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WORK IN THE HEAT AS AFFECTED BY INTAKE OF WATER, SALT AND GLUCOSE[1]

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The performance of physical work in the heat can be affected for better or worse by a variety of factors, the most important being physical fitness and acclimatization, nutritional state, clothing and drugs. This paper deals with the effects of water, salt and glucose, with principal emphasis upon the attainment of the best possible performance. The effects of water soluble vitamins will be mentioned briefly. The present material will be restricted in two ways. First, attention will be confined to performance of fixed tasks by fully acclimatized men working intermittently in moist or in dry heat. Therefore, the results are applicable to steel workers, miners and soldiers in the desert, all of whom usually do a day's work in the heat and spend the rest of the time in cooler surroundings. Second, we shall consider only the immediate hour to hour effects of the above dietary factors upon men whose overall daily intake was always adequate in water, salt, carbohydrate and vitamins. There will be no consideration of prolonged deficiency or excess from day to day.

Methods. Experiments were performed in the late fall or winter in a heated room under hot dry (100 F., 30 per cent relative humidity) and hot moist conditions (95 F. and 90 F., 83 per cent relative humidity). Six healthy young men, fully acclimatized as judged by the criteria of Robinson and colleagues (1943), marched at least three times a week at 3.5 m.p.h. up grades which will be specified in the tables. Depending upon the severity of the temperature and humidity, which were constant in individual series of experiments, they marched anywhere from one to six hours with a ten minute rest in each hour. Certain measurements were made periodically in every experiment. These were: *a*, environmental temperature and humidity with a sling psychrometer; *b*, pulse rate by palpation; *c*, rectal temperature with a calibrated clinical thermometer; *d*, sweating by net change in nude body weight. Other measurements were made in some, but not all, experiments. These were: *e*, respiratory exchange by collection of expired air in a Tissot gasometer after the subject was in a steady state, analysis for carbon dioxide and oxygen with the Haldane apparatus, and calculation of the oxygen consumption by standard procedures (Haldane, 1934; Peters and Van Slyke, 1932); *f*, protein by the micro Kjeldahl method of Ma

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and Zuazaga (1942), in serum or heparinized plasma depending upon the series of experiments under way at the time; g, serum or plasma chloride by the method of Volhard-Harvey (1878, 1910); and h, whole blood sugar by the method of Folin and Malmros (1929). Ingestion of water, salt, glucose or vitamins was as described below for individual series of experiments, and the results will be treated in four separate sections.

RESULTS. 1. *Water.* The most recent papers on the effects of water during work in hot climates (Lee and colleagues, 1940, 1941; Adolph, 1943; Bean and Eichna, 1943; Johnson, 1943) deal in general with the end results of dehydration. The present data show the changes which occur progressively in work at

