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ASSESSMENT OF GROUP ACCLIMATIZATION TO HEAT AND HUMIDITY

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As pointed out by Robinson (1949), conditions in actual industrial or climatic situations are not so severe as those that may be imposed experimentally; but heat tolerances have, to a considerable extent, been measured on men artificially acclimatized to these unrealistic extremes (Adolph, 1946; Medical Research Council, 1946, 1947; Robinson, Turrell & Gerking, 1944; Eichna, Bean, Ashe & Shelley, 1945). Naturally acquired acclimatization to heat such as is exhibited by Bantu mine workers (Weiner, 1950) or by West African labourers (Ladell, 1950), when judged by the usual criteria of sweat rate and rectal temperature changes in a standard severe climate, falls short of the 'full acclimatization' which can only be acquired by successive repeated exposures to, and work in, a severe climate over a period of time; no method has yet been suggested, however, by which any but an arbitrary qualitative assessment can be made of such incomplete states of acclimatization. A numerical scale is required, based on some objective changes found during acclimatization, such as a rise in rectal temperature or in sweat rate. The variation between individuals, however, is so great that observations on the heart rate, rectal temperature rise or sweat rate made on an individual during a single exposure to a standard test could not be used to assess with any accuracy his degree of acclimatization to heat; for example, the sweat produced by one man on his first exposure to heat may be as much as that produced by another man who is nearly fully acclimatized (see Table 1). Even with several successive exposures the acclimatization could only be deduced from the improvement shown in the performance, and the testing would in fact become an acclimatization course.

Although it would be ideal to be able to assess the degree of acclimatization to heat of individual men, this is not absolutely necessary in practice. Men are dealt with in groups rather than as individuals, e.g. as 'novices' or 'veterans'; each group is usually composed automatically of men who have had the same 'treatment' and who, therefore, may be assumed to have approximately the same degree of acclimatization to heat. A mine manager, for example, might wish to know the 'inherent' acclimatization of a batch of new recruits, none of whom had previously been exposed to severe heat; or, on another occasion, the degree of acclimatization attained by a group of men working in one particular district prior to transferring them to another, hotter, one. A method of assessing group acclimatization would therefore be useful. Now a regression could be calculated of the mean value for a certain observation on 'day of exposure' to show how this mean value, obtained from a group of subjects during a standard routine, changed as the group became acclimatized by successive exposure to and work in the heat. If none of the group had previously been exposed to heat, and the regression of, for example, sweat rate on certain days was given statistical validity, this regression could subsequently be used as a standard of comparison, or 'scale', against which the partial acclimatization could be measured, by means of their mean sweat rate, as equivalent to so many days of 'artificial acclimatization'. In this contribution an attempt is made to derive two such regressions from the acclimatization records of the subjects investigated by the Medical Research Council team at the National Hospital, Queen Square, during 1944 and 1945 (Ladell, 1947*b*).

Over forty men were acclimatized by the team; none of the forty had recently been to the tropics or had been working under hot conditions; all were military or naval personnel who had been passed fully fit and who had volunteered for the tests. The oldest man of the group was 38 years, the youngest 18. Of the forty only fourteen were subjected to an identical acclimatization routine; three others, however, had routines sufficiently similar for observations on these men to be included with those on the fourteen. The regressions to be described were therefore derived from a selected sample of seventeen men. Acclimatization was never formally completed; after the first nine exposures, spread over 2 weeks, when acclimatization was nearly complete, the subjects were placed in other climates and subjected to other routines, and their acclimatization completed without any further formal observations. Some men failed to complete the 2 week's course or were switched to other routines before the 2 weeks had expired; figures are in fact available only as follows: ten men for nine exposures, three for eight exposures, two for six exposures and one for five. In the calculations allowance had to be made for these missing values. Also the protocols for four experiments were inadvertently destroyed, so in all nineteen sets of results, out of a possible 153, were estimations and not observations; this still left, however, 133 degrees of freedom for any statistical analysis, whereas if consideration had been confined to those results on the ten subjects who completed the full course there would only have been 89 degrees of freedom. It was therefore considered preferable to use all the results available.

TABLE 1. Observed sweat losses (not corrected for weight) for each of the seventeen subjects during the index period (time 12–92 min.). For comparison the mean corrected sweat loss in 80 min. (C.S.L.) for each day is shown, with its standard error in Part II of the table. The individual C.S.L. values are plotted in Fig. 2(*a*).

