \pm 2^{\circ}$ C, (*b*) sat still, wearing only shorts, in a room at 5° C, (*c*) did a stepping exercise (18 cm, 24/min) in the warm room or (*d*) in the cold room. They sat in the cold room, or did the exercise, for three periods of 50 min during the morning, with two 10 min breaks in which they rested in the warm. The last of the periods finished at 11.45 a.m. The men were able to hold a fixed bar during the stepping exercise, and so to use their arms as well as their legs. These four experiments were crossed over in a 'Latin Square' pattern for each group of four men. Two men in the second group, however, were injured in a car accident during the second week, and had to be dropped from the later experiments; the results from the two remaining men are only fully 'crossed-over' as regards comparison of the effect of 'warm' and 'cold' mornings, and results are available on only eight men for comparing the effect of 'working' and 'still' mornings. In most of the tables the means of the results for these eight men are given as well as the means for all the men, in order to facilitate a general comparison of the results from all types of experiment. The order in which each man went through each group of experiments is shown in Table 3. The men took no exercise on the day of an immersion except for that prescribed; they were always driven from the naval unit where they lived to the laboratories, and were kept under observation on the mornings before immersions.

In the statistical analysis all the results were assumed to be normally distributed except values for heat loss from the finger, which frequently included a number of values much higher than the mean and were therefore subjected to non-parametric analysis by the sign test.

TABLE 1. Ages, heights, weights and fat thickness of the subjects

Subject	Age (years)	Height (cm)	Weight (kg)	Skinfold thickness (mm): Sub-scapular (means of 4 determinations)	Abdomen	Biceps	Subcostal	Average for subject
1	18	175	88·4	35·9	31·2	9·3	30·9	26·8
2	23	167	69·4	10·9	8·2	3·8	9·3	8·1
3	23	178	67·1	14·0	12·9	3·7	14·4	11·2
4	22	176	66·2	6·5	6·0	2·8	6·2	5·4
5	19	170	61·7	8·6	6·6	3·4	7·0	6·4
6	18	174	63·7	8·3	8·8	3·8	7·5	7·1
7	19	183	86·6	13·1	13·9	6·1	11·1	11·1
8	19	169	64·4	8·3	8·3	3·4	8·7	7·2
9	22	181	63·9	5·6	4·9	2·5	4·4	4·4
10	22	180	73·5	9·6	7·1	3·8	6·7	6·8
11	19	176	73·0	11·9	10·5	5·3	10·8	9·6
12	19	171	67·1	8·2	6·7	3·7	7·2	6·5
Mean	20·3	175·0	70·42	11·74	10·43	4·30	10·35	9·22

RESULTS

Table 1 gives the ages, heights and weights of the subjects and their skinfold thicknesses; each skinfold thickness reading represents the mean of four readings at each site, two from each side of the body. Subject 1 had by far the greatest mean skinfold thickness, 26·8 mm, and was also the heaviest, while the skinfold thicknesses of the remaining men varied from 4·4 to 11·2 mm.

Table 2 shows that when the men were exposed to an ambient temperature of 38–39° C for half an hour before immersion their rectal temperatures at the time of immersion were on average 0·31° C higher, their skin temperatures 3·5° C higher, their heart rates were higher by 14·7 beats/min and the rates of heat loss from their index fingers in water at 15° C, used as an index of blood flow, were always much higher than when they had previously been in a cool room. These differences were all significant, often highly so. There were no significant differences in any of these measurements before different experiments in the subsequent four immersions, although the skin and rectal temperatures tended to be slightly higher after 'warm' than 'cold' mornings.

