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THE REGIONAL DISTRIBUTION OF SWEATING

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Kuno's monograph (1934) contains a review of studies which have been made of the variations in the rate of sweating on different parts of the body. The data available refer only to a number of small areas of a few sq.cm. scattered over the surface of the body. A complete analysis of the contribution made by separate anatomical regions such as the arms, legs, trunk, head and neck, to the total sweat loss does not appear to have been made. In addition, there is a lack of data on the changes in the rate of sweating in such regions, when, for some reason, the rate as a whole increases. In this paper an attempt to achieve a complete partition of sweat loss according to such anatomical regions is described.

Methods

Observations were made on three naked male subjects, P., McK. and W., aged respectively 36, 31 and 34 years. These men were being acclimatized to a tropical environment by repeated exposures in a hot room to an atmosphere of dry bulb 100° F., wet bulb 93° F., giving an 'effective' temperature (Houghten, Teague & Miller, 1926) of 94° F.

Every 20 min. during the first 2 hr. of each exposure the men performed a set amount of work. The work consisted of stepping on and off a stool, 1 ft. high, for 5 min., and the grade of work was altered by increasing the rate of stepping on and off. During the first exposure, the first three bouts of work were at such a rate that the men stepped on and off the stool twelve times per min. and, for the last two, twenty-four times per min. During the next four or five exposures the first bout of work only was at the slower rate. In the cases of W. and McK. the duration of the work period was lengthened to 7½ min. in the last three exposures.

These rates of work were so designed as to allow the rectal temperature of each subject to rise to 102° F. or slightly over.

Observations on sweating were made in the 50-60 min. following the last work period, at a time when the subject had a maximum rectal temperature and was sweating profusely.

Sweat was collected from a number of small areas in each anatomical region by the following technique. The area selected was dried for 10 sec., and then a brass ring 7 cm. in diameter and 2 cm. deep was held lightly pressed down on the area. The ring carried a well-fitting lid, to minimize evaporation from the sweat accumulating within the ring. The ring prevented sweat trickling away from the area or reaching it from adjacent areas. After 2 min. the lid was removed, and, during the next ½ min., the sweat within the ring was mopped up by means of a previously dried and weighed cotton pledget. The increase in weight of the pledget was then determined. Thus sweat, accumulating in 2½ min. within the ring from an area corresponding to a plane surface of 38·5 sq.cm., was collected. The actual skin surface under the ring is of course not a flat surface. By means of the ring, observations were made on thirty such areas scattered over the various anatomical regions of the body. The area on the scalp was dried for a longer time, about 30 to 40 sec., as in one subject the hair was rather damp. As much hair as possible was pushed away from the test area, before applying the ring.

The men were dried with a towel and weighed before and after each bout of work and also at the end of each experiment. During the period of 50–60 min. when sweat was being collected the subjects were weighed twice to keep a check on the constancy of rate of sweating. As, occasionally, the rate of sweating was found to decrease in this period, the 'effective' temperature was raised 1 or 2° F. in the last 20–30 min. of the experiment. This helped to maintain the sweat rate constant.

The sequence of areas, from which the sweat was collected, was so arranged that the sweat was obtained from three successive groups each of ten areas. Each group included areas from every region, so that the total rate of sweating of each group reflected the rate of sweating of the body as a whole. In choosing comparable groups of areas reliance was placed on figures obtained for the rates of sweating of the various areas in exploratory experiments on subject P. Only experiments were used in which the total sweat rate remained constant.

The surface area of the various regions of the three subjects was found by taking the measurements and using the formulae suggested by du Bois & du Bois (1915).

Results

The number of areas from which sweat was collected in each anatomical region is shown in Table 1. The table also gives the percentage of the total body surface occupied by each anatomical region, these percentages representing the average for the three subjects P., McK. and W. (Table 2). These values are quite similar to those of an individual (surface area 1·8 sq.m.) studied by du Bois & du Bois (1915).