Subject	Wt. (kg.)	ml. sweat in 80 min.									
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day10
		Part I. Individual Observations									
KEN	62·13	665	639	780	Lost	755	878	860	757	1090	961
BRA	77·58	448	820	848	790	700	789	930	864	900	813
BOL	63·37	700	903	748	Lost	770	754	1003	1067	—	—
CAP	99·98	426	980	Lost	1110	1504	—	—	—	—	—
MOA	66·25	485	332	520	520	416	530	377	528	730	572
HAM	73·88	922	819	1247	1025	903	720	926	1084	1113	1180
COL	62·80	730	685	Lost	867	820	1035	—	—	—	—
REE	67·33	915	1030	865	940	955	1095	875	856	690	671
PIK	64·21	540	640	655	575	775	755	850	1040	825	—
WIL	56·23	965	1145	1160	1330	839	1570	1435	1082	1480	1337
MCK	61·36	720	900	880	980	886	1125	1131	1180	1079	1120
PAR	68·39	1010	1070	1200	1260	1270	1188	1374	1450	1545	1488
BYR	67·66	1035	1163	1370	1264	1167	1473	—	—	—	—
FLE	62·43	672	857	891	839	909	994	1208	1354	1132	—
BEN	78·78	1572	1253	1538	1893	1721	1905	1922	—	—	—
CUS	59·98	561	676	731	837	907	1022	981	1078	—	—
EDE	64·03	1136	1165	1382	1239	1520	1523	1655	1697	—	—
		Part II. Means (Corrected for Weight)									
C.S.L.	68·02	779	865	952	972	955	1071	1107	1153	1157	Not calculated
S.E.	—	66·3	54·7	65·6	74·1	70·0	86·1	84·9	83·1	82·5	

PART I. EXPERIMENTAL OBSERVATIONS

Acclimatization routine

The subjects were exercised in the hot room maintained at a dry-bulb temperature of 100° F. (37·8° C.), wet bulb 93–94° F. (34° C.), aqueous vapour pressure 38·5 mm. Hg, air movement 50 ft./min. (15 m./min.). On entering the hot room the subject rested for 15 min., then began a series of 20 min. cycles, each of 5 min. work and 15 min. rest. The work consisted of stepping up and down a stool 1 ft. high 12 times a minute in two of the first four cycles and 24 times a minute in the other two cycles; the mean metabolic cost of this routine was 87 kg. cal./m.^{2}/hr. The subjects were nude, but wore on one arm a bag for collecting sweat (Ladell, 1948); the first seven subjects only wore the bag on alternate days. Subjects were weighed on entering and on leaving the hot room, and except for the first seven subjects when they were wearing bags, before and after each bout of work, i.e. at approximately 10 min. intervals. Rectal temperatures and the pulse rates of the subjects (standing) were taken before and after work in all cases and on entering and leaving the room; sitting pulse rates were taken before each work. The first seven subjects were not allowed to drink, but the others were allowed enough water to make good their sweat losses. The three subjects who worked at a higher rate did so at a mean metabolic cost, for two of 92 kg.cal./m.^{2}/hr. and for one of 98 kg.cal. The effects of the variations in work and in fluid intake will be considered in the final discussion.

Missing values. From examination of those sets of observations which were complete it appeared that two approximations were justified for the purpose of estimating the missing values:

(1) That a subject's performance tended to improve steadily with each successive exposure.

(2) That the performance of a given subject relative to the mean performance of the whole group was approximately the same at all stages of acclimatization.

From (1) figures for rectal temperature and sweat production were assessed for those tests for which the protocols had been lost as the means between the corresponding figures for the day before and the day after the test in question. In those tests where intermediate weights had not been observed sweat losses for intermediate periods were estimated as proportions of the total sweat loss for the whole exposure, the proportion being estimated from that observed on the subject on the days immediately before and after the day in question. Except for estimates of the overall sweat loss in the case of the four missing protocols figures derived in this way were not utilized in the construction of the acclimatization scale.

Sweat losses were estimated for the hypothetical later exposures of those subjects who failed to complete the series of nine tests by the application of approximation (2) as in the following example: subject Q only completed eight exposures; the ratios of the daily sweat losses of subject Q to the daily summed losses of the group who completed nine exposures were, for days 1–8 respectively, 1 to 6·4, 7·0, 6·4, 7·2, 5·2, 6·3, 6·0 and 5·9; the mean value of this ratio calculated by reciprocals is 1 to 6·3. The missing value for day 9 was assessed as that figure which would give the same ratio, 1 to 6·3, to the summed losses for those subjects actually observed on day 9. Similar ratios were calculated for the other subjects who failed to complete 9 days and the hypothetical values derived in the same way. The day-to-day variation in the ratio for any one subject was never greater than in the example given. The values estimated in this way were used in the construction of the acclimatization scale.

Course of acclimatization

The acclimatization followed the course described by other workers (McArdle, 1944; Eichna, Bean, Ashe and Nelson, 1945; Bean & Eichna, 1943; Robinson, Dill, Wilson & Nielsen, 1941), except that changes in pulse rate were not marked. McArdle's method of plotting daily sweat rate/rectal temperature curves was adopted; the series for the present set of seventeen men acclimatized for 9 days is shown in Fig. 1. This figure was constructed as follows.

To obtain the curve for a given exposure the group means were calculated of the mean rectal temperature and of the sweat rate in each successive work and rest period. The first point on each curve is the mean temperature and sweat rate for the first 10 min. of that exposure; the second point, however, was not plotted from the corresponding figures for the second 10 min. but from the mean between these and those for the first 10 min.; it therefore represents a mean for a 20 min. period of rest then work. The third point is the mean between the second and third 10 min. (work followed by rest), the fourth is the mean between the third and fourth 10 min. and so on.