TABLE 2. Rectal temperatures, skin temperatures, heart rates and finger heat loss before immersion. Sd̄ = sample standard error of difference between two sets of results

	Initially hot	Initially cool	Activity during morning before immersion: Still, warm	Still, cold	Working, warm	Working, cold
			Rectal temperatures (°C)			
Mean (all subjects)	37·98	37·67	37·80	37·70	37·81	37·77
Range	37·45–38·50	37·15–38·45	37·20–38·20	37·20–38·15	37·40–38·25	37·65–38·00
	Difference Sd̄ 0·133 $P < 0.05$					
Mean for subjects 1–4 and 9–12	38·00	37·68	37·74	37·71	37·83	37·78
			Mean skin temperatures (°C)			
Mean (all)	35·80	32·30	34·58	34·35	34·86	34·73
Range	34·24–36·87	30·10–33·87	33·73–35·41	33·13–35·39	33·93–37·73	33·77–35·82
	Difference highly significant					
Mean for subjects 1–4 and 9–12	—	—	34·76	34·38	35·18	34·92
			Heart rates (beats/min)			
Mean (all)	97·4	82·7	82·4	83·6	86·5	85·8
Range	70·5–114·3	55·5–104·2	75·9–93·4	70·8–102·9	71·4–96·8	69·0–106·7
	Difference Sd̄ 3·40 $P < 0.05$					
			Heat loss from index finger (cal/cm²/min)			
Mean (all)	0·318	0·016	0·121	0·051	0·079	0·048
Range	0·070–0·911	0·004–0·042	0·014–0·666	0·009–0·105	0·021–0·158	0·018–0·082
	Difference highly significant					
Mean for subjects 1–4 and 9–12	—	—	0·052	0·045	0·075	0·046

Tables 3 and 4 show that the rectal temperatures fell faster in the water when the men were initially hot than when they were cool. The difference was significant but it was small, and even at the end of the experiment the rectal temperatures were still higher when the men were hot than when they were cool at the time they were immersed. The tables also show that the falls in temperature were not significantly altered by exercise or exposure to cold during the morning before immersion, and that although the temperatures of different men fell at very different rates, the fall in the rectal temperature of each man varied little in these four experiments. Figure 1 shows that the average fall in the rectal temperature of each man during these four immersions was closely dependent on his mean skinfold thickness; there was an approximately linear relationship, which was highly significant ($P < 0.001$), between the men's falls in temperature and the reciprocal of their mean skinfold thickness. The relationship is given by the equation $\Delta T = 11{\cdot}7/F - 0{\cdot}62$, where ΔT is the fall in rectal temperature (°C) and F the mean skinfold thickness (mm).

Table 5 shows that 8 min after immersion the rate of heat loss from the men's index fingers was always very low; it always remained low until the end of the experiment. It was always greater when the men were hot than when they were cool at the time of immersion but was not affected by prior exercise or exposure to cold. Some small differences between the rate at which the men's rectal temperatures fell in the latter experiments were associated with differences in peripheral blood flow. This is best

TABLE 3. Fall in rectal temperature (°C) during 1st 10 min of immersion

Subject	Initially hot	Initially cool	Activity during morning before immersion: Still, warm	Still, cold	Working, warm	Working, cold	Mean for individual
1	0·20† (1)*	0·05 (2)	0·05 (3)	0·10 (1)	0·10 (4)	0·10† (2)	0·04
2	0·35 (2)	0·30 (1)	0·05 (4)	0·20 (2)	0·10 (3)	0·15 (1)	0·13
3	0·40 (1)	0·05 (2)	0·05 (1)	0·20† (3)	0·15 (2)	0·10 (4)	0·03
4	0·45 (2)	0·35 (1)	0·20 (2)	0·20 (4)	0·25 (1)	0·30 (3)	0·24
5	0·05† (1)	0·25 (2)	0·10 (3)	0·05† (1)	0·05 (4)	0·35 (2)	0·11
6	0·30 (2)	0·20 (1)	—	—	—	—	—
7	0·05† (1)	0·00 (2)	0·10 (1)	0·00 (3)	0·05 (2)	0·05 (4)	0·05
8	0·15 (2)	0·10 (1)	—	—	—	—	—
9	0·60 (1)	0·40 (2)	0·05 (3)	0·20 (1)	0·30 (4)	0·20 (2)	0·19
10	0·40 (2)	0·10 (1)	0·10 (4)	0·10 (2)	0·10 (3)	0·00 (1)	0·08
11	0·05† (1)	0·00 (2)	0·00 (1)	0·00 (3)	0·15† (2)	0·00 (4)	0·04†
12	0·45 (2)	0·25 (1)	0·10 (2)	0·10 (4)	0·15 (1)	0·00 (3)	0·09
Mean (all subjects)	0·23	0·17	0·08	0·06	0·11	0·11	
Mean for subjects 1–4 and 9–12	0·30	0·19	0·08	0·09	0·13	0·08	

