THE WATER LOSS AND BLOOD CHANGES BY PROLONGED SWEATING WITHOUT INTAKE OF FOOD AND DRINK

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Thirst sensations due to the water loss of the body by sweating exhibit a characteristic time lag so that men always fail to drink enough to replace immediately their sweat losses. If a heavy sweating has took place under such a state of water debt, the chloride concentration of the body fluid has to be remarkably raised, for the chloride content of sweat is far lower than that of the body fluid. But previous reports indicated that the Cl content of blood remained unchanged or even decreased slightly after heavy sweating (1-5). If so, some regulatory mechanisms preventing the rise of osmotic pressure of the body fluid must be in action during the sweating. The following mechanisms appear to be responsible for the regulation: (1) renal regulation, (2) the shift of water in the body and (3) the storage of Cl in some tissues.

Experiments with regard to this problem were previously made by members of this Institute on men walking for hours on midsummer days without taking food and drink. The general symptoms, sweating and changes in the blood were investigated, special reference being taken to renal regulation. The results of the experiments were published in 1942 in two Japanese papers by Itoh, Masui, Hattori, Okuda and Suzuki (6) and by Itoh, Masui and Matsumoto (7) respectively. The present paper presents an account of the experimental results described in these two papers and some discussion newly considered by the author.

METHOD

18 healthy men (11 Japanese and 7 Chinese) were tested. Most of them were laborers. A part of experiments was made in Nagoya, and the other in Taipei, Formosa, all on fine days from July to the beginning of September.

Subjects took breakfast early in the morning, but not taking much water. They took baths and washed their bodies fully, then washed again with distilled water and wiped off water with Cl-free towels. Long underwears, trousers, and socks, all treated not to contain any Cl, were worn. They had to walk with usual pace for 3 to 8 hours without taking food and drink under the blazing sun. After walking, their whole bodies, except the head, were washed with distilled water and Cl-free towels, while standing in a large enamelled basin. The washing water, into which all of the clothings touched to the skin were put, was fully stirred up, and its Cl content was measured.

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Body temperature, rates of pulse and respiration, body weight, urine volume, Cl contents of sweat, blood and urine, and total protein concentration of blood serum were measured. The body temperature was measured in the rectum or mouth in some experiments, but in greater part of experiments in the armpit. To weigh, a Sauter balance with a sensitivity of 1 g. was used at Nagoya, and a platform scale with 10 g. sensitivity at Taipei. The amount of sweat was calculated by subtracting the amount of blood taken, the respiratory weight loss (assuming to be 12.5 g. per hour) and the urine volume from the difference of body weight at the beginning and at the end of the walking.

With regard to the method of estimation of chloride in sweat above described, a recovery test coating all the body surface with diluted salt solution was previously made in this Institute. It was confirmed that 10 per cent of salt was lost. The acquired values plus 10 per cent were therefore regared to be the Cl content of the sweat. The Cl of sweat and urine was determined by the method of Volhard-Harvey and that of blood by Rusznyak. For the measurement of total protein of serum Pulfrich's refractometer was used.

RESULTS

The experimental results are summarized in table 1.

General symptoms. Subjective symptoms such as thirst and fatigue and changes in body temperature, pulse rate and respiration frequency were variable with weather conditions, duration of walking and also with strengths of subjects. Generally speaking, however, the symptoms were extreme in no cases. In spite of heavy sweatings, no acute thirst was felt except a few cases, while, in cases of walking over 5 hours, subjects complained of fatigue and hunger to more or less extent.

An increase of body temperature of about 1° C. was found in four cases (No. 4, 7, 10 and 14), while there was almost no change in five cases (No. 2, 5, 11, 17 and 18). The extents of increase in the rates of pulse and respiration were also very variable from case to case. The individual variations of the changes of these three phenomena were also pronounced in three experiments of No. 5, 6, and 7, in which the subjects walked together for 6 hours under the same surrounding conditions. It will be noted that the changes in the three phenomena did not run parallel to one another in most cases. The stress of walking under hot weather seems therefore to vary in different subjects, probably due to variable physical strength and character.

