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U. S. ARMY MEDICAL RESEARCH & NUTRITION LABORATORY

THE DERMAL EXCRETION OF MINERALS AND ITS POSSIBLE RELATION TO MINERAL BALANCE AND REQUIREMENTS

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Report of

THE DERMAL EXCRETION OF MINERALS AND ITS POSSIBLE RELATION TO MINERAL BALANCE AND REQUIREMENTS

(Sodium, Potassium, Iron, Magnesium and Phosphorus)

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THE DERMAL EXCRETION OF MINERALS AND ITS POSSIBLE RELATION TO MINERAL BALANCE AND REQUIREMENTS

(Sodium, Potassium, Iron, Magnesium and Phosphorus)

OBJECT:

The purpose of this study was to measure the daily sodium, potassium, iron, phosphorus and magnesium losses in sweat, of men exposed to high environmental temperatures. These mineral losses were evaluated in relation to the total daily intake, the total mineral balance and to mineral requirements. Another problem investigated was whether the diurnal variation of the minerals in sweat was decreased during acclimatization to extreme heat.

SUMMARY AND CONCLUSIONS:

The results of this experiment show that a considerable quantity of the various minerals are lost in sweat, on men living and working at environmental temperatures of 100°F. The sodium excretion in sweat averaged 0.601 gm/hour, potassium 0.125 gm/hr, magnesium 2.3 mg/hr, and iron 0.13 mg/hr during a 7½ hour collection period.

These findings were very important since they show additional mineral losses that have not been considered in many of the past studies in the literature on mineral balance, where equilibrium was supposedly attained. Under conditions of profuse sweating, the inclusion of these mineral losses in mineral balance studies may greatly aid in estimating more realistic daily mineral allowances.

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Introduction and Background

In two recent studies on calcium (1) and nitrogen (2) excretions in sweat, it was observed that these losses were fairly high, accounting for 18 - 30% of the total calcium excretion and 13 - 18% of the total nitrogen excreted, of men exposed to 100°F environmental temperatures. As a result of these fairly high excretions of calcium and nitrogen in sweat, other mineral contents were also investigated in relation to intake, balance and requirements. These minerals included sodium, potassium, magnesium, phosphorus and iron. In addition, the daily osmolarity was also computed from the freezing point of the sweat.

A considerable amount of data is available in the literature on the mineral concentration in sweat (3, 4) but very few, if any, of these studies have been related to balance and requirements. Many values for the sodium excretion in sweat have been reported in the literature, ranging from 13 - 104.4 meq/liter of sweat (30 - 240 mg/100 ml) (3, 4).

Potassium losses in sweat have been reviewed extensively (3, 4) and reported values range from 2.3 - 16.0 meq/liter (9 - 62 mg/100 ml). Magnesium concentrations reported in the literature (3, 4) range from 0.04 - 4.5 mg/100 ml and values for sweat iron ranging from 0.10 - 5.3 mg/hr have been reported by many investigators (3, 4) including Foy and Kondi (5) and Hussain and Patwardhan (6). It has been shown that the iron in the cell rich portion of sweat is at least 4 times the concentration of the cell poor sweat (centrifuged supernatant fluid).

The phosphorus concentrations in sweat reported in the literature are fairly low, ranging from 9 - 43 mcg/100 ml of sweat.

The fairly high nitrogen and calcium excretions in sweat reported previously (1, 2), especially during profuse sweating conditions, indicate that mineral losses in sweat may be sufficiently important to warrant further investigation. It is the opinion of investigators (7, 8), that sweat losses should be included as part of the total daily output in balance studies, otherwise erroneous conclusions can be drawn.

A study was designed in an attempt to answer some of the following questions: (a) what are the mineral losses in sweat of men performing fairly light, controlled physical activities at high environmental temperatures; (b) what are these losses in relation to the mineral intake and mineral balance; (c) what are these losses in relation to mineral requirements; and (d) do these mineral losses in sweat decrease appreciably during acclimatization?