Table 1. The percentage of the surface area in each region from which sweat was collected

Anatomical region	Regional area sq.cm.	Each region as % of total skin surface	No. of test areas in region	Total test area per region sq.cm.	Total test area as % of regional area
Head	1087	6·6	4	154·0	14·1
Trunk	6476	39·3	10	385·0	5·9
Thighs	2310	14·0	4	154·0	6·7
Legs	2153	13·1	3	115·5	5·4
Feet	1155	7·0	2	77·0	6·7
Arms and forearms	2234	13·6	5	192·5	8·6
Hands	1035	6·3	2	77·0	7·4
Totals	16450	99·9	30	1155·0	—

The fact that in some regions sweat is collected from relatively more of the surface than in other regions is to a large extent unavoidable. In some cases the accessible surfaces comprise a larger proportion of the region, as for example the head, hands, arms, and forearms. In other cases the contrary is true, and the convenient areas for applying the ring and collecting the sweat are limited. This is so over the legs. More areas could have been used on the trunk and thighs, but this gain would have been offset by the longer time required to carry out the experiments. In any case the areas chosen seemed on the whole adequately representative of these regions.

Having determined the rate of sweating of each particular test area in each anatomical region, the average rate of sweating of each anatomical

TABLE 2. Surface area (sq.cm.) of body regions and total surface estimated according to methods of du Bois & du Bois (1915)

Body region	Subject P. Area sq.cm.	Subject P. % of total area	Subject McK. Area sq.cm.	Subject McK. % of total area	Subject W. Area sq.cm.	Subject W. % of total area
Head	1,192	6·6	1,009	6·3	1,060	7·0
Trunk	7,166	39·2	6,337	39·6	5,925	39·3
Thighs	2,694	14·7	2,125	13·3	2,110	14·0
Legs	2,314	12·6	2,231	14·0	1,914	12·7
Feet	1,243	6·8	1,079	6·8	1,142	7·6
Arms and forearms	2,544	13·9	2,268	14·2	1,889	12·5
Hands	1,143	6·2	929	5·8	1,035	6·9
Totals	18,296	100·0	15,978	100·0	15,075	100·0
Surface area (sq.cm.) from formula of du Bois	18,113	—	16,670	—	15,169	—

The total area of the body surface was calculated from the du Bois formula:

$$A = W^{0\cdot425} \times H^{0\cdot725} \times 71\cdot84,$$

where A is surface area in sq.cm., W is body weight in kg. and H is standing height in cm.

The body measurements of subjects P., McK. and W. were, for standing height, 177·8, 166·1 and 158·4 cm. respectively, and for weight, 65·0, 60·0 and 55·0 kg. respectively.

region per 100 sq.cm. surface was calculated (Table 3). The value per sq.cm. surface was multiplied by the surface area of the region to give the total rate of sweating of the anatomical region. This calculation of the regional rate of sweating involves the assumption that each anatomical region behaves uniformly all over its surface with regard to sweating and that the chosen test areas are truly representative of the region. This assumption is considered below in relation to the results obtained.

Local variations in sweating

Table 3 shows the rate of sweating (mg./min./100 sq.cm.) in the subdivisions of each anatomical region, together with the average rate for each region as a whole. The marked variation in the different areas is apparent—a fact emphasized by Kuno (1934). The low sweating of the palm and the sole are due to the fact that the sweat glands of these localities are far more sensitive to mental stimuli than to thermal. Consistent differences between particular areas as shown in Table 3 are to a large extent in agreement with those described by Ikeuchi & Kuno (quoted by Kuno, 1934), who studied three Japanese males and three Japanese females. With nearly the whole of the following statement, representing Kuno's main conclusions, one can agree, though with some reservation regarding the rate of sweating on the cheek and on the extensor surface of the forearm. The axilla proper was not studied in the present investigation. Kuno's statement (1934) is as follows:

...we may classify the body surface into the following parts according to the profuseness of sweating: (1) the forehead, the neck, some larger areas of the anterior and posterior surfaces of the trunk, the lumbar region, the dorsal region of the hand and the adjacent part of the forearm are the parts which sweat most. (2) The cheek, the lateral surface of the trunk and the greater part of the extremities sweat remarkably less than the former. (3) The internal femoral region and the axilla sweat still less. (4) The palm and the sole are the parts which sweat least.

TABLE 3. Local sweating (mg./min./100 sq.cm.)