Sweat amount. It was reported by Sengoku (8) that the rate of sweating during walking did not much vary individually when observed under the same surrounding conditions in the summer, while it varied considerably with weather conditions and walking speed. So it is undesirable to compare the results of experiments which were made on different days.

All the data concerning the amount of sweat are shown in table 2, No. 5, 6 and 7 and No. 8 and 9 were two respective groups which were tested simultaneously, and the sweat amount per hour per 10 kg. of body weight was 0.073–0.077 kg. in the former and 0.058 kg. in the latter, indicating no individual variation.

TABLE

Place of experiment	No.	Race	Age	Vocation	Date of experiment	Outdoor temperature D.B.	Outdoor temperature W.B.
Nagoya, Japan	1	Japan.	37	Servant	early in September	29.2-32.0	25.0-26.0
	2	Japan.	58	Labourer		28.0-32.0	24.0-26.0
	3	Japan.	38	Labourer		27.7-32.2	25.3-27.0
	4	Japan.	37	Labourer	8 Aug.	30.0-35.0	25.8-27.5
	5	Japan.	62	Labourer	19 Aug.	28.0-33.5	25.0-26.8
	6	Japan.	33	Labourer			
	7	Japan.	36	Labourer			
	8	Japan.	43	Servant	13 Aug.	28.8-27.0	25.0
	9	Japan.	42	Labourer			
Taipei, Formosa	10	Chin.	26	Shopman	11 July	29.8-33.2	25.8-28.0
	11	Chin.	39	Labourer	17 July	29.6-31.6	27.0-28.6
	12	Chin.	46	Labourer	6 July	29.6-32.0	26.0-28.0
	13	Chin.	41	Labourer	7 July	31.4-32.0	28.7-29.0
	14	Chin.	24	Labourer	8 July	28.0-32.0	26.6-27.2
	15	Chin.	48	Labourer	5 July	33.7-36.2	28.0-28.9
	16	Japan.	64	Labourer			
	17	Chin.	26	Labourer	9 July	28.6-31.7	27.2-27.6
	18	Japan.	30	Physician			

Place of experiment	No.	Body weight (kg.) Before	Body weight (kg.) After	Body weight (kg.) Dif.	Amount of sweat (kg.)	Cl in sweat Total amount (g.)	Cl in sweat Per cent	Cl in blood (%) Before	Cl in blood (%) After	Serum protein Before	Serum protein After
Nagoya, Japan	1	47.451	45.095	2.356	2.238	2.347	0.105			7.85	8.68
	2	64,606	61.211	3.395	3.230	5.563	0.172			8.11	9.26
	3	53.381	49.355	4.026	3.315	2.468	0.074			7.73	8.66
	4	60.560	57.736	2 824	2.498	2.572	0.103	0.316	0.318	7.33	7.79
	5	55.482	52.756	2.726	2.435	5.602	0.230	0.289	0.289	7.44	7.76
	6	56.682	53.488	3.194	2.576	2.524	0.098	0.330	0.319	7.46	7.72
	7	49.713	47.199	2.514	2.296	3.285	0.143	0.312	0.312	8.06	9.03
	8	48.650	47.768	0.882	0.841	0.502	0.060	0.320	0.320	8.09	8.09
	9	52.895	51.927	0.968	0.924	0.640	0.069	0.318	0.318	7.45	7.45
Taipei, Formosa	10	56.600	52.720	3.880	3.675	8.798	0.239	0.319	0.308		
	11	52.960	50.940	2.020	1.942	3.796	0.195	0.308	0.306		
	12	55.590	54.150	1.440	1.399	0.697	0.050	0.331	0.335		
	13	47.400	44.970	2.430	2.394	5.292	0.221	0.308	0.304		
	14	53.160	51.430	1.730	1.691	1.378	0.081	0.321	0.317		
	15	55.810	53.520	2.290	2.249	3.418	0.152	0.311	0.311		
	16	53.160	50.510	2.650	2.447	4.637	0.189	0.325	0.323		
	17	51.000	49.800	1.200	1.155			0.312	0.312		
	18	49.670	48.260	1.410	1.367			0.315	0.311		