Experimental Design

A study was conducted for a total of 32 days on three healthy young men. It consisted of an 8-day preliminary period (I) at 24°C (75°F) and 50% relative humidity (RH), four 4-day periods at 37.8°C (100°F) and 70% RH (II, III, IV and V), and an 8-day recovery or adjustment period at 24°C (75°F) and 70% RH (VI), and sweat rates were computed daily on each man. Sweat samples were collected during morning and afternoon periods. Since the quantities of sweat collected during the control and adjustment periods at 75°F were limited, no values will be reported in this paper. The daily physical activity was constant and consisted of only 30 minutes of moderate activity on the bicycle (Exercycle), the remainder of the day being spent in sedentary type activities. When the men left the test area (evenings) no moderate to heavy activities were permitted.

All of the test phases were performed in an environmental chamber between the hours of 8 a.m. and 4:30 p.m. daily with the exception of each 4th evening when the men slept overnight in the hot room at 100°F. At this time sweat samples were collected for 2 - 8 hour intervals to determine whether the sweat concentrations of the minerals were decreased with longer exposure to the heat.

The food menus consisted of 4 daily menus that were rotated during each period. The diets contained 8.7 gm of sodium, 2.49 gm of potassium, 343 mg of magnesium, 23.4 mg of iron and 1.41 gm of phosphorus. All food was offered and consumed at regular mealtimes and no other food was permitted during the day. Salt was the only mineral available ad libitum and was measured for each man during each period.

Chemical analyses of the food composites, urine, feces and sweat were performed for sodium, potassium (9), magnesium, iron, and phosphorus (10). In addition freezing points (11) were performed on the daily sweats.

Sweat rates were measured for each period using the method of Adolph, et al. (12). These sweat rates were determined by measuring weight changes during the morning and afternoon periods and then adjusting for water intake, and for water loss in urine, feces and insensible loss from skin and lungs. (Gaseous exchanges of respiration does contribute a small quantity, which usually constitutes less than 1% of the observed decrease in body weight.) Sweat samples were collected during both the morning and afternoon periods. These samples were collected in polyethylene bags which covered one whole arm, and were representative for the entire period each subject was in the chamber. The arm and the bag were rinsed with distilled water and dried before each collection period began. The immediate question that comes to mind is the comparison of arm sweat to total body sweat. It has been shown by some investigators (2) that the constituents of arm sweat are reasonably representative of the total body sweat. Van Heyninger and Weiner (13) on the other hand are in disagreement, observing that the arm sweat is more concentrated than the rest of the body.

Collins and Weiner (14) have observed a rapid depression of sweat gland activity in the forearm when the arm was covered with a sweat collection bag. They feel that the sweat depression in the arm bag may have been due to obstruction of the sweat gland ducts, by the excessive skin hydration.

Complete urine and fecal collections were made for 4-day periods coinciding with the repetition of the 4 menus utilized. Mineral balances were computed on each man for each period, based on the inclusion and exclusion of the minerals in sweat as a source of mineral loss.

Results

The chemical analyses of the various minerals performed on the supernatant sweat after centrifuging, are presented in quantities/100 ml of sweat (Table I). This table also includes the means, standard deviations during the 7½ hours exposure to 100°F temperatures. After the first 4 days of acclimatization to heat, the potassium excretion in sweat ranged from 25 - 28 mg/100 ml, magnesium excretion ranged from 0.61 - 0.64 mg/100 ml, iron from 25 - 39 mcg/100 ml, and phosphorus from 0.11 - 0.26 mg/100 ml of sweat. The mean excretion rate in mg/hour for the same exposure periods ranged from 78 - 106 mg for potassium, 2.0 - 2.4 for magnesium, 0.11 - 0.16 mg iron, and 0.45 - 0.81 mg/hour for phosphorus. The sodium excretion in sweat was quite variable due to the fact that salt intake was not controlled (Table I).

The daily 7½ hour mineral excretion in sweat for 16 consecutive days at 100°F are compared in Table II. Sodium, potassium, phosphorus and the total osmolarity of sweat decreased after the first 4 days of acclimatization, but the magnesium and iron excreted in sweat remained fairly constant from days 1 - 16.