* Numbers in brackets indicate order in which experiments were made on each man in each series. † After a number denotes a rise in temperature.

TABLE 4. Fall in rectal temperature (°C) between 10th and 30th minute of immersion

Subject	Initially hot	Initially cool	Activity during morning before immersion: Still, warm	Still, cold	Working, warm	Working, cold	Mean for individual
1	0·15	0·10	0·10	0·10	0·15	0·10	0·11
2	0·10	0·85	0·95	0·80	1·00	0·85	0·90
3	0·55	0·55	0·45	0·25	0·10	0·40	0·30
4	1·35	1·20	1·40	1·50	1·80	1·45	1·54
5	0·85	0·80	1·00	0·85	1·00	0·80	0·91
6	0·80	0·85	—	—	—	—	—
7	0·55	0·15	0·50	0·60	0·50	0·45	0·51
8	0·65	0·75	—	—	—	—	—
9	2·15	1·95	2·05	2·00	2·35	2·00	2·10
10	0·80	0·60	0·95	1·10	0·70	0·75	0·88
11	0·30	0·05	0·30	0·10	0·25	0·15	0·20
12	0·80	0·70	0·70	0·40	0·65	1·05	0·70
Mean (all subjects)	0·84	0·71	0·84	0·77	0·85	0·80	—
Difference $S\bar{d}$ 0·0415 $P < 0·025$							
Mean for subjects 1–4 and 9–12	0·90	0·75	0·86	0·78	0·88	0·84	—

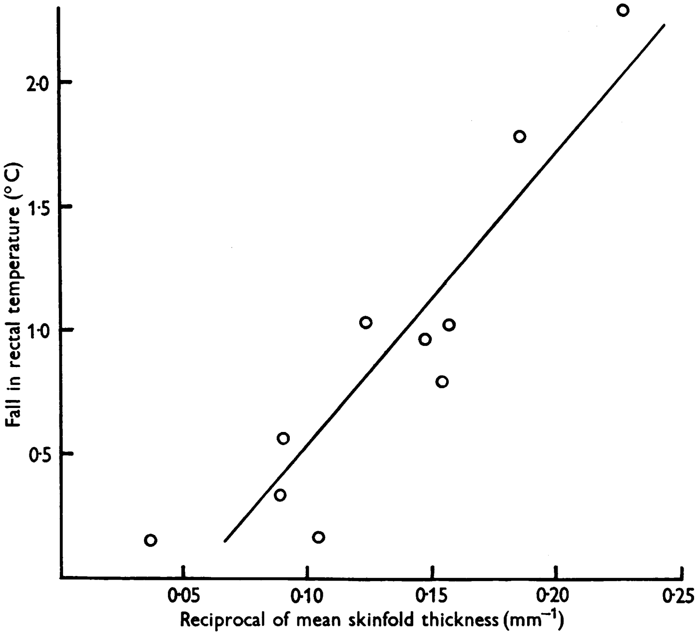

Fig. 1. The relationship between the men's subcutaneous fat thickness and their fall in rectal temperature during the 30 min immersions in stirred water at 15° C. ('Mean skinfold thickness' is the mean of sixteen readings at four standard sites. 'Fall in rectal temperature' is the mean fall in the man's last four immersions.)