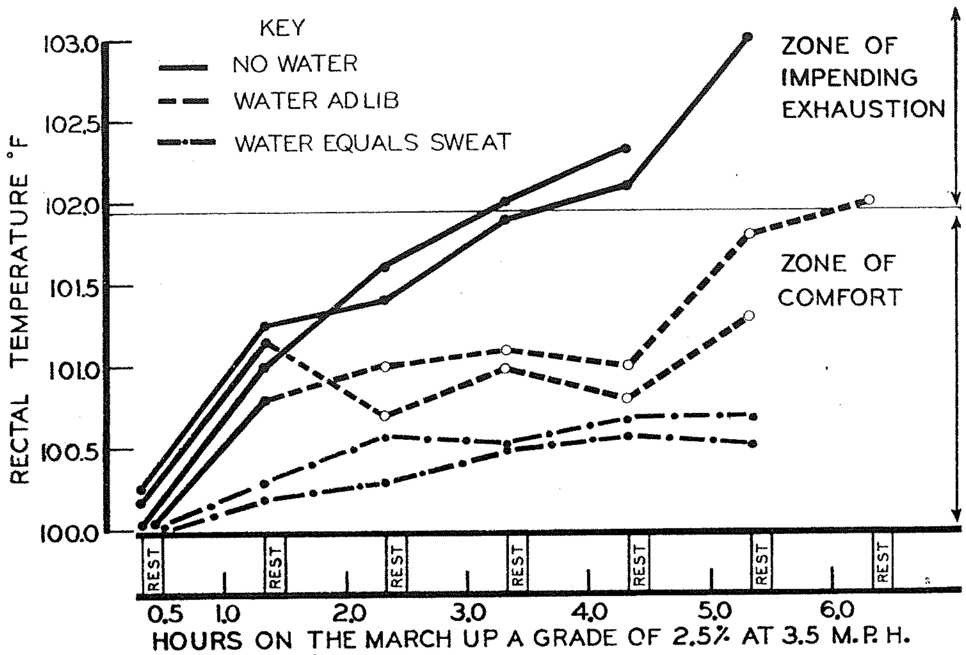

Fig. 1. Effect of water consumption on marching in the heat. (Six experiments on subject J. S. at temperature 100°F., relative humidity 35 to 45 per cent.)

various levels of water intake. Six successive experiments on a single subject marching in dry heat are illustrated in figure 1. In individual experiments he drank either nothing, water enough to keep his thirst satisfied, or water every fifteen minutes equal to the sweat lost in that period. Two complete cycles of experiments were undertaken in twelve days. Three points are clear from the figure: First, without water the rectal temperature rose steadily to high levels and showed no signs of reaching a steady state. Although the subject, being of far better than average stamina, was able to march sixteen miles, he was very tired and inefficient at the end. Second, without water for the first hour, but thereafter with enough to keep thirst quenched at all times, the rectal temperature finally started to rise after remaining constantly low for thirteen miles.

The subject was able to finish nineteen miles in fairly fresh condition. Finally, when he forced himself to drink water at the same rate as he lost sweat, the body temperature remained very low for this type of work, and the subject after sixteen miles said that he could easily go on all day. It should be emphasized that during work men never voluntarily drink as much water as they sweat,

TABLE 1

Effects of water, saline and glucose during marching in the heat (In all experiments the pace was 3.5 m.p.h., with 10 minutes' rest in each hour)

INGESTED DURING EXPERIMENT	ROUTINE MEASUREMENTS: Time of marching	Experiments averaged	Rectal temperature	Pulse rate	Rate of sweating	OCCASIONAL MEASUREMENTS: Experiments averaged	Oxygen consumption	Serum or plasma chloride	Serum or plasma protein	Blood sugar
	hrs.	*total no.*	*°F.*	*beats/min.*	*l./hr.*	*total no.*	*ml./kg./min.*	*meq./l.*	*gms./100 ml.*	*mgm./100 ml.*
A. Moist heat (dry bulb 90°F.; relative humidity, 80%; grade 4%; 2 subjects, fully clothed; constant diet)										
Nothing	1	6	101.0	136	1.48	6	21.5	107	6.3	
	3		102.4	168	1.25		23.5	108	7.4	
Water every 15 min. at rate equal ⅔ sweat loss	1	6	100.6	128	1.39	6	21.6	104	6.3	
	3		100.9	142	1.29		22.3	103	7.1	
B. Moist heat (dry bulb, 95°F.; relative humidity, 83%; grade 2.5%; 5 subjects, nude)										
Nothing	1	6	101.7	143	1.17					
	2		102.7	163	0.98					
	In ten other experiments, the subjects stopped before the end of the second hour with rectal temperatures over 103°F. and pulse rates over 170									
Water every 15 min. at rate equal ⅔ sweat loss	1	22	101.6	139	1.41					
	2		102.3	153	1.25					
C. Dry heat (dry bulb, 100°F.; relative humidity, 35%; grade 2.5%; 6 subjects, nude)										
Nothing	1	11	100.7	122	0.88	3	19.3	102	7.1	99
	4		102.1	154	0.76		20.0	103	8.2	112
(In all the experiments below, nothing was ingested in the first hour; water, saline or glucose were ingested every hour thereafter)										
Water ad lib.	1	7	100.9	130	0.86	1	20.7	102	7.3	
	4		101.2	143	0.74		21.2	100	7.8	
Water every 15 min. equal to sweat loss	1	6	100.8	126	0.94	2	18.8	103	7.5	104
	4		100.9	132	0.80		18.4	97	7.8	104
0.2% saline every 15 min. equal sweat loss	1	5	100.9	123	0.92	3	20.0	101	7.1	102
	4		100.9	131	0.81		20.2	99	7.6	106
No water; 25 grams glucose per hour	1	4	100.5	119	0.82	3	18.7	101	7.3	103
	4		101.5	144	0.74		19.6	101	8.1	103
Water equal sweat loss; 25 grams glucose per hour	1	3	100.6	128	0.90	3	19.2	101	7.1	98
	4		100.5	126	0.71		18.6	95	7.7	92
No water; 100 grams glucose per hour	1	1	100.7	118	0.77	1	18.6	97	7.2	95
	4		102.4	154	0.74		18.6	105	7.8	154
Water equal sweat loss; 100 grams glucose per hour	1	1	100.6	134	0.99	1	18.8	102	7.3	122
	4		101.3	148	0.77		16.9	96	8.2	160