No. 15 and 17 were experiments performed on Chinese born in Formosa. With the purpose of comparing the rate of sweating of these natives of hot country with that of unacclimatized Japanese, simultaneous observations were made with No. 15 and 16 and with No. 17 and 18 respectively. The results show that Japanese sweat more profusely than the natives under the same experimental conditions. This result well coincides with the findings of Kosuge and Kawahata (9) and of Kawahata and Itoh (10) who compared the sweating activity of Japanese with that of tropical inhabitants.

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Hours of walking	Body temperature			Pulse rate			Respiration		
	Before	After	Dif.	Before	After	Dif.	Before	After	Dif.
5	37.3	38.0	0.7	69	128	59	16	22	6
5	37.3	37.2	−0.1	98	110	12	22	25	3
7	37.25	37.5	0.25	66	132	66	22	24	2
6	36.4	37.4	1.0	72	106	34	24	32	8
6	36.3	36.4	0.1	66	92	26	22	25	3
6	36.9	37.3	0.4	64	69	5	15	17	2
6	36.3	37.3	1.0	82	108	26	15	18	3
3	36.2	36.4	0.2	68	82	14	16	20	4
3	36.4	36.8	0.4	74	80	6	20	27	7
8	36.1	37.2	1.1	62	100	38	21	27	6
6	36.7	36.7	0	70	92	22	25	27	2
3	36.55	36.8	0.25	60	64	4	19	20	1
3	37.0	37.4	0.4	76	96	20	14	20	6
3	36.3	37.2	0.9	72	96	24	20	23	3
3	36.1	36.7	0.6	68	83	15	22	25	3
3	37.1	37.65	0.55	74	90	16	20	23	3
3.5	36.6	36.6	0	73	82	9	20	22	2
3.5	36.8	36.8	0	98	104	6	24	31	7

Amount of urine (ml.)			Cl in urine (%)			Total Cl in urine (g.)			Amount of water taken after experiment (ml.)
Before	During	After	Before	During	After	Before	During	After	
									700
									500
									500
80	220	125	0.786	0.877	0.927	0.628	1.929	1.158	500
150	185	165	0.227	0.746	1.024	0.341	1.379	1.690	150
90	515	255	1.036	1.128	1.262	0.933	5.809	3.217	200
55	138	65	1.068	1.219	1.150	0.588	1.683	0.748	0
5		93	0.606		0.732	0.030		0.681	0
120		55	1.002		1.106	1.201		0.608	0
50	95	170	0.908	1.140	1.163	0.454	1.083	1.977	400
80		120	0.848		0.943	0.678		1.131	300
50	80	30	0.424	0.673	0.769	0.212	0.539	0.231	0
		150			0.876			1.314	200
140		300	0.674		0.971	0.971		2.914	250
180		200	0.720		0.903	1.296		1.805	150
70		170	0.496		0.640	0.347		1.088	400
									200
									200

Sweat chloride. It is well known that the Cl content of sweat varies proportionally to the rate of sweating, but that there are great individual differences in its values. As can be seen from table 1, the concentration of Cl conspicuously varied in different cases, namely from 0.05 to 0.024 per cent. It was reported by Matsumoto (11) and by Kawahata (12) that the Cl content of sweat is lower in tropical inhabitants compared with that of Japanese. Such a difference, however, could not be detected between the Japanese and the Chinese used in this experiment, possibly because the experimental conditions were not uniform.