	Subject P.			Subject McK.			Subject W.		
	Day 4	Day 6	Day 8	Day 4	Day 7	Day 11	Day 3	Day 6	Day 9
Head:									
Scalp	—	13	13.	28	33	60	7	11	0
Forehead	46	209	208	30	47	50	137	130	199
Cheek	—	—	27	110	144	184	84	71	49
Neck	73	82	85	32	110	187	74	79	91
Average for head	**59·5**	**101·3**	**83·2**	**50·0**	**83·5**	**120·2**	**75·5**	**72·7**	**84·7**
Trunk:									
Upper chest	119	105	111	113	120	198	140	173	143
Lower chest	—	—	102	117	122	193	114	189	100
Upper abdomen	81	93	102	115	60	109	96	157	134
Lower Abdomen	70	80	—	87	49	148	59	113	80
Suprascapular region	62	92	95	70	81	76	93	101	120
Scapular region	49	65	62	60	29	86	91	118	138
Infrascapular region	—	88	—	48	—	93	67	31	120
Lumbar region	14	79	80	35	—	71	53	54	104
Upper axillary region	—	—	—	103	33	125	85	126	127
Lower axillary region	—	—	—	82	36	94	70	40	146
Average for trunk	**66·0**	**86·0**	**92·2**	**83·0**	**66·2**	**119·3**	**86·8**	**110·2**	**121·2**
Thighs									
Medial surface	20	34	37	14	—	31	23	23	49
Lateral surface	47	86	79	38	35	44	99	118	96
Posterior surface	22	40	62	27	34	39	68	76	96
Buttock	48	32	57	14	12	24	54	21	62
Average for thighs	**34·3**	**48·0**	**58·7**	**23·3**	**27·0**	**34·5**	**61·0**	**59·5**	**75·7**
Legs:									
Medial surface	38	67	44	50	52	61	74	86	100
Lateral surface	—	65	56	51	35	44	76	94	110
Posterior surface	—	—	—	27	26	25	73	—	130
Average for legs	**38·0**	**66·0**	**50·0**	**42·6**	**37·6**	**43·3**	**74·3**	**90·0**	**113·3**
Feet:									
Sole	9	13	22	19	8	10	12	11	16
Dorsum	3	61	80	40	25	21	28	23	21
Average for feet	**9·0**	**37·0**	**51·0**	**29·5**	**16·5**	**15·5**	**20·0**	**17·0**	**18·5**
Arms and forearms:									
Shoulder	34	55	43	47	25	23	95	40	—
Deltoid region	42	36	40	52	28	45	43	34	—
Medial surface upper arm	—	—	—	28	21	34	43	29	16
Extensor surface forearm	28	—	23	25	42	116	46	82	46
Flexor surface forearm	—	—	—	56	86	99	75	52	61
Average for forelimb	**34·6**	**45·5**	**35·3**	**41·6**	**40·4**	**63·4**	**60·4**	**47·4**	**41·0**
Hands:									
Back of hand	25	22	22	15	21	33	59	26	43
Palm	3	5	9	0	7	10	7	0	7
Average for hands	**14·0**	**13·5**	**15·5**	**7·5**	**14·0**	**21·5**	**33·0**	**13·0**	**25·0**

The following additional points may be made on the basis of the figures set out in Table 3:

(1) There is no consistent difference between the rate of sweating on the medial and lateral surfaces of the leg and the arm.

(2) The individual differences in the amount of moisture one can collect from the scalp is marked. Subject McK., not bald, sweated apparently at about the same rate on the scalp as on the forehead. In the other subjects the scalp was usually nearly dry, whereas the forehead sweated very profusely.

(3) There is some suggestion in the figures of Table 3 that sweating on the back is less than on the front of the trunk, if roughly the same anatomical levels are considered. There seems also a tendency for the rate of sweating to diminish the more caudal the area on the trunk.

Regional distribution of sweating

In Table 4 is given the rate of sweating of each of the seven anatomical regions of the body surface. The rate of sweating in g./hr. of the individual regions was calculated from the average rate of sweating of the test areas investigated in the region (Table 3) and the estimated surface area of the region (Table 2). The 'calculated total' is obtained by adding together the rates for the individual regions, and the result may be compared with the actual loss measured directly by loss of body weight. The change in weight due to water loss in respiration and to the excess of oxygen retained over carbon dioxide eliminated was neglected.

The correspondence between the calculated and the observed loss may be regarded as not unsatisfactory. The agreement obtained depends no doubt to some extent on the mutual cancellation of errors in the various regions. It suggests, however, that the method of calculation does not involve gross errors, particularly in the assumptions that the area of collection corresponds to a plane area under the ring and that the average of the areas used may be taken to represent the regions as a whole. There is one factor inherent in the method which will counteract any tendency to overestimation of the sweat rate which may result from the assumptions made. Not all the sweat produced during the 2 min. periods can actually be collected. During the $\frac{1}{2}$ min. when the area is dried, evaporation must be fairly high owing, not only to the exposure of the sweating area to an atmosphere of suddenly reduced vapour pressure, but also to the air movement created as the area is being dried. It is possible that only half the sweat actually produced in the $\frac{1}{2}$ min. is picked up. Assuming that the pledget collects the sweat produced in the preceding 2 min. without loss, then only $2\frac{1}{4}$ min. may be represented in the $2\frac{1}{2}$ min. collection—a loss of 10%. This loss, on the whole, may be fairly constant though it will vary with the skin temperature and air conditions prevailing. A fairly constant error in the opposite direction arises from the tendency to take rather more sweat off the curved skin surface under the ring than allowed for by the area in the calculation.