The diurnal excretion rate showed a sharp decrease during the sleeping hours, to approximately one half of the daily excretion when the men were up and moving around (Table III). This was due to the reduced sweat rates during the sleeping periods. Mineral balances, based only on sweat losses during the 7½ hour collection period, were computed for sodium, potassium, magnesium, iron and phosphorus. These balances were calculated with and without the inclusion of the sweat mineral losses. The sodium balance as expected varied due to the variation in daily intake (Table IV). The potassium balance was positive when the sweat losses were excluded but were negative when the sweat losses were included, averaging -1522, -578, -66 and -195 mg/day for the 4 consecutive 100°F periods (Table II). Magnesium balances did not vary greatly when comparing the inclusion and exclusion of the sweat losses, due to the extremely high retention of magnesium. On a daily intake of 343 mg of magnesium, approximately 200 mg of magnesium was retained (Table VI). Iron balances even though they were reduced by approximately one half, were still on the low positive side (Table VII). The quantities of phosphorus in sweat were so small in comparison to the total daily intake that they did not change the highly positive balances significantly (Table VIII). These 5 mineral balances could be greatly changed with the inclusion of the sweat losses for the 16½ hours during the time the men were out of the environmental chamber.

The sweat losses during the 7½ hour exposure periods are presented as per cent of the total excretion in Tables IV - VIII. Sodium in sweat accounted for 54 - 68% of the total sodium excretion, potassium from 19 - 44%, magnesium from 10 - 15%, iron from 4 - 5% and phosphorus from 0.4 - 1.2% of the total excretion. If one included an average value for mineral losses in sweat during the remaining 16½ hours of the day when the men were exposed to 100°F temperatures (days 7, 11 and 15) the total daily mineral excretion in sweat was approximately doubled (Table X). It is realized that an average value for the 3 evening exposures at 100°F would not be realistic since normally the environmental temperature will fall appreciably during the evening, and as a result the sweat rate and excretion rate will also decrease (Table XI).

Discussion

Sodium is essential for the normal functioning of the body since it contributes to the acid-base balance of the body and since it is responsible in large measure, for the total osmotic pressure of the extracellular fluids (15). Minimal allowances have not been established by the NRC (15) due to lack of sufficient information but it has been observed that a normal American intake will range from 3 - 7 gm of sodium/day. It has been reported (15) that under normal conditions 90 - 95% of the sodium intake is excreted in the urine and usually sweat sodium losses are not considered in sodium balance studies, under these conditions. Sodium can be excreted in sweat in fairly large quantities to disturb homeostasis and as a result seriously impair the economy of the organism (3). Sodium excretion in sweat is variable being dependent on physical activity, acclimatization, adrenal cortical activity, environmental temperature, humidity and body temperature. Under conditions of this study, where the daily sodium intake ranged from 8 - 10 gm/day, the losses of sodium in sweat accounted for more than 50% of the total daily excretion. Urinary excretion accounted for 31 - 45% of the fecal excretion for 1.2 - 1.8% of the total daily excretion. The sodium intake in this study was excessive which could have accounted for the exceptionally high excretion in sweat. Since the salt intake was ad libitum, it was not possible to study the effects of acclimatization for the 16 days, but it was observed that the sweat sodium decreased appreciably during the first 12 days exposure to heat, which is in agreement with data reported in the literature. On three separate occasions the men spent the day at 100°F, and it was observed that the sodium in sweat and the sweat rate decreased considerably by approximately 50% during the sleeping hours, but on arising and being active again, the morning values were again at a higher level. Low sodium intakes, under conditions that produce profuse sweating may eventually lead to muscular cramps, nausea, decreased physical performance and heat prostration. The high excretion of sodium in sweat, during profuse sweating conditions, must be considered in any sodium balance study. These losses are directly related to the daily requirements.