even though this is advantageous for maintaining heat balance, but usually drink at a rate approximating about two-thirds of the water loss in sweat. Although cool water is more palatable, water at any temperature up to 100°F. is equally beneficial. The deficit is made up in the rest periods following the day's work (see Adolph and Dill, 1938; Dill, 1938).

Significant physiological and biochemical changes may occur in the heat during prolonged work without water to drink. The data presented in table 1 are most satisfactorily interpreted by comparing increments or decrements during the course of the various types of experiment. The absolute levels for any given measurement are less instructive, since the same subjects were not used in all cases, and individual peculiarities in some cases make large differences in the absolute value of the mean. However, all of the subjects showed the same type of change in individual experiments, which makes the increment or decrement more satisfactory than the absolute level for purposes of comparison. When water is withheld it is found that: the rectal temperature and pulse rate rise steadily to uncomfortably high levels; the rate of sweating declines steadily; mechanical efficiency decreases as is shown by an increase in oxygen consumption; and serum protein increases. The subject gradually feels worse and worse, and eventually becomes incapacitated from exhaustion of dehydration, no matter how tough or well acclimatized he may be. Administration of water combats all of these undesirable changes, and in general the more nearly water intake approximates sweat loss, the better off the subject remains. This is true for moist as well as dry heat as will be seen by comparing sections A and B with C in table 1.

There is a common misconception that evaporation is of relative unimportance as an avenue of heat loss under humid conditions. When men have to dissipate about 400 Cal. per hour, as our subjects did, evaporation of sweat has to be the chief source of heat loss so long as the relative humidity remains below 100 per cent. Otherwise heat exhaustion supervenes rapidly unless the rate of work decreases. Under the almost intolerable conditions listed in table 1 B, ingestion of water enabled the subjects to maintain their relative rate of sweating and strikingly to improve their performance. The reason that so few experiments without water are listed is that for comparative purposes we have listed only experiments in which the subject could finish two hours. In most of the experiments without water, the subjects failed to finish the second hour.

2. *Salt.* The ill effects of progressive depletion of the salt reserves are well known (Talbott, 1935; Taylor and colleagues, 1943). We investigated the effects of administering salt during the day's work in an attempt to determine whether this is advantageous for fully acclimatized men who receive adequate amounts of salt in the daily diet. As pointed out above (section 1) the effects of plain water are so striking that any further effects of salt have to be compared with this large effect of water. As is common experience, in experiments testing the effects of salt without water, 10 per cent saline or salt tablets without water were so distressing to the subjects that it was far preferable to go without anything. Administration of plain water equal in volume to the sweat led to the beneficial effects discussed above (table 1 C). It is appropriate to emphasize at this point that the serum chloride remains remarkably constant in prolonged work in the heat, even in spite of profuse sweating, provided the overall daily intake of salt with the meals is adequate. Therefore in the present experiments it caused no surprise that administration of 0.2 per cent aqueous saline equal in

volume to the sweat produced substantially the same effects as the administration of an equal volume of plain water. There was perhaps a tendency for the saline to maintain the rate of sweating better than plain water and also to sustain the serum chloride better. Neither of these tendencies was striking, and the performance of the subjects certainly did not benefit from them.