Conclusions

In spite of the limitations of both method and calculation it seems possible to draw certain general conclusions from the figures available.

(*a*) *Partition of sweating.* Examination of Table 4 reveals that in all three subjects, as a rough generalization, about 50% of the sweating comes from the trunk, about 25% is derived from the lower limbs, and the remaining

TABLE 4. Regional distribution of sweating.

Subject P.

	Day 4		Day 6		Day 8	
	g./hr.	% of total sweat	g./hr.	% of total sweat	g./hr.	% of total sweat
Head	43	8·2	73	10·1	60	8·3
Trunk	284	54·4	370	51·4	396	54·8
Thighs	55	10·5	78	10·8	95	13·1
Legs	53	10·1	92	12·8	69	9·5
Feet	*25	4·8	28	3·9	38	5·3
Arms and forearms	53	10·1	70	9·7	54	7·5
Hands	10	1·9	9	1·3	11	1·5
Calculated total	523	100·0	720	100·0	723	100·0
Observed total	524	—	664	—	680	—
Percentage difference: Calculated/Observed	0	—	108/100 +8	—	106/100 +6	—

Subject McK.

	Day 4		Day 7		Day 11	
	g./hr.	% of total sweat	g./hr.	% of total sweat	g./hr.	% of total sweat
Head	30	5·9	51	11·1	73	9·9
Trunk	316	61·6	252	54·6	454	61·5
Thighs	30	5·8	34	7·5	44	6·0
Legs	57	11·1	50	10·8	58	7·9
Feet	19	3·7	11	2·4	10	1·4
Arms and forearms	57	11·1	55	11·9	86	11·7
Hands	4	0·8	8	1·7	12	1·6
Calculated total	513	100·0	461	100·0	737	100·0
Observed total	485	—	470	—	725	—
Percentage difference: Calculated/Observed	106/100 +6	—	98/100 −2	—	102/100 +2	—

Subject W.

	Day 3		Day 6		Day 9	
	g./hr.	% of total sweat	g./hr.	% of total sweat	g./hr.	% of total sweat
Head	48	7·7	46	6·7	54	6·9
Trunk	308	49·6	391	56·7	430	54·8
Thighs	77	12·4	75	10·9	96	12·2
Legs	85	13·6	103	14·9	130	16·5
Feet	14	2·3	12	1·7	13	1·7
Arms and forearms	68	11·0	54	7·9	46	5·9
Hands	21	3·4	8	1·2	16	2·0
Calculated total	621	100·0	689	100·0	785	100·0
Observed total	660	—	740	—	800	—
Percentage difference: Calculated/Observed	94/100 −6	—	92/100 −8	—	98/100 −2	—

* In absence of data this value is assumed to be not less than that of day 6.

25% comes from the head and the upper limbs. The lower limbs (thighs, legs and feet) contribute more than the upper (arms, forearms and hands). It is an interesting fact that the legs contribute as much as, and often more than, the thighs. Differences between individuals are quite marked as shown in the figures given in Table 4. Subject McK. produces a markedly smaller proportion of sweat on the thighs and perhaps rather more on the trunk than do the other subjects. Subject P. produces a bigger proportion on the feet. The proportions derived from head, legs, forelimbs and hands are roughly similar in the three subjects.

(*b*) *Changes in rate of sweating.* In the third of each series of three experiments on each subject a rate of sweating greater than that of the preceding days was found, due in large part to the process of acclimatization. During this process certain regional changes appear to be consistently connected with the total increase in sweating which occurs. The loss from the trunk and the thigh appears to be invariably increased and is responsible for the bulk of the increase, though not to the same extent in the three subjects. The changes in sweating on hands and feet are rather irregular though small. The sweating on the legs generally increased, but on the arm and forearm the results are irregular.