Potassium has been shown to be a required nutrient; and is one of the principle basic elements in intracellular fluid, being found in greatest quantities within the cell. It is also a very important extracellular fluid constituent since it can influence muscular activity, notably the cardiac muscle, and can affect the excitability of the nerve tissue. The NRC (15) has not established minimal allowances for potassium but a normal United States diet usually contains from 2.4 - 4.5 gm/3000 Calories. It has been shown in one experiment (15) that an intake between 0.8 - 1.3 gm of potassium/day would be very close to the daily potassium requirements. Potassium deficiencies, manifested by muscular weakness, increased nervous irritability, mental disorientation and cardiac irregularities, can be produced by gastrointestinal losses, by renal losses or by low potassium intake, and are frequently accompanied by metabolic alkalosis. Muscle protein repletions may demand an additional potassium intake at the rate of 1 gm of nitrogen to 2.7 meq of potassium.

Under normal conditions, it has been observed that the urinary excretion of potassium usually reflects the daily intake, since only a small quantity is excreted in the feces. In this study the urinary potassium excretion ranged from 54 - 78% of the total daily output and the fecal excretion as expected, was low ranging from 2.2 - 4.0% of the total.

The data in the literature are fairly limited to draw any specific conclusions on the relationship of potassium excretion in sweat and the total daily potassium excretion, as they may be related to such variables as body temperature, acclimatization to extreme heat, sweat rate and physical exercise (3). In some instances, appreciable quantites of potassium in sweat have been reported (3, 4) in men, who have been living and exercising in extremely hot environments, but Davidson, et al. (16) and the British Ministry of Agriculture (17) feel that sweat potassium losses are usually negligible, in relation to the daily intake. It has been shown that sweat potassium excretion will decrease with acclimatization to extreme heat (18, 19) which was also true in the present study. Potassium excretions in sweat ranged from 600 - 800 mg for the 7½ hour collection period, which was approximately 30% of the total daily excretion. If the potassium losses in sweat for the remainder of the day were included, these losses could account for up to 50% of the total daily excretion. The potassium balances, on an intake of 2.5 gm/day, exclusive of the sweat losses, were positive; but with the addition of the sweat potassium losses, these balances were all on the negative side. On these separate occasions when the men spent the 24 hours at 100°F, the sweat rate and the potassium excretion in sweat decreased to approximately one half, during the sleeping period. The excretions were doubled, after arising and moving around the next morning. These data suggest that the potassium losses in sweat are quite appreciable, and must be considered under conditions that will produce heavy sweating, otherwise balance and daily minimal allowances data would be greatly misinterpreted. Studies in the literature under profuse sweating conditions, where equilibrium was attained, should be reevaluated.

Even though magnesium is a very important cellular constituent, there is very limited information in the literature in relation to magnesium metabolism in the body. It is a known fact that for normal function, cardiac and skeletal muscles and nervous tissue, depend greatly on a proper balance between calcium and magnesium ions. Magnesium will replace the calcium in bone salts when there is a calcium deficiency, but magnesium in excess will inhibit calcification. Even though the NRC has no minimal allowance, it has been calculated that the daily magnesium allowance for adults in the United States is between 250 - 300 mg/day (15).

Under normal conditions, it has been reported that approximately 50 - 75% of the magnesium excretion is in the feces, the remainder being in the urine. No mention is made in the literature of the possible magnesium losses during profuse sweating conditions. The fecal excretion of magnesium ranged from 66 - 74% and the urine excretion ranged from 16 - 19% of the total daily excretion.

Unlike sodium and potassium, the magnesium excretion in sweat did not decrease appreciably during acclimatization, ranging from 14 - 19 mg during a 7½ hour collection period. This accounted for approximately 12.5% of the total daily excretion, but when the overnight sweat losses were included, this excretion of magnesium could account for 25% of the total. This sweat loss did not greatly affect the magnesium balance, due to the fact that on a 343 mg intake, the daily retention was approximately 200 mg/day. This retention may be in part compensation for the negative calcium balance reported in the same study (1); or it may be that the estimate of the minimal daily allowances of 250 - 300 mg of magnesium/day may be too high. Under the present conditions on a fairly high intake the magnesium losses in sweat are relatively unimportant, but in studies on low magnesium intakes, these losses should be considered.