Each point therefore represents the mean for a 20 min. period of work and rest, but the periods overlap. In this way gross differences between working and resting periods are eliminated. The resultant curve is representative of a mean metabolic rate, and corresponding points on different curves represent corresponding periods in the exposures. The series of curves, shown in Fig. 1 and constructed in this way, demonstrate McArdle's observation that one of the earliest changes in acclimatization is a lowering of the threshold rectal temperature for sweating; which is followed later by an increase in the sweat rate at a given rectal temperature.

The means of the rectal temperatures (observed and estimated) in each exposure are shown in Table 2. Initial resting temperatures become lower as the subjects were acclimatized; this may be an effect of acclimatization. Rectal temperatures were still rising even after five cycles at the end of every exposure, and thermal equilibrium was not achieved no matter what the state of acclimatization. The rate of rectal temperature rise was approximately

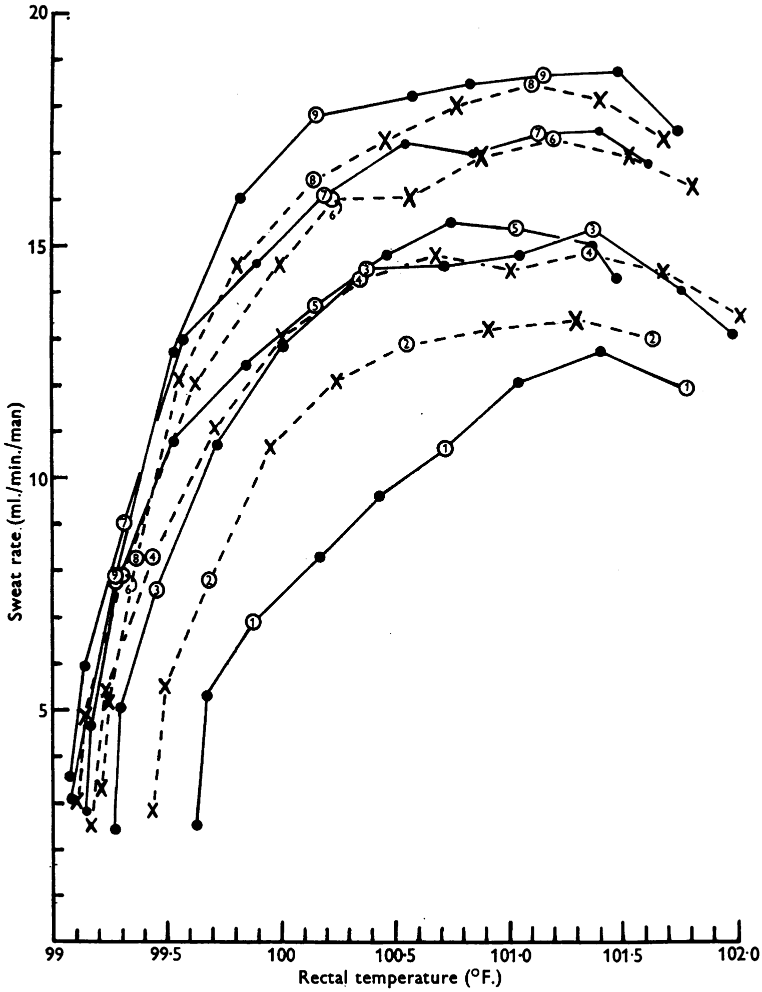

Fig. 1. Mean sweat rate/rectal temperature curves for the group of seventeen men on successive exposures during nine days' acclimatization. Odd-numbered days are shown as solid lines with dots, even-numbered days are shown as broken lines with crosses. There is a time element in these curves; corresponding points on the different curves refer to the same overlapping period in each exposure. To facilitate counting, the 3rd, 6th and 9th points on each curve are shown as circles with the number of the day to which the curve refers inside. Note that in early exposures point 9 comes after the maximum sweat rate, and on later exposures point 9 is either before or at the maximum.

the same in all exposures; the mean over-all rise during the whole exposure showed no tendency either to decrease or increase as acclimatization proceeded. Taking recorded observations only, the mean rises in rectal temperature were, for days 1–9 respectively, 2·41, 2·43, 2·27, 2·29, 1·86, 2·32, 2·21, 2·18 and 2·46° F. from time 0 to time 92 min.; the mean rise for the whole 134 observations was 2·27° F. (1·26° C.), S.E. 0·062; the variance between days (8 degrees of freedom) was 0·54, and for the remaining degrees of freedom (125) was 0·52. The greater part of the variance due to days was attributable to the low value on day 5, which will be discussed later.

TABLE 2. Mean rectal temperatures for each day throughout the whole exposure.

Notes. (1) These means include estimations and are not strictly comparable with the values shown in the text, which are derived from actual observations only, and have been analysed statistically.

(2) Each value shown is the mean of those taken at one particular time during an exposure. The temperatures plotted in Fig. 1 are means for different periods during an exposure.