The total amount of Cl excreted in the sweat varied from 0.5 to 8.8 g.

TABLE 2. Amount of Sweat

Place of experiment	No.	Hours of walking	Amount of sweat (kg.)	Amount of sweat per hour (kg.)	Amount of sweat per hour per 10 kg. of body weight (kg.)
Nagoya	1	5	2.238	0.448	0.094
	2	5	3.230	0.646	0.100
	3	7	3.315	0.474	0.089
	4	6	2.498	0.416	0.069
	5	6	2.435	0.406	0.073
	6	6	2.576	0.429	0.076
	7	6	2.296	0.383	0.077
	8	3	0.841	0.280	0.058
	9	3	0.924	0.308	0.058
Taipei	10*	8	3.675	0.459	0.081
	11*	6	1.942	0.324	0.061
	12*	3	1.399	0.466	0.084
	13*	3	2.394	0.798	0.168
	14*	3	1.691	0.564	0.106
	15*	3	2.249	0.750	0.134
	16	3	2.447	0.816	0.185
	17*	3.5	1.155	0.330	0.065
	18	3.5	1.367	0.391	0.079

* Experiments on Chinese.

This was because both the amount of sweat and the Cl concentration of sweat varied considerably in different experiments. The three items of sweating, the amount of sweat, the Cl concentration and the total amount of Cl discharged, are most important for consideration of changes in the body fluid as will be discussed later.

Blood changes. The total protein concentration of serum was measured only in nine experiments made in Nagoya before and immediately after walking, which lasted from 3 to 7 hours. In two experiments, No. 8 and 9, in which subjects walked for 3 hours and the amount of sweat was less than one liter, there was no change in the protein concentration. But in the other seven experiments walking for 5 to 7 hours, distinct increases in the protein concentration were visible after walking, although the extent of increase was not quite proportional to the amount of sweat. These results indicate that the blood was concentrated by sweating, but that this concentration took place only when sweating lasted over 3 hours. Lehman and Szakáll (4) reported that the protein value increased quickly in the initial stage of exercise under hot environments. Such an early concentration of the blood could not be seen in our experiments.

In contrast to the above results, the Cl concentration of the blood showed no significant changes. But in two cases of No. 6 and 10 producing the largest amounts of sweat among others, a slight, but noticeable, decrease of Cl concentration was found. It may be surmized that the Cl concentration of blood tends towards fall when sweating becomes very profuse.

Urine. Subjects should urinate securely before and after walking and whenever there is any desire during walking. Its volume, Cl content and specific gravity were measured. The volume of urine was variable, but in all cases the Cl concentration increased with the progress of experiment, accompanied with increase in the specific gravity (see table 1).

It is worthy of note that the Cl concentration of the urine obtained after walking is always much higher than that of the serum, reaching in some cases over 1 per cent. At first sight this result seems to be strange as very many investigators reported that the urinary chloride was considerably reduced or entirely vanished by heavy sweating. The difference in results between these and other experiments is probably due to the difference in experimental procedures, *i.e.* in these experiments no water was ingested throughout the course of experiment while in the experiments of other investigators, water was taken so that the increase in the relative chloride content of the body due to sweating was prevented by drinking water.

The total amount of Cl excreted in urine during walking varied conspicuously, namely from 0.5 to 9 g. as can be seen from table 1. Such a great variation seems to be partly due to the difference of duration of walking, but the individual variation is also prominent. In seven experiments walking for 3 hours, the urinary excretion of Cl varied from 0.5 to 2.9 g. The significance of the urinary Cl discharge is entirely different from that of the discharge in sweat, since the former seems to be resulted from a compensatory process of preventing the increase of the osmotic pressure of body fluid. Its variation seems therefore to indicate the individual variation in the compensatory activity. This point will be discussed later.