Even though a few studies have been performed on the relationship of sweat losses of iron to the daily requirements, the quantitative importance of the cutaneous iron losses still is a disputed issue. It is the feeling of one group (5) that the inclusion of the integumental iron losses may possibly increase the iron requirements by as much as 50% under non-stress conditions; and that these excessive sweat losses in hot environments may be a contributing factor in the development of iron deficient anemias. On the other hand Hussain and Patwardhan (6) feel that the body tends to conserve iron in the anemia state by reducing the losses through the skin. Duback, et al. (20) using radio iron as a tracer observed that during maximum sweating from 0.36 - 1.48 mg of iron may be lost in sweat in a 24 hour period.

Comparisons have been made on the cell rich and cell free sweat iron (6) showing that the cell rich portion contains from 3 - 10 times the concentration of iron than the cell free sweat. It was concluded that the major portion was present in the products of cellular desquamation; and since active thermal sweating is always accompanied by cell desquamation, the loss of iron in sweat could be of far greater importance than is generally supposed.

In the present study, the iron excretion of the cell free sweat of healthy young men, did not change appreciably with acclimatization, averaging from 110 - 140 mcg/hr for 16 consecutive days exposure to heat. This amounted to approximately 1 mg during the exposure period, which was 4.5% of the total daily excretion. If the iron losses in sweat during the remainder of the day are included, they could account for up to 11% of the total daily excretion, which is an appreciable quantity. Under normal conditions most of the iron excreted by the human body is found in the feces. This was also observed in the present study where 95% of the total excretion was found in the feces.

On a fairly high intake of 23.4 mg/day, the iron balance was on the positive side by approximately 2 mg/day but when the sweat iron losses were included, the balance was reduced to approximately +1 mg/day. These sweat iron losses could be considerably higher if one included the evening losses. Under conditions where profuse sweating occurs, these sweat iron losses should be considered in balance studies, since they could be related to the daily requirements.

When the men were exposed to high temperatures, on three separate occasions for 24 hours, it was observed that the sweat rate and sweat iron excretion was halved during the inactive sleeping periods. On arising the next morning, the sweat rates and sweat iron excretions were again doubled.

Phosphorus contains the lowest concentration of any of the minerals analyzed in this study; averaging less than 0.5% of the total daily excretion. These values, which agree fairly well with data from other investigators (3, 4), are relatively unimportant in computing balance studies.

The total osmolarity of sweat (freezing point) was decreased after acclimatization ranging from 116 - 141 milliosmoles after the acclimatization period. These values are comparable to other values on human sweat reported in the literature, which has been thoroughly reviewed by Adams, et al. (21). These authors concluded that the osmotic concentration of sweat is hypotonic to serum and as the sweat increases, the osmotic concentration usually decreases.

The results of this study show that a considerable quantity of sodium, potassium, magnesium and iron are lost in sweat of men during 16 consecutive days exposure to environmental temperatures of 100°F. During a 7½ hour collection period, the sweat excretions averaged 0.601 gm/hr for sodium, 0.125 gm/hr for potassium, 2.3 mg/hr for magnesium and 0.13 mg/hr for iron. In the past, with the exception of sodium, very few investigators have recognized the fact that sweat losses could be appreciable, and as a result these losses have, all too frequently, been neglected in computing mineral balance. This would result in misinterpretation of the data, especially under conditions of profuse sweating. The inclusion of these mineral losses in sweat should be considered as part of the total losses. This in turn would help in estimating more realistic minimal daily requirements.

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LITERATURE CITED

1. Consolazio, C. F., Matoush, L. O., Nelson, R. A., Hackler, L. R. and Preston, E. E.: Calcium in sweat and its possible relation to calcium requirements. USAMRNL Report No. 266, February 1962.

2. Consolazio, C. F., Nelson, R. A., Matoush, L. O., Harding, R. S. and Canham, J. E.: The nitrogen excretion in sweat and its relation to nitrogen balance and requirements. USAMRNL Report No. 270, October 1962.

3. Comar, C. L. and Bronner, F.: Mineral metabolism, an advanced treatise. Academic Press, New York, 1960.

4. Altman, P. M. and Dittmer, D. S.: Biological Handbooks. Blood and other body fluids. Fed. of Am. Soc. Exptl. Biol., Washington 25, D. C., 1961.