Further tests on this point were conducted on eleven subjects marching outdoors in a Boston summer. On two occasions all marched 10 miles continuously at 4.5 m.p.h. receiving every two miles water approximately equal in volume to the sweat. On the first occasion the first five subjects received a total of nine grams of salt in enteric coated tablets taken three grams per hour for three hours prior to the march. On the second occasion the last six subjects, but not the first five, received salt in the above manner. By comparing the averages for the two groups, it was possible to observe the effects of the salt independently of the water. There was no beneficial effect of the salt on the subjects' feelings, pulse rates or rectal temperatures. In fact, gastro-intestinal uneasiness was felt by those who had received salt tablets, and their pulse rates and rectal temperatures were slightly less good than those who received only water.

3. *Glucose.* It has been reported that ingestion of glucose may be beneficial in avoiding or treating heat cramps and heat exhaustion (see a critical review by Talbott, 1935). In testing the possible beneficial influence of glucose, we compared the effects of moderate and of large amounts of glucose with and without water to drink against the effects of water alone (table 1, C). We may dismiss the large doses (100 grams per hr.) of glucose briefly. The subjects felt nauseated and so uncomfortable that there was obviously no point in getting more data than we got in the two experiments listed. With small doses of glucose (25 grams of glucose dissolved in about 30 ml. of water) there was a small but definite advantage over experiments when no water was permitted. This could have been due to the small amounts of water in which the glucose had to be dissolved before ingestion. In these experiments with glucose, but almost no water, the increases in pulse rate and rectal temperature, and the decreases in rate of sweatings were almost as large as when neither water nor glucose were taken. The effects upon oxygen consumption, plasma chloride, plasma protein and blood sugar were insignificant. These effects were very small in comparison with the beneficial effects of water equal in volume to the sweat, and were more than counterbalanced by the feeling of gastro-intestinal uneasiness, with occasional twinges of nausea, which all of the subjects experienced. When 25 grams of glucose hourly were administered in addition to water equal to the sweat, no significant advantage in favor of glucose could be detected with the possible exception of a slightly more favorable pulse rate. There were no gastro-intestinal complaints in such experiments.

4. *Vitamins.* We have been unable to detect any advantage from administering 200 mgm. of ascorbic acid, 20 mgm. of thiamine hydrochloride, 20 mgm. of riboflavin or large doses of brewer's yeast, either singly or together either during work or the day before. In this connection, recent reports suggest that

losses of water soluble vitamins in sweat are negligible. For a review of this somewhat controversial field see Sargent, Robinson and Johnson (1944).

DISCUSSION. It would appear from the present experiments that in the case of well acclimatized young men whose daily diet is adequate, the best performance of intermittent work in the heat is to be achieved by replacing water loss hour by hour and salt loss meal by meal.

The practical limitations of this idealized situation are many. Water transport and supply are sometimes difficult. When water is available, it should not be forbidden on the traditional ground that during work it is bad for one (see Johnson, 1943, for a discussion of this point), but men should be encouraged to drink to capacity. Even the toughest, best acclimatized men suffer serious inefficiency in a few hours while working hard without water. We have seen a case of true exhaustion of dehydration in a man marching for six hours at −20°F. In addition, there is no economy in water to be gained by restriction during work, since for practical purposes the loss of sweat is about as great whether or not water is drunk.

Another practical difficulty sometimes is that a good daily diet is not available because of failure of supply or is not eaten because of ignorance, or anorexia which is so common in hot environments. Under such circumstances it is highly desirable to ensure adequate intake at least of salt, by means of salted drinking water or tablets, and probably of vitamins by means of concentrates.

SUMMARY

1. The best performance of fully acclimatized young men on a good daily diet, performing intermittent hard work in the heat, is achieved by replacing hour by hour the water lost in sweat. Any amount of water considerably less than this leads in a matter of hours to serious inefficiency and eventually to exhaustion.

2. Replacement of salt hour by hour under such circumstances has no demonstrable advantage.

3. Administration of glucose is of little if any advantage when compared with the great benefit of large amounts of water.

4. When practical problems of transportation and supply, lack of appreciation of the importance of water and salt, or the anorexia which is so common in hot environments, interfere with adequate intake, it may become desirable to supply salt in the drinking water, or less satisfactorily, in the form of tablets.

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