TABLE 5. Rate of heat loss (cal/cm²/min) from the index finger 8 min after immersion

			Activity during morning before immersion				
Subject	Initially hot	Initially cold	Still, warm	Still, cold	Working, warm	Working, cold	Mean for individual
1	0·004	0·000	0·002	0·000	0·002	0·002	0·002
2	0·007	0·004	0·002	0·005	0·005	0·000	0·003
3	0·014	0·004	0·005	0·002	0·000	0·002	0·002
4	0·009	0·000	0·002	0·004	0·004	0·004	0·004
5	0·002	0·000	0·002	0·005	0·002	0·002	0·003
6	0·014	0·000	—	—	—	—	—
7	0·012	0·000	0·026	0·011	0·021	0·008	0·017
8	0·014	0·000	—	—	—	—	—
9	0·014	0·000	0·002	0·000	0·002	0·002	0·002
10	0·012	0·002	0·002	0·014	0·002	0·007	0·006
11	0·012	0·000	0·004	0·002	0·000	0·004	0·003
12	0·014	0·004	0·002	0·002	0·007	0·004	0·004
Mean	0·011	0·001	0·005	0·005	0·005	0·003	—
	Difference highly significant						
Mean for subjects 1–4 and 9–12	—	—	0·003	0·004	0·003	0·003	—

illustrated by the results from subjects 3 and 7, who had an almost identical skinfold thickness; subject 7 suffered the larger falls in temperature and had appreciably higher heat losses from his finger.

Tables 6 and 7 give the men's metabolic rates during immersion. These were considerably lower, both in the first 10 min and in the subsequent

TABLE 6. Metabolic rates (kcal/min) during 1st 10 min of immersion

			Activity during morning before immersion					
							Mean for individual	
Subject	Initially hot	Initially cool	Still, warm	Still, cold	Working, warm	Working, cold	kcal/ min	kcal/ m²/min
1	2·88	3·43	2·66	2·87	2·54	3·13	2·80	1·38
2	2·34	2·61	1·89	2·28	2·05	2·27	2·12	1·20
3	2·71	3·88	2·77	3·43	3·30	3·19	3·17	1·73
4	3·36	4·19	4·05	3·85	4·09	3·59	3·90	2·17
5	2·13	2·54	2·41	2·92	2·34	2·84	2·63	1·55
6	2·51	1·77	—	—	—	—	—	—
7	2·33	2·40	2·42	2·57	2·37	2·50	2·47	1·18
8	1·82	2·15	—	—	—	—	—	—
9	4·44	4·69	3·82	4·62	4·02	4·57	4·26	2·37
10	3·83	6·34	3·74	4·58	3·53	4·21	4·02	2·10
11	3·05	3·94	2·74	3·63	3·27	3·42	3·27	1·74
12	2·27	2·48	2·46	2·75	2·28	2·87	2·59	1·46
Mean (all subjects)	2·81	3·37	2·90	3·35	2·98	3·26	—	—
	Difference $S\bar{d}$ 0·225 $P < 0·05$		Difference $S\bar{d}$ 0·111 $P < 0·005$		Difference $S\bar{d}$ 0·119 $P < 0·01$			
Mean for subjects 1–4 and 9–12	3·11	3·95	3·02	3·50	3·14	3·41	—	—
			Difference $S\bar{d}$ 0·134 $P < 0·01$					