5. Foy, H. and Kondi, A.: Anemias of the tropics; relation to iron intake, absorption and losses during growth, pregnancy and lactation. J. of Trop. Med. and Hyg. 60: 105-118, 1957.

6. Hussain, R. and Patwardhan, V. N.: Iron content of thermal sweat in iron-deficiancy anaemia. Lancet: 276: 1073-1074, 1959.

7. Mitchell, H. H. and Hamilton, T. S.: The dermal excretion under controlled environmental conditions of nitrogen and minerals in human subjects with particular reference to calcium and iron. J. Biol. Chem. 178: 345-361, 1949.

8. Mitchell, H. H. and Edman, M.: Nutritional significance of dermal losses of nutrients in man, particularly of nitrogen and minerals. Am. J. Clin. Nutr. 10: 163-172, 1962.

9. Baird Associates: Flame photometer manual. Third Edition, Cambridge, Massachusetts, 1953.

10. Consolazio, C. F. and Johnson, R. E.: Biochemical and dietary procedures. USAMRNL Report No. 242, Denver, Colorado, 1960.

11. Fiske Associates: The Fiske osmometer instruction manual. Boston, Massachusetts, 1954.

12. Adolph, E. F. and Associates: Physiology of man in the desert. Interscience Publishers, Inc., New York, 1947.

13. van Heyninger, R. and Weiner, J. S.: A comparison of arm-bag sweat and body sweat. J. Physiol. 116: 395-403, 1952.

14. Collins, K. J. and Weiner, J. S. : Observations on arm-bag suppression of sweating and its relationship to thermal sweating "fatigue". J. Physiol. 161: 538-556, 1962.

15. National Academy of Sciences, National Research Council; Food and Nutrition Board: Recommended dietary allowances. Publication No. 589, Washington, D. C., Revised 1958.

16. Davidson, S., Meikeljohn, A. P. and Passmore, R.: Human nutrition and dietetics. The Williams and Wilkins Company, Baltimore, Maryland, 1959.

17. Ministry of Agriculture, Fisheries and Food: Manual of nutrition. Her Majesty's Stationery Office, 5th Edition, London, 1959.

18. Bass, D. E., Kleeman, C. R., Quinn, M., Henschel, A. and Hegnauer, A. H.: Mechanisms of acclimatization to heat in man. Medicine 34: 323-380, 1955.

19. Dill, D. B., Hall, F. G. and Edwards, H. T.: Changes in composition of sweat during acclimatization to heat. Am. J. Physiol. 123: 412-419, 1938.

20. Duback, R. Moore, C. V. and Callender, S.: Studies in iron transportation and metabolism. IX. The excretion of iron as measured by the isotope technique. J. Lab. and Clin. Med. 45: 599-615, 1955.

21. Adams, R., Johnson, R. E. and Sargent, F. II: The osmotic pressure (freezing point) of human sweat in relation to its chemical composition. Quart. J. Exptl. Physiol. 43: 241-257, 1958.

TABLE I

Concentration of Minerals in Sweat*

16 Days at 100°F

Minerals	Days Exposure							
	1 - 4		5 - 8		9 - 12		13 - 16	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Sodium, mg/100 ml	337	183.0	113	67.5	118	99.4	420	296.3
Potassium, mg/100 ml	84	72.1	25	12.6	25	6.3	28	9.7
Magnesium, mg/100 ml	0.70	0.29	0.61	0.21	0.61	0.16	0.64	0.28
Iron, mcg/100 ml	36.4	21.2	33.2	16.0	38.6	21.1	25.0	20.9
Phosphorus, mg/100 ml	0.155	0.119	0.260	0.152	0.109	0.087	-	-

* Concentration/100 ml of sweat as collected and centrifuged. Chemical analysis on supernatant fluid.