		Work 1		Work 2		Work 3		Work 4		Work 5		
Day	Initial	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Final
1	99·60	99·67	99·99	100·07	100·52	100·60	101·18	101·26	101·90	102·06	—	—
2	99·47	99·41	99·73	99·87	100·35	100·43	100·98	101·26	101·71	101·85	—	—
3	99·34	99·20	99·50	99·63	100·14	100·30	100·81	100·95	101·50	101·55	102·00	101·96
4	99·22	99·15	99·48	99·65	100·12	100·21	100·76	100·89	101·48	101·58	102·07	101·97
5	99·25	99·06	99·32	99·44	99·94	100·06	100·55	100·65	101·16	101·16	101·62	101·53
6	99·15	99·06	99·36	99·52	100·03	100·11	100·68	100·77	101·33	101·40	101·95	101·90
7	99·08	99·08	99·36	99·49	99·99	100·12	100·66	100·76	101·23	101·32	101·71	101·73
8	99·25	99·17	99·41	99·48	99·88	100·05	100·59	100·67	101·20	101·32	101·79	101·83
9	99·10	99·06	99·34	99·43	99·91	100·05	100·64	100·71	101·26	101·43	101·84	101·87

(All temperatures in degrees Fahrenheit.)

The total sweat loss for the whole exposure of five cycles, adjusted for a mean body weight of 65 kg. according to the method of Adolph (1947), rose from 1100 g. on the first day (allowance has been made here for those subjects who only completed four exposures) to 1560 g. on the ninth day; these are the means for all seventeen subjects. Half this increase took place in the first three days and was the result of the subjects sweating earlier, with respect to rectal temperature, after their first exposure. The subsequent increase in sweat loss was due to the subjects sweating faster at a given rectal temperature as acclimatization proceeded. Sweat rate appeared to fall off earlier when the subjects were unacclimatized (point 9 on curve for day 1) than when they were acclimatized (point 11 on curve for day 9). This falling off in sweat rate, when subjects have been sweating near-maximally, has often been described before (Ladell, 1945; Gerking & Robinson, 1946; Robinson & Gerking, 1947; Johnson, Pitts & Consolazio, 1944), and in these circumstances is probably correctly ascribed to fatigue of the glands.

Heart rates during resting and working increased throughout the course of each exposure; this is shown in Table 3 for the ten men who completed the nine exposures. After the first two or three exposures, however, the heart rate at any given stage in the exposure did not alter substantially from one exposure to the next. A fall in the initial rate, from 103 on the first to

84 beats/min. on the ninth day, was probably to be associated with the lower rectal temperatures found initially in the later exposures.

TABLE 3. Mean heart rates, in beats/min. before and after work for ten subjects who completed nine exposures, in each successive exposure. Counts made over 15 sec. with subjects standing.

Cycle...	...	1		2		3		4		5	
Work...	1		2		3		4		5		
Day	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Final
1	103	119	110	139	124	144	124	167	140	—	—
2	98	121	109	133	118	152	128	159	135	—	—
3	94	110	104	130	115	149	124	162	131	167	134
4	94	116	104	127	113	152	121	163	132	162	135
5	90	114	100	126	110	148	121	156	133	167	135
6	88	115	101	132	114	152	121	162	131	164	135
7	91	112	97	133	112	149	123	157	131	162	135
8	89	113	101	125	111	144	122	158	126	160	130
9	84	110	97	131	112	146	123	154	128	160	131

Stamina increased with successive exposures, but no objective estimate was made of this, beyond noting that certain subjects who could only complete four cycles with difficulty in the first few days were able to carry out six cycles after eight exposures.

DISCUSSION

The course of acclimatization in these experiments had no unusual features. It could be divided into two phases: an initial phase of 2–3 days, characterized by a decrease in the heart rate and a lowering of the threshold rectal temperature for sweating, and a second phase characterized by an increase in the sweat rate at a given rectal temperature and a diminished susceptibility of the sweat glands to fatigue.

Very early in acclimatization to heat there is an increase in the circulating blood volume (Bazett, 1938). This probably determined the slowing of the heart rates observed during the first phase of acclimatization. Until this increase in circulating blood volume is adequate to compensate for the great expansion of the vascular bed which results from the cutaneous vaso-dilatation initiated by the heat, subjects may suffer syncope, or at least dizziness or partial blackout on standing up; such symptoms were complained of by most subjects during the first two or three exposures of this series. In control experiments at normal room temperature there was no change in the resting heart rate even after six cycles; hence the exercise was mild and no training effect was to have been expected during the second phase of acclimatization; none was observed.

The climatic conditions of these exposures imposed severe physical limitations on the rate of heat loss from the body. Some unpublished observations by McArdle showed that in these tests the skin temperature probably never rose above 100° F. (37·8° C.); this was the temperature of the ambient air and of the walls. Heat could only be lost, therefore, by evaporation. As the dew-point of the ambient air was within the range of that reported for alveolar air (Christie & Loomis, 1933), all evaporation had to be from the skin. If a 65 kg. man, surface area 1·75 m.^{2}, working at a mean metabolic cost of 87 kg. cal./m.^{2}/hr., is to lose all his metabolic heat by evaporation, the rate of evaporation must be 5 ml./hr. This is probably a slightly greater rate than can be physically achieved; from the formulae of Powell, quoted by Bedford (1948), for the rate of evaporation from single cylinders, the maximum rate from a collection of cylinders chosen in shape, proportion and positioning to represent the human body, surface area 1·75 m.^{2}, will be about 4 ml./min., in air at 100° F. (37·8° C.) moving at 50 ft./min. with a water-vapour pressure of 38·5 mm. Hg. Hence, even when the whole of the body surface was wetted, the rate of evaporation was still not sufficient for thermal equilibrium. This is the phenomenon termed by Robinson & Gerking (1947) 'environmental resistance'. Nevertheless, in somewhat longer exposures with subjects carrying out a routine, in the second hour, of the same mean metabolic cost, thermal equilibrium was established after about 100 min. in the heat (Ladell, 1947*a*, 1949); rectal temperatures were then 102° F. (38·8° C.) or higher. But these experiments were on fully acclimatized subjects, and skin temperatures may have been high enough, by that time in those longer exposures, to allow of some heat loss by convection and radiation.