TABLE 7. Metabolic rates (kcal/min) between 10th and 30th min of immersion

			Activity during morning before immersion					
							Mean for individual	
Subject	Initially hot	Initially cool	Still, warm	Still, cold	Working, warm	Working, cold	(kcal/ min)	(kcal/ m²/min)
1	2·25	2·82	1·83	2·64	1·77	2·75	2·25	1·11
2	2·29	2·35	1·80	1·56	1·55	3·22	2·03	1·15
3	4·22	4·96	3·36	2·65	2·52	3·55	3·02	1·65
4	5·89	6·07	5·66	6·62	5·68	6·31	6·07	3·37
5	2·61	4·73	4·28	4·64	3·52	3·98	4·11	2·42
6	3·03	2·45	—	—	—	—	—	—
7	2·26	1·92	1·94	2·28	1·86	2·20	2·07	0·99
8	1·67	2·98	—	—	—	—	—	—
9	5·55	5·64	4·50	4·89	5·03	5·31	4·93	2·74
10	5·59	8·50	6·36	6·99	6·07	5·76	6·30	3·30
11	3·38	3·69	2·92	4·11	3·37	3·73	3·53	1·88
12	2·34	2·74	2·22	2·83	2·88	2·82	2·69	1·52
Mean (all subjects)	3·42	4·07	3·49	3·92	3·43	3·96	—	—
	Difference $S\bar{d}$ 0·293 $P < 0·05$		Difference $S\bar{d}$ 0·178 $P < 0·05$		Difference $S\bar{d}$ 0·181 $P < 0·025$			
Mean for subjects 1–4 and 9–12	3·94	4·60	3·58	4·04	3·61	4·18	—	—
					Difference $S\bar{d}$ 0·227 $P < 0·05$			

20 min of immersion, when the men were initially hot than when they were initially cool. They were also significantly lower after a morning in the warm than in the cold room, but work during the morning before immersion did not alter them significantly. These tables give the mean metabolic rate of each man during both the first 10 and the 20 min of his last four immersions and show that the thin men generally had higher metabolic rates in the water than the fat men. In the first 10 min the metabolic rate expressed as kcal/m^2/min (surface area calculated from height and weight by the nomogram of Hawk, Oser & Summerson (1947)) depended comparatively little on the fat thickness of the individual (slope of line $b = 5{\cdot}26$ kcal/min/(fat thickness, mm)$^{-1}$, $P < 0{\cdot}05$), and there were large and fairly consistent individual differences in metabolic rate which were not related to fat thickness or to the fall in rectal temperature. For example, subject 11 had a higher metabolic rate than subject 12 in every experiment,

TABLE 8. Oxygen deficit of expired air, and change in heart rate and ventricular extrasystoles during immersion

			Activity during morning before immersion			
	Initially hot	Initially cool	Still, warm	Still, cold	Working, warm	Working, cold
	Oxygen deficit of air expired during 1st 10 min of immersion					
Mean	2·68	3·06	2·85	2·98	2·84	3·02
Range	1·53–4·04	1·67–4·10	2·06–4·28	2·32–4·01	2·17–4·01	2·02–4·16
Difference $S\bar{d}$ 0·136 $P < 0{\cdot}025$						
	Oxygen deficit of air expired between 10th and 30th minute of immersion					
Mean	4·07	4·04	4·02	3·91	3·89	4·09
Range	2·23–5·10	2·70–4·42	3·54–4·60	3·13–4·64	3·03–4·60	2·74–4·83
	Change in heart rate during 1st minute of immersion					
Mean	+ 8·6	+ 16·6	+ 9·9	+ 7·5	+ 8·8	+ 11·0
Range	− 9·0 to + 19·2	− 5·4 to + 50·1	− 11·9 to + 29·8	− 19·5 to + 34·2	− 24·3 to + 34·9	− 17·3 to + 33·6
	Ventricular extrasystoles 15–70 sec after immersion					
Total number	2	9	9	3	0	8
No. of men who developed them	1	5	3	1	0	3

both in absolute terms and in relation to surface area, in spite of his smaller falls in rectal temperature and greater fat thickness. In the last 20 min of immersion, although these individual differences persisted, the metabolic rates of the thin men rose while those of the three fattest men fell somewhat, and the men's metabolic rate was considerably more affected by their fat thickness (slope of line $b = 11{\cdot}84$ kcal/min/(fat thickness, mm)$^{-1}$, $P < 0{\cdot}025$). In the first 2–3 min of immersion only occasional irregular bursts of shivering were seen; the thinner men then started to shiver steadily and with progressively greater intensity as the experiment proceeded. All except those with the largest falls in temperature ceased to shiver immediately they left the tank.