TABLE II

SWEAT STUDY - 1961

Sweat Excretion of Minerals and Total Osmolarity
Total Quantity During Daily 7½ Hour Exposure at 100°F

Days at 100°F	Sodium mg	Potassium mg	Magnesium mg	Iron mg	Phosphorus mg	Osmolarity* Milliosmoles
1	11176	2780	-	0.91	21.9	-
2	6210	3068	15.9	0.93	3.3	-
3	3535	658	18.5	1.13	3.8	194
4	-	-	-	-	-	221
5	2500	537	13.7	1.12	6.9	139
6	2379	555	15.4	0.81	5.4	131
7	-	-	-	1.12	-	143
8	4696	672	16.6	0.79	6.0	151
9	2623	660	17.3	0.76	3.1	112
10	3050	669	18.3	1.16	3.6	111
11	1644	516	18.6	1.26	5.2	111
12	4050	560	16.4	1.09	1.7	128
13	7090	772	17.5	0.83	-	120
14	7650	793	18.3	0.66	-	115
15	3380	757	18.6	1.41	-	135
16	6310	863	16.7	0.55	-	139

* -1.86°C for each 1000 milliosmoles.

TABLE III

Diurnal Variation of Minerals in Sweat, mg/Hour

Days at 100°F

Time	Sodium, mg			Potassium, mg			Magnesium, mg			Iron, mcg		
Hours	7-8	11-12	14-15	7-8	11-12	14-15	7-8	11-12	14-15	7-8	11-12	14-15
0 - 3½	375	234	944	57	74	108	3.2	2.3	2.8	159	107	179
4½ - 8½	844	289	1837	111	65	104	2.0	2.1	2.2	140	221	195
9½ - 15	1235	1590	1331	115	101	82	2.2	1.8	1.5	110	155	84
15-23 (Sleeping)	441	582	262	95	52	59	-	-	-	141	71	52
0 - 3½ (Next Day)	626	945	841	90	85	115	1.8	2.2	2.2	101	193	73

TABLE IV

SWEAT STUDY - 1961

Sodium Balance, mg/Day

16 Consecutive Days at 100°F

Days at 100°F	Intake	Output			Balance	
		Urine	Feces	Sweat*	Sweat Excluded	Sweat Included
1 - 4	10229	2600	105	5784	+7524	+1740
5 - 8	8729	2170	81	3188	+6478	+3290
9 - 12	8729	2360	95	2840	+6274	+3434
13 - 16	-**	2440	94	6110	-	-

* Includes only sodium excreted in sweat while in environmental chamber for 7½ hour period. During three overnight exposures to 100°F the sodium excreted in sweat averaged 902 mg/hr, or 14.88 gm for the 16½ hr period.

** Extra salt from shaker not recorded.

TABLE V

SWEAT STUDY - 1961

Potassium Balance - mg/Day

16 Consecutive Days at 100°F

Days at 100°F	Intake	Output			Balance	
		Urine	Feces	Sweat*	Sweat Excluded	Sweat Included
1 - 4	2493	2150	89	1776	+254	-1522
5 - 8	2493	2400	83	588	+10	-578
9 - 12	2493	1860	103	596	+530	-66
13 - 16	2493	1820	72	796	+601	-195

* Includes only potassium excreted in sweat for 7½ hours in environmental chamber. During the three overnight exposures to 100°F, the potassium excreted in sweat averaged 84 mg/hr for a total of 1.39 gm for the 16½ hour period.

TABLE VI

SWEAT STUDY - 1961

Magnesium Balance - mg/Day

16 Consecutive Days at 100°F

Days at 100°F	Intake	Output			Balance	
		Urine	Feces	Sweat*	Sweat Excluded	Sweat Included
1 - 4	343	25.7	107	17.2	+210.3	+193.1
5 - 8	343	23.6	112	15.2	+207.4	+192.2
9 - 12	343	23.1	102	17.7	+217.9	+200.2
13 - 16	343	21.9	76	17.8	+245.1	+227.3

* Includes only magnesium excreted in sweat for 7½ hours in environmental chamber. During the three overnight exposures at 100°F, the magnesium excreted in sweat averaged 1.82 mg/hr for a total of 29.7 mg during the 16½ hour period.