Preliminary tests carried out in this laboratory on the minimum depth of water needed to give a continuous film of water on the skin suggest that this is about 0·002 cm., hence at least 35 ml. of sweat must be secreted before the whole of the skin area is wetted. If some allowance is made for the evaporation of some sweat as it is produced, it can be shown that in no exposure of the present series could the skin have been fully wetted, so that maximum evaporation could take place, until after the first work period. During the early stages of every exposure, therefore, it might be expected that the rate of body temperature rise would be more rapid than when sweating was fully established; but, in so far as rectal temperature may be considered to be an indication of body temperature, this was not the case; it usually fell during the first 10 min. (see Table 2). This initial fall in rectal temperature has been observed by all workers in this field, and it is most recently described by Grayson (1950); a similar fall in mouth temperature has also been recorded by Cooper & Kerslake (1948). This phenomenon is usually attributed to the redistribution of blood within the body, consequent upon vasodilatation; this allows the mean body temperature to increase while the rectal, or core, temperature remains the same or falls slightly, and there is, in fact, storage of heat. In the present series of experiments, once the body was wetted there was always enough sweat being produced to satisfy evaporation needs, and by the middle of each exposure the subjects, even when relatively unacclimatized, were producing three or more times as much sweat as could be evaporated; after acclimatization the amount of unevaporable sweat was even greater. The physiological significance of this apparently useless increase in sweat rate is still obscure.

Some authorities, e.g. Critchley (1948), have suggested that acclimatization is predominantly a matter of cardiovascular adjustment. Improvements in circulatory efficiency continue, they suggest, throughout the period of acclimatization. Such improvements would result in the more efficient transfer of heat to the skin, and the skin/core temperature difference would, unless more heat was lost, become less. In these tests no more heat could be lost because of environmental resistance, and the mean body temperature must have remained the same from day to day; hence a diminution in gradient would only have resulted in a fall in rectal temperature. But Table 2 shows that the mean final rectal temperatures in all exposures from the third were all, with the exception of day 5, within 0·25° F., and there was only 0·1° F. between the figures for day 3 and day 9. Hence any improvements in cardiovascular efficiency that took place during the second phase of acclimatization must have been slight; on the other hand, the achievement of thermal equilibrium by hyper-acclimatized subjects in a similar routine, already referred to, does suggest an ultimate improvement.

PART II. CONSTRUCTION OF REFERENCE SCALE FOR A GROUP OF SUBJECTS

An estimation of group acclimatization could be made by constructing a sweat rate/rectal temperature curve for the group as described in the first part of this paper and comparing it with the set of curves shown in Fig. 1; but this would be laborious and give an approximate answer only. A continuous scale for comparison can be provided, however, as suggested in the introduction, by calculating a regression for the value of some physiological variable or observation on days of exposure. Two regressions have been calculated, one for mean sweat loss over a given period, and the other for the ratio of mean sweat loss to mean rectal temperature rise. The test period chosen was not timed to start until after the initial pre-work rest in the heat, so that pre-exposure conditions could not grossly affect the results. The maximum difference between acclimatized and unacclimatized subjects was obtained by cutting short the period during which observations were used for the regression after 4 cycles had been worked, i.e. at time 92 min. At this point sweat-gland fatigue was beginning to show in unacclimatized subjects, but even complete novices in the heat could work for that length of time in the test climate.

Regression based on sweat output only

The observed weight losses for the standard period were corrected for weight differences according to the method of Adolph (1947), by multiplying by the two-thirds power of the ratio (standard weight/actual weight). The standard weight chosen was 65 kg. The sweat loss over the 80 min. period (from time 12 to time 92 min.) corrected for weight will be referred to in the rest of this paper as C.S.L. (corrected sweat loss in 80 min.). In all, 153 values of C.S.L. were obtained, 134 actual observations and 19 estimations.