Table 8 shows that the oxygen deficit of the expired air was significantly lower during the first 10 min of immersion, though not in the next 20 min, when the men were initially hot than when they were initially cool. The men's change in heart rate was not significantly affected by their initial thermal state. Work and exercise on the morning before immersion had no significant effect on either the oxygen deficits or on the change in heart rates, and neither of these changed significantly with successive immersions. The table also gives the number of ventricular extrasystoles recorded between 15 and 70 sec after immersion; only those which could be identified with confidence as grossly abnormal ventricular complexes are recorded. Six men developed a total of 31 ventricular extrasystoles during this period, but their numbers are too few to draw conclusions about their frequency in different types of experiment. Extrasystoles were observed later in immersion and before immersion in only one man, subject 3; none were observed on this man between the 15th and 70th seconds of any immersion.

DISCUSSION

It is clear that the rate at which each man's rectal temperature fell during these immersions depended principally on the thickness of his subcutaneous fat. The fact that the relationship between their falls in temperature and the reciprocal of their fat thickness was approximately linear, small differences of fat thickness in thin men having a proportionately large effect on their fall in temperature, implies that skin and subcutaneous fat provided a major part of even the thin men's total tissue insulation. Presumably the insulation of their deeper tissues was low during these experiments as a result of a high muscle blood flow; Burton & Bazett (1936) have shown that shivering causes a decrease in total body insulation, presumably by this means. Extrapolation of the line relating fall in temperature to reciprocal fat thickness (see Fig. 1) suggests that an infinitely fat man would have increased his temperature by 0·62° C; this is almost the increase that would be expected in 30 min for a totally insulated man of 85 kg with a metabolic rate of 2·0 kcal/min, allowing for some respiratory heat loss. (In practice such a rise would presumably cause vasodilatation and so limit itself; this may have happened to some extent with subject 1, the fattest.) This, together with the fact that blood flow in the men's fingers virtually ceased within a few minutes of immersion, suggests that their skin and subcutaneous fat had a low blood flow and provided nearly their maximal insulation under the conditions of these experiments. However, peripheral blood flow was maintained somewhat better when the men were hot than when they were cool before immersion, and was probably responsible for their slightly more rapid falls in rectal temperature when they were hot; their lower metabolic rates when they were hot probably tended to reduce their falls in deep temperature

(Keatinge, 1959). Differences in peripheral blood flow also appeared to be responsible for some individual differences in the rate of fall of the rectal temperature, but they were much less important than subcutaneous fat thickness in this respect.

The large number of ventricular extrasystoles in the first 70 sec of the immersions confirms the previous observation (Keatinge, 1959) that they may occur on sudden immersion in cold water. They provide evidence of increased cardiac irritability, and the probable causes of this and its possible bearing on the problem of sudden death in cold water have been discussed already.