The amount of water intake. After the end of experiment, the subjects were allowed to drink as much as they liked. The amount of water so ingested are mentioned in table 1. Compared with the amounts of sweat, the amounts of water intake are far smaller, indicating that their thirsts were temporarily quenched with small intakes of water. This and the fact that the amount of water required to relieve thirst varies individually are well known facts.

DISCUSSION

As already mentioned, previous investigations unanimously noticed that the chloride level of the blood did not change during heavy sweating. In the present experiment, men sweated profusely for hours without intake of water so that chloride must have been in excess in the body from the osmotic point of view. Yet there was also no sign of increase in the blood chloride; on the contrary it showed a tendency to decrease when sweating lasted long. Some compensatory processes were therefore in function. One of the processes seems to be involved in renal function since urine with high chloride concentration was produced during sweating. We have now to consider to what extent the renal regulation comes into play.

This consideration will first be made taking experiment No. 4 (table 1) as example. In this experiment, the amount of sweat was 2498 ml. containing 2.572 g. Cl, with a mean concentration of 0.103 per cent. This Cl concentration is less than 1/3 of that of blood, 0.316 per cent. On the other hand, the amount of urine was 345 ml., containing 3.087 g. Cl. Its mean Cl concentration was 0.895 per cent or 2.8 times higher than that of blood. The Cl concentration of serum was not determined, but it may be assumed to be 1.24 times that of blood, and the Cl content of the extracellular fluid 1.05 times that of serum. The Cl of extracellular fluid will then be 0.411 per cent. On the basis of the above figures, the following calculation will be made: The amount of body fluid corresponding to 2.572 g. Cl, excreted in sweat, is 625 ml. Yet the amount of sweat being 2498 ml., 2498 − 625 = 1873 ml. is the net amount of water lost out of the body by sweating. The Cl amount excreted in urine is 3.087 g. and the amount of body water corresponding to this Cl is 751 ml. But the actual amount of urine is 345 ml. Therefore, the difference 406 ml. would be considered the amount of water supplied to the body by the kidney from the view-point of Cl metabolism. Then 1873 − 406 = 1467 ml. is the water lost from the body in osmotic view-point, or 6.03 g. of Cl corresponding to this water is considered to remain excessively in body.

Similar calculations were made with other 12 experiments, and all the data are summarized in table 5. We see from this table that, in all the cases, the renal regulation takes effect although its extent varies considerably in different subjects. The intrinsic conditions of the body induced from sweating in the experiments may be a potent stimulus for the posterior pituitary and make it secrete the anti-diuretic hormone. It was found by several investigators (13-16) that an excess of this hormone appeared in urine during dehydration. Recently Kimura (unpublished) has demonstrated its existence in the urine of sweating men. As already mentioned, the production of urine with high chloride concentration during sweating has not been noticed by previous investigators. This was probably so because in thier experiments more or less water was taken during sweating and consequently the chloride excess in the body hardly occured.

Table 3 shows that the renal regulation is never sufficient to compensate completely the chloride unbalance caused by sweating. The chloride still in excess in the body must have been equilibrated by some other mechanisms. As

TABLE 3. Water Loss Due to Sweating and Its Renal Regulation

No.	Hours of walking	Amount of sweat (ml.)	Amount of pure water lost by sweating (ml.)	Amount of pure water covered by kidney (ml.)	Amount of pure water lost from body (ml.)	Amount of Cl remained in excess in body (g.)	Blood Cl concentration (%) Before	After
4	6	2498	1873	406	1467	6.03	0.316	0.318
5	6	2435	945	464	481	1.81	0.289	0.289
6	6	2576	1988	1334	654	2.81	0.330	0.319
7	6	2296	1487	396	1091	4.43	0.312	0.312
8	3	841	720	71	649	2.70	0.320	0.320
9	3	924	769	92	677	2.80	0.318	0.318
10	8	3675	1555	472	1083	4.49	0.319	0.308
11	6	1942	993	163	830	3.32	0.308	0.306
12	3	1399	1273	15	1222	5.25	0.331	0.335
13	3	2394	1071	179	892	3.57	0.308	0.304
14	3	1691	1361	399	962	4.01	0.321	0.317
15	3	2249	1403	247	1156	4.67	0.311	0.311
16	3	2447	1351	87	1264	5.35	0.325	0.323