As sweat rate increases with acclimatization some correlation can be found between it and any function of days of exposure, linear or otherwise. But the increase is not truly linear, being more rapid during the first few days of acclimatization and relatively slow after the first seven or eight exposures; e.g. the mean C.S.L. for eight subjects on whom observations were made for 10 successive days was 981, 1073 and 1012 for days 8, 9 and 10 respectively. After ten exposures the rate of increase is, it is agreed by all workers, very slight; this was confirmed at Queen Square by observations made intermittently over many months on subjects who were continually exposed experimentally to hot humid conditions. Any mathematical relationship between sweat production and days of exposure should therefore describe a rapid increase in sweat output during the first few days, followed by a slowing up of the rate of increase, and a tendency for the output to reach a limiting maximum not much greater than the output on the 9th or 10th day. This pattern of increase is similar to that shown by an organism during the self-decelerating phase of growth (Brodie, 1928); and so by analogy the increase of sweat output with acclimatization might be described by an equation of the type:

$$\text{C.S.L.} = \text{M.S.L.} - B\,\mathrm{e}^{-kD},$$

where M.S.L. is the value for C.S.L. at full acclimatization, e the base of natural logarithms, D the day of exposure in the acclimatization series and B and k are constants. Using Brodie's (1945) method, a series of curves of this type was fitted to the mean values of C.S.L. Suitable values for M.S.L. varied from 1275 to 1325, but the best fit was obtained with an intermediate value;

$$\text{C.S.L.} = 1295 - 610\,\mathrm{e}^{-0 \cdot 17D} \tag{1}$$

The sum of the squares of the deviations of the observed means from the value predicted from equation (1) was 77377·17, of which 6844·01 was contributed by day 5.

Table 4 gives a complete statistical analysis of the results in relation to this regression (Fisher, 1941) and taking into account the individual values. 'Differences within days', mostly due to individual variation, caused most of the observed variation. The standard deviation between individuals was 885 ± S.D. 50·4, which is greater than the observed increase in mean C.S.L. during 9 days' acclimatization. Comparison of the variance within days, due to 'error', with that due to deviations from the regression, calculated directly

TABLE 4. Statistical analysis of regression of C.S.L. on day of exposure. Each section of the table shows one main variable and its components.

Variables			Degrees of freedom		Sums of squares		
Main	Component	Total no.	Main	Component	Main or total	Components	Variance
All values	—	153	152	—	16,166,521	—	—
	Estimated	19	—	—	—	—	—
	Observed	134	—	133	—	—	—
Variation between days	—	9	8	—	2,331,711·5	—	—
	Due to regression	—	—	1	—	2,206,299·6	—
	Deviations from regression	—	—	7	—	125,411·9	17,916
Variation within days and discrepance	—	—	125	—	13,834,809·5	—	—
	Between persons	17	—	16	—	12,535,602·2	783,475
	Discrepance	—	—	109	—	1,299,207·3	11,919·3

from the differences, gave a z value of 0·2037, which is less than the 10 % point (0·285 for these degrees of freedom). Variance due to deviation is not therefore significantly greater than that due to error, and the regression may be accepted. Variance due to individuals is significantly greater than that due to error; the z value being 2·188, with the 1 % point at 1·3. This confirms what was pointed out in the introduction that single estimations of physiological variables such as C.S.L. cannot be used to compare the acclimatization of individuals; this is further shown by comparing the variance due to acclimatization (calculated from the regression by difference) with individual variance; a z value of 0·518 is obtained, equal to the 10 % point when $n_1 = 1$, $n_2 = 16$, which indicates that the variation due to acclimatization would be no greater than that due to individuals in 10 % of trials.

Regression based on sweat output per unit body temperature rise

During acclimatization the overall rectal temperature rise remained the same or decreased while sweat output increased; hence sweat output per degree rise in rectal temperature increased also. It was considered therefore that better correlation might be obtained if an allowance were to be made for day-to-day variations in rectal temperature rise. When such an allowance was made on day 5, which had a low C.S.L. value and on which the rectal temperature rise was also low in comparison with other days, by multiplying the observed C.S.L. by the ratio

$$\frac{\text{Observed mean temperature rise during index period for all days except 5}}{\text{Observed rise on day 5}} = \frac{2{\cdot}32}{2{\cdot}11}$$

a corrected value of 1049 was obtained; the predicted value was 1034. This suggested the desirability of incorporating similar allowances on other days.