A fall in deep temperature, without cutaneous stimulation, can cause shivering (Sherrington, 1923–4), but observations that rats (Davies & Mayer, 1955), dogs (Good & Sellers, 1957*a*, *b*) and man (Uprus, Gaylor & Carmichael, 1935; Spurr, Hutt & Horvath, 1957) can be made to shiver by cutaneous cold when their deep body temperatures are unchanged or even raised have been regarded as evidence that the effect of deep temperature is of little importance in the metabolic response to cold. In the present experiments the importance of cutaneous stimulation was shown by the fact that men often ceased to shiver as soon as they left the water, in spite of moderate falls in rectal temperature. However, Carlson (1954) reported that men exposed to cold air shivered more readily when they had drunk cold water than when they had not, and the present experiments provide further evidence that the intensity of the metabolic response to cutaneous cold is greatly reduced by a small increase in the deep body temperature; cutaneous stimulation must have been greater, if anything, when the men were initially hot, but their metabolic rate was lower. Since the men's early response to cold was poorly related to their subcutaneous fat thickness and to their subsequent falls in rectal temperature, and there were large individual differences in metabolic rate during this time which were not related to either, their metabolic response to cutaneous cold clearly was poorly adjusted to their need to produce heat. As their deep temperatures fell the metabolic rates of the thin men increased and a continuing fall in deep temperature must ultimately have caused them to increase until each man achieved thermal balance, if balance was possible. The effect of a fall in deep body temperature would, then, presumably be the principal factor enabling the thin men to achieve thermal stability in a cold environment. These experiments, therefore, provide evidence that deep receptors play the main part in adjusting the metabolic rates of fat and thin men to their differing rates of heat loss during prolonged exposures to cold.

The men's metabolic rate during immersion was also substantially increased by exposure to cold earlier in the day. By the time of immersion both their skin and rectal temperatures had returned to much the same level after 'cold' as after 'warm' mornings, but even the small and statistically insignificant difference in average temperatures that was still present might indicate a small but real difference in hypothalamic temperature and the possibility that a persistent change in hypothalamic temperature was responsible for the effect of a morning in the cold cannot be entirely excluded. The increased metabolic response in water after a morning in the cold room was not a consequence of the muscular work of shivering in the cold room, since a similar period of moderate exercise in the warm had no such effect.

This increased metabolic rate in the water produced by exposure to cold air earlier in the day contrasts with a diminution in metabolic response produced earlier by repeated brief immersions in water at the same temperature (Keatinge, 1959). Such opposite modification of the metabolic response by different types of exposure to cold is unlikely to take place in the cutaneous receptors. It may be related to the men's need to shiver or work in order to maintain their deep temperatures in the cold room, while shivering was certainly unnecessary and was probably, like work, undesirable during the brief immersions (Keatinge, 1959). The central nervous system would thus merely be modifying the metabolic response in the direction which was found to be appropriate in the previous exposure to cold. Brief repeated immersion of men in water at 15° C reduced their increase in heart rate and over-ventilation, as well as their metabolic rates, in the water; the heart rate and blood-pressure responses to immersion of a hand in either painfully hot or painfully cold water are also reduced by repetition (Glaser & Whittow, 1957; Glaser, Hall & Whittow, 1959), and such reductions may represent a general central nervous reaction to repeated brief unpleasant stimuli. In contrast, previous exposure to cold air in the present experiments increased the metabolic response to immersion without affecting other responses, probably through a conditioned reflex.

SUMMARY

1. The fall in the rectal temperature of each of ten young men immersed motionless for 30 min in stirred water at 15° C varied little in successive immersions and was closely related to the man's subcutaneous fat thickness by the equation $T = 11{\cdot}7/F - 0{\cdot}62$ (where T = fall in rectal temperature in °C and F = mean skinfold thickness in mm, measured at four standard sites).

2. The falls bore relatively little relation to the men's finger blood flow, which was always low during immersions, but both were slightly greater when the men were hot than when they were cool at the time of immersion.

3. The men's metabolic rates during immersion were substantially lowered by a small increase in their body temperatures at the time of immersion, and were increased by exposure to cold air, though not by moderate exercise, several hours before immersion.

4. In the first 10 min of immersion the metabolic rates of thin men were little higher than those of fat men, and there were a number of substantial and consistent individual differences in metabolic rate which were not related to the individual's fat thickness or to his fall in rectal temperature. In the last 20 min of immersion the metabolic rates of the thin men increased substantially but those of fat men did not.

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