TABLE VII

SWEAT STUDY - 1961

Iron Balance - mg/Day

16 Consecutive Days at 100°F

Days at 100°F	Intake	Output			Balance	
		Urine	Feces	Sweat*	Sweat Excluded	Sweat Included
1 - 4	23.4	NEGLIGIBLE	20.5	1.01	+2.9	+1.9
5 - 8	23.4		19.4	0.96	+4.0	+3.0
9 - 12	23.4		21.1	1.07	+2.3	+1.2
13 - 16	23.4		21.5	0.86	+1.9	+1.0

* Includes only iron excreted in sweat for 7½ hours in environmental chamber. During the three overnight exposures at 100°F, the iron excreted in sweat averaged 0.102 mg/hr, a total of 1.68 mg for the 16½ hour exposure.

TABLE VIII

SWEAT STUDY - 1961

Phosphorus Balance - mg/Day

16 Consecutive Days at 100°F

Periods	Intake	Output			Balance	% Total
	Food	Urine	Feces	Sweat		Output
I	1405	770	9.8	9.9	+615	1.2
II	1405	891	7.8	6.1	+500	0.7
III	1405	896	8.7	3.4	+497	0.4
IV	1405	868	8.1	-	+523	-

TABLE IX

SWEAT STUDY - 1961

Fecal, Urine and Sweat Excretions of Minerals As Per Cent of Total Excretion Per Period*

Days Exposure at 100°F	Sodium	Potassium	Magnesium	Iron	Phosphorus
Fecal Excretion					
1 - 4	1.2	2.2	71.3	95.3	97.6
5 - 8	1.5	2.7	74.1	95.3	98.4
9 - 12	1.8	4.0	71.3	95.2	98.6
13 - 16	-	2.7	65.5	96.1	-
Urinary Excretion					
1 - 4	30.7	53.5	17.2	NEGLIGIBLE	1.2
5 - 8	40.0	78.2	15.8		0.9
9 - 12	44.5	72.6	16.2		1.0
13 - 16	-	63.8	19.1		-
Sweat Excretion					
1 - 4	68.1	44.3	11.5	4.7	1.2
5 - 8	58.5	19.1	10.1	4.7	0.7
9 - 12	53.7	23.4	12.5	4.8	0.4
13 - 16	-	33.5	15.4	3.9	-

* 16 days exposure to 100°F environmental temperatures. Based on sweat excretion for only 7½ hours while in environmental chamber.

TABLE X

SWEAT STUDY - 1961

Minerals in Sweat

	Total Excretion		mg/Hour		Sweat as Per Cent of Total Excretion	
	7½ Hrs	16½ Hrs*	7½ Hrs	16½ Hrs	7½ Hrs	16½ Hrs
Sodium, gm	4.51	14.9	601	902	62.8	88.7
Potassium, gm	0.94	1.39	125	84	30.1	52.0
Magnesium, mg	17.0	29.7	2.3	1.8	12.4	27.5
Iron, mg	0.98	1.68	0.131	0.102	4.5	11.0

* Mean of three evenings spent at 100°F

TABLE XI

SWEAT STUDY - 1961

Diurnal and Hourly Sweat Rate When Exposed to 100°F for 23 Hours, Continuously

Time, Hours	Day of Exposure		
	7	11	15
	gm/hr	gm/hr	gm/hr
0 - 3½	362	363	293
4½ - 8½	438	399	376
9½ - 11	430	399	376
11 - 15	430	436	334
15 - 23 (Sleeping)	131	138	138
0 - 3½ (Next Day)	412	413	413

E

US Army Med. Res. & Nutr. Lab.
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Report No. 271

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The results of this experiment show that a considerable quantity of the various minerals are lost in sweat, in men living and working at environmental temperatures of 100°F. The Na excretion in sweat averaged 0.601 gm/hr, K 0.125 gm/hr, Mg 2.3 mg/hr, and Fe 0.13 mg/hr during a 7½ hour collection period.

These findings are very important since they show additional mineral losses that have not been considered in many of the past studies in the literature, where equilibrium was supposedly attained. Under conditions of profuse sweating, the inclusion of these mineral losses in balance studies may greatly aid in estimating more realistic daily allowances.

1. Mineral Balance
2. Mineral Metabolism
3. Mineral Requirements
4. Sweat Excretion of Minerals

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