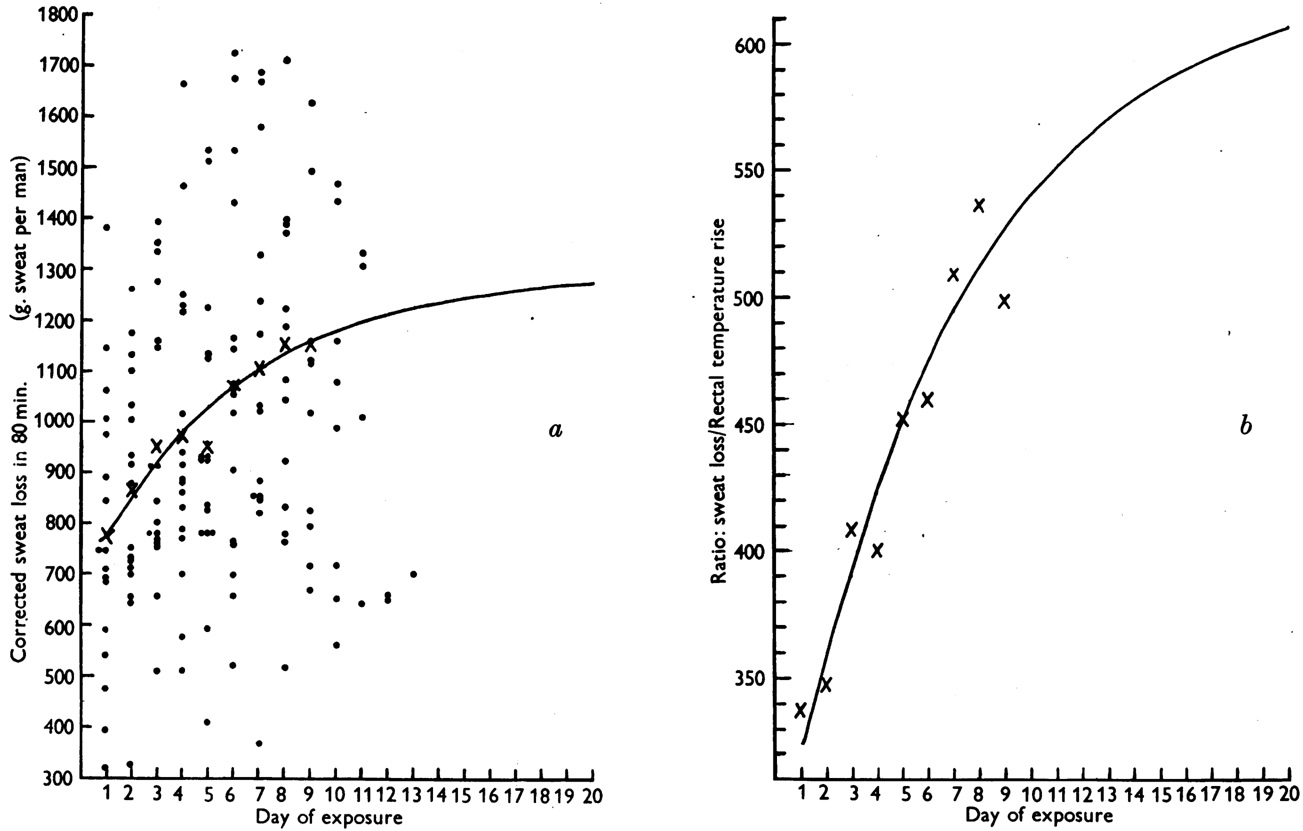

Fig. 2. These two figures show, in 2*a* and 2*b* respectively, the regressions of mean C.S.L. (corrected sweat loss in 80 min.) and of mean S.L.T. (ratio of mean C.S.L. to mean rectal temperature rise) on day of exposure, extrapolated for twenty exposures. The mean value for the group of seventeen subjects are shown as crosses. In Fig. 2*a* all values actually observed over 13 days have also been plotted, as dots. After taking out variation between days the standard error of the mean C.S.L. is 29·7.

All the figures for daily sweat outputs were therefore recalculated as the ratios of mean sweat output to mean rectal temperature rise. This ratio measures the sweat output per degree rise in rectal temperature, and it increased from 327 on day 1 to 498 on day 9. The increase is described by the expression

$$\text{S.L.T.} = 625 - 359\,e^{-0\cdot145D}, \tag{2}$$

where S.L.T. is the sweat loss per degree rise in rectal temperature. The sum of the squares of the deviations of the observed S.L.T.'s from the values predicted from regression (2) is 2758. For comparison with regression (1) this sum was multiplied by the square of the mean temperature rise for the whole series, giving a value of 14,590, and the z value for the two variances calculated; the value of z is 0·34, the 20% point for when $n_1 = n_2 = 7$. Hence the arithmetically much greater deviations from regression (2) are not statistically significant. The curves for both regressions are shown in Fig. 2.

The day 5 deviations. Day 5 was, for most subjects, a Monday, and the exposure therefore came after 2 day's rest from the heat. Some diminution of acclimatization might have been expected, but this would have been shown by a smaller sweat output for the same or greater rise in rectal temperature. Actually both sweat output and rectal temperature rise were diminished on day 5; hence, in these tests, there was no indication of a falling off in acclimatization. On the other hand, the subjects reactions indicated that the conditions on day 5 had been slightly less severe, but no reason for this could be found. This 'Monday effect' has been a constant source of trouble in all work on climatic physiology, and many authors discard Monday results; for obvious reasons this could not be done in the present instance.

DISCUSSION

Both the regressions calculated are equally good statistically; hence either could be used as a standard against which the performance of a group of approximately equally acclimatized subjects could be measured. But as the regression for S.L.T. takes into account two physiological measurements, rectal temperature and sweat rate, it is preferable to the other which is only concerned with sweating. Inasmuch as both regressions are based on incomplete results and observations were only continued for 9 days, it would have been better if a second group of men could have been investigated. This has been done, but on West Africans (Ladell, 1950, and in preparation), and as results obtained on men indigenous to the tropics may not be strictly applicable to men who have never previously been exposed to hot humid conditions, it is felt that the present regressions still offer the best standards for comparison. It should also be pointed out that the group was not a true random sample of the temperate climate population, so the regressions may not describe exactly the reactions of the average temperate climate man; the regressions may still, however, be used as standards.