(*c*) *Relative intensity of sweating.* It is evident that the sweat rate per unit area is markedly different in different regions. This can be shown by a comparison between the percentage which each region contributes to the total sweating and the percentage of the total surface area of the body represented by each region. The ratio between these figures is a measure of the 'relative intensity' and is given in Table 5. An average has been calculated for all three

TABLE 5. Relative intensity of sweating over various regions of body surface

$$\text{Relative intensity} = \frac{\text{Proportion of total sweating contributed by region}}{\text{Proportion of total surface represented by region}}.$$

	Subject P.				Subject McK.				Subject W.			
Region	Day 4	Day 6	Day 8	Av.	Day 4	Day 7	Day 11	Av.	Day 3	Day 6	Day 9	Av.
Head	1·3	1·5	1·3	1·4	0·9	1·8	1·6	1·4	1·1	1·0	1·0	1·0
Trunk	1·4	1·3	1·4	1·4	1·6	1·4	1·6	1·5	1·3	1·4	1·4	1·3
Thighs	0·7	0·7	0·9	0·8	0·4	0·6	0·5	0·5	0·9	0·8	0·9	0·8
Legs	0·8	1·0	0·8	0·9	0·8	0·8	0·6	0·7	1·1	1·1	1·3	1·2
Feet	0·7	0·6	0·7	0·7	0·5	0·4	0·2	0·4	0·3	0·2	0·2	0·2
Arms and forearms	0·7	0·7	0·5	0·6	0·8	0·8	0·8	0·8	0·9	0·6	0·5	0·7
Hands	0·3	0·2	0·2	0·2	0·1	0·3	0·3	0·2	0·5	0·2	0·3	0·3

days in each case since changes in sweat rate do not, for our present purpose, make any great difference to this ratio. Definite individual differences are revealed, but in general it appears that the average intensity of sweating on the trunk is greater than elsewhere. In all the other regions, with the exception of the head (and of the legs in subject W.), the contribution to the total sweating is less than one would expect from the area involved. The 'intensity' of sweating on the hands and feet is, in general, notably less than that of other regions, being one-fourth to one-fifth of that on the trunk and one-half to one-third of that on the other regions.

Discussion

The results presented above make it clear that variations in sweating between different regions of the body may be quite considerable, and that between particular small areas of the skin surface the differences may be very large indeed. How far these differences are related to the number, the size or the activity of the sweat glands in each area cannot be definitely answered. However, by the use of some such method as that described in this paper, especially on restricted areas, it may be possible to reveal whether or not a close correlation exists between the total number of sweat glands and their physiological activity as measured by sweat production. If such a correlation were found, it would imply that all glands in a given area are to some extent active even over a short period of time. An increase in sweating in a given area would then depend not on the employment of hitherto unused glands but on a more intense average activity of all the glands. It is equally possible, however, that in some cases at least, as for example in acclimatization to heat, the increase in sweating may ultimately be dependent on a morphological hypertrophy of the sweat glands.

The present results, in the absence of data as to the number of sweat glands in each area, do not permit any definite conclusion as to the functional or anatomical factors underlying variations in intensity of sweating. The fact that in some regions the rate of sweating increases relatively more than in others, when the overall rate of sweating increases, does not favour particularly either of the alternative explanations. It may be that in some areas, e.g. the trunk, there is a greater reserve of 'unused' glands, so allowing a greater increase, or it may be that the individual glands are on the average larger, or for some reason, are able to secrete more intensely.

Certain of Kuno's experiments (1934) support the findings of Jurgensen (quoted by Kuno, 1934), that the rate of secretion of a sweat gland varies according to the intensity of stimulation. He believes, therefore, that changes in the amount of sweating may be due partly to the variable activity of each acting sweat gland. In addition, he believes that the number of sweat glands in action may increase, especially as the sweating during a given time increases. The observations of Saito (quoted by Kuno, 1934) on thermal sweating from the back of the hand indicate that individual sweat glands vary in excitability and that on different days in the same locality previously inactive glands may come into action. Kuno's final conclusion is that changes in rate of sweating are due more essentially to the number of active sweat glands. However, it still remains to be decided how far these findings apply in a quantitative fashion to variations in sweating in the different regions of the body surface and in those regions where the rate of sweating varies.

SUMMARY

1. A method is described for measuring the rate of sweating from small areas of the skin surface.

2. The rate of sweating from thirty small areas has been measured by this method.

3. By using the average rate of sweating and by measuring the surface area, the total rate of sweating has been approximately partitioned between the head, trunk, thighs, legs, feet, arms and forearms.

4. The possible factors responsible for variations in intensity of sweating in different regions and for changes in sweating in the same regions are discussed.

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