one of these mechanisms the outflow of intracellular water comes first into question. Ladell (17) observed the changes in the chloride concentration of the blood and plasma on a person who heavily sweated, and found that disturbance of the osmotic equilibrium between the extra- and intracellular components which might be expected depending upon the extent to which water and Cl losses are made good, does not develop to any great extent, the equilibrium being quickly restored by simple fluid trasfer. Experimental results of Nadel, Pedersen and Maddock (18) also indicated that in water deprivation water is lost from both the extra- and intracellular compartments. Therefore, in our experiments it is reasonable to consider a considerable amount of water flowed from intra- to extracellular compartment.

It is however difficult to judge to what extent the above mechanism participates in the compensation. As can be seen from table 1, the total protein concentration of serum decidedly increased when sweating lasted over 3 hours. The protein level being the best index for judging the concentration of the blood, the volume of the blood can be considered to be reduced. But an increase in the protein content of plasma does not show properly the variation of the amount of the extracellular fluid as the experimental results of Ladell (17) and Lee *et al.* (19) indicated.

Another mechanism for controlling the excess of chloride in the body is a temporary deposit of chloride in some tissues. It has been known for many years that the skin is the organ which contains the greatest amount of chloride, and it is also reported that its amount varies widely according to various kinds of conditions (Hinkel; Leva; Urbach; Padtberg; Roseman, etc.). The Cl contents in the skin before, during and after sweating have been observed by many members of this Institute, and it was confirmed that the amount of Cl in the skin considerably increased during sweating. Basing on these findings, Kuno (20) advanced a tentative theory of "the cutaneous circulation of chloride during sweating." Recently a decidedly increase of chloride in the skin during sweating has been evidenced by means of a more trustworthy method by investigators of other laboratories (unpublished). This item is rather complicated and requires a long explanation. In this paper its description will be omitted and only mentioned that the accumulation of chloride in the skin during sweating is quite certain.

As above mentioned, the secretion of the posterior pituitary hormone seems to be accelerated during sweating. This secretion may act not only on the kidney, but also on the control of the osmotic pressure of the body fluid during sweating. It has been reported that the blood dilution due to administration of posterior pituitary extract also occured after the ligation of the kidney vessels (Underhill and Pack). In my experiments on the Cl balance after the injection of pituitrin these facts were confirmed (unpublished). In some cases of the present investigations, a tendency of decrease in blood Cl concentration was noticed after prolonged sweatings. Snch a paradoxical phenomenon may be explained by this effect of the posterior pituitary hormone.

From the above account, I may conclude that the excess of chloride in the body brought about by heavy sweating is compensated by (1) renal regulation,

(2) the outflow of the intracellular water and (3) the deposit of chloride in the skin. The extents of participation of the latter two cannot be clarified at present.

SUMMARY

On 18 men walking for hours on midsummer days without taking food and drink, general symptoms, sweating and changes in blood and urine were observed, special reference being taken to chloride balance and its regulation by the kidney.

1. The period of walking varied from 3 to 8 hours, and the total amount of sweat from 841 to 3675 g., with chloride concentration ranging from 0.050 to 0.239 per cent.

2. The Cl concentration of the sweat being strikingly less than that of the body fluid, the sweating must result in an excess of Cl in the body. But no increase in the Cl concentration of the blood was found, while the protein concentration of serum rose distinctly.

3. More or less amount of urine with Cl concentrations varying from 0.674 to 1.262 per cent were discharged during sweating. The excess of Cl in the body was therefore compensated by renal function, partly but not completely.

4. Tentative discussion on other mechanisms of compensation was given.

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