To estimate the degree of acclimatization of a group of subjects, using either regression as a standard for comparison, or 'scale', each individual needs to go through the standard routine in the standard climate once only. Measurements of weight and rectal temperature are required just before the first work and at the end of the fourth cycle, 80 min. later. Drinking may be allowed, but the fluid balance must be recorded. C.S.L. is calculated separately for each individual by multiplying his observed sweat loss by the factor $(65/W)^{\frac{2}{3}}$, where W is the initial weight of the subject. The mean C.S.L. for the whole group is then calculated and S.L.T. is given by the ratio

(mean C.S.L./mean rectal temperature rise for whole group).

The equivalent days of acclimatization are then read off the curves in Fig. 2, or the relevant equations may be solved for D.

The use of these regressions to estimate, by comparison, group acclimatization may be queried for the test conditions were very severe, the period of exposure was short and no account was taken of cardiovascular changes or adjustments. It is reasonable to test men in the most severe climate to which they are ever likely to be subjected, but though conditions as severe as those of the test are sometimes found, e.g. in certain West African mines, where the temperatures at the working place may be 96° F. (35·6° C.) dry bulb, 95·5° F. (35·3° C.) wet bulb with still air, it is now realized that the test climate was unduly severe for most purposes, and consequently some of the responses were conditioned by physical rather than physiological factors; the lack of continued cardiovascular improvement was probably due to the severity of the stress, so that the maximum adjustments were completed early in acclimatization. The short test period was necessitated by the severity of the climate; even fully acclimatized subjects could not continue for more than six cycles without becoming exhausted, and some unacclimatized subjects could only manage four. A short index period has the advantage, however, of emphasizing differences between acclimatized and unacclimatized men: the shorter the test period the greater the proportionate effect on total sweat output of an earlier onset of sweating; also the maximum sweat rate, in a given exposure, will be reached before the end of an 80 min. period by an acclimatized subject and will be maintained, but unacclimatized subjects may not reach their maximum so soon and if they do, owing to the earlier onset of sweat gland fatigue, they do not keep it up. The duration of the exposures could be increased to make the test an endurance test, but it would not be correct to label any man 'heat intolerant' because he was unable on his first exposure to complete more than four cycles. Several successive exposures would be required, and then the diagnosis should only be made if the subject showed little or no improvement in performance.

In these tests the fluid intake varied from nil to full replacement; but though there is no doubt that in experiments of long duration the man who drinks sufficient to replace his sweat losses benefits physically (Pitts, Johnson

& Consolazio, 1944), it has been shown that moderate water deficiency has no effect on sweat rate (Eichna *et al.*). In 110 min. exposures to the test climate, with a slightly heavier routine, there was no statistically significant variation in the sweat output of fully acclimatized subjects with changes in salt and water intake (Ladell, 1949, and in preparation).

As three of the seventeen subjects forming the group whose results were used for the regression worked at a higher rate than did the others, the effect of changes in work rate was investigated. Nine European service personnel, all of whom had been stationed in Lagos for at least 6 months, were tested on two successive weeks; first at the standard work rate, 87 kg.cal./m.^{2}/hr. and then at the highest rate worked by any of the seventeen, 98 kg.cal./m.^{2}/hr. Sweat outputs and rectal temperature rises were higher in the second test, but S.L.T. fell from 524·7 to 508·4; this is not a significant change, and it was concluded that the effect of such variations in the work rate as this on S.L.T. was negligible. When the same subjects were tested again, 2 months later, the mean C.S.L. was 1481 g. and the mean rectal temperature rise was the same as the observed mean rise for the group of seventeen subjects from whom the regressions were derived; this value for C.S.L. is only 43 g. above the maximum calculated from regression (2), which is 1438 g. As an extra 2 months' residence in the tropics coupled with strenuous work and exercise (football and hockey) might be expected to result in full acclimatization, the near approach of these figures, obtained in 1950, to those predicted for fully acclimatized subjects from results obtained in 1945 may be taken as confirmation of the suggested standards. Further tests were carried out on the same service subjects in Lagos to determine whether it was necessary to keep exactly to the test climate. It was found that with less severe climates, when the rectal temperature rise was less, higher values of S.L.T. were obtained than with the same subjects in the test climate; hence the correct climate must be used in this test in determining S.L.T.

The value of any standards can only be judged after they have been used. These 'scales' have, in fact, already been employed to estimate the degree of acclimatization of West African labourers, of novice and veteran African gold-miners and of British service men stationed in Lagos. The results, which will be reported later, show that this method of assessing acclimatization is both practical and useful; and the answers obtained are reasonable and reproducible.

SUMMARY

1. The course of acclimatization of a group of seventeen men to a hot humid climate over a period of nine exposures is described. The main changes seen were in the pattern and rate of sweating.

2. Regression equations on number of exposures to heat have been calculated, one for the daily mean overall sweat productions of the group and the

other for the daily mean sweat outputs of the group per degree rise in rectal temperature.

3. Despite their limitations and defects, it is suggested that either of these regressions may form a basis of comparison for estimating the degree of acclimatization of a group of approximately equally acclimatized men, after a single test on each individual.

4. Owing to the great individual variation it is not possible, by means of a single test, to estimate the degree of acclimatization of each individual separately.

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