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REDUCTION OF VOLUNTARY DEHYDRATION DURING EFFORT IN HOT ENVIRONMENTS

by

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16. Abstract

During an experimental trip from Eilat to Metullah, the daily positive fluid balance was preserved by providing a wide choice of beverages during the hours of the day.

It was found that the beverage most suitable for drinking in large quantities during periods of effort was a cold drink with sweetened (citrus) fruit taste. Carbonated drinks, including beer, but milk also, were found unsuitable for this purpose.

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REDUCTION OF VOLUNTARY DEHYDRATION DURING EFFORT IN HOT ENVIRONMENTS

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Introduction

The system of perspiration is the main system for maintenance of temperature balance in the human body when the temperature of the surrounding environment is high. Continued perspiration, without replacement of the needed body fluids, will lead to gradual dehydration. The intensity of perspiration is not a function of the state of the body's dehydration and definitely not of the amount of fluid intake; perspiration continues according to the demands of temperature balance, at least until the body's dehydration amounts to 6% of body weight [1].

The loss of weight due to heat represents a true indicator for the degree of dehydration of the body. At slight dehydration -- up to 5% of body weight -- tiredness, impatience, lack of appetite, nausea and sleepiness, as well as increase of rectal temperature and of pulse beat, will make their appearance. During more serious dehydration -- up to 10% of body weight -- headaches and dizziness, breathing difficulty, disturbances in saliva formation, cyanosis, disturbances in speech and walk, and hemoconcentration with reduction in blood volume will occur. When dehydration exceeds 10%, severe disturbances will occur, particularly of the central nervous system such as: disturbed vision and hearing, as well as difficulties in swallowing, spasticity, delirium and anurea; danger to life exists.

Adolph et al. [1] found that under conditions of increased perspiration, the sense of thirst is not sufficient to urge a person to replace the entire quantity of fluid lost during a period of effort so that in spite of the availability of unlimited amounts of fluids, he will for most of the time remain in a state of partial dehydration,

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*Numbers in the margin indicate pagination in the foreign text.

which Adolph named "voluntary dehydration." Voluntary dehydration is the greater, the higher the rate of perspiration and it increases during work or other physical efforts when not much attention is paid to the need for liquid intake. The signs of voluntary dehydration are identical with those of dehydration for other reasons, of course; while rare cases of severe dehydration are known, in spite of availability of unlimited supplies of water, in general voluntary dehydration comes to 4-5% of body weight.

During the experimental trip from Eilat to Metullah, the problem of voluntary dehydration was divided into two parts:

a) an attempt was made to find means for preventing negative fluid balances from day to day;

b) an attempt was made to find out whether there was a possibility for reducing the voluntary dehydration created during a period of effort.

An unlimited amount of beverages was put at the disposal of the men during all hours of the day to investigate the first part of the problem. As for the second part, we tried to solve it by testing the type and temperature of the beverage that the men were most likely to drink in large quantities during a short period of time, at intervals between periods of effort as well as by investigation of the influence of the duration of effort and rest periods on the amount of the fluid intake.

Materials and Methods

The conditions of the trip were explained elsewhere [6]. During the entire time of experiment, there was no limitation to fluid intake. A mobile canteen accompanied the marchers along almost the entire march and supplied a choice of cold drinks during all hours of the day. The canteen was open during most hours of the day so that the marchers could quench their thirst whenever they wanted.

Sufficient time was allowed for breakfast, particularly to allow the marchers to fill up on coffee or tea before they got started. A water wagon was with the marchers 24 hours a day. At the time of the march, the men drank only during the intermission and not while marching, the only limitation to liquid intake.

On the days when the "preferred beverage" was tried out, the mobile canteen arrived at every rest location some time before the marchers did to give them a chance to start drinking immediately on arriving at the rest stop.

Together with the noontime meal, each marcher received a bottle of the beverage of his choice without connection to other tests. Generally the men chose light beer or a citrus drink. During the evening meal and at breakfast, tea and coffee were available in unlimited amounts.

Eleven times during the trip the marchers were divided into four groups and each group was permitted to drink only one type of beverage during that day, according to the test schedule (see Table 3). During all those tests, there was always a control group that drank water from the wagon and the members of the various groups could also drink water instead of or in addition to the beverage that had been assigned to them.

The beverages investigated during this experiment were:

1) water from the wagon (regular drinking water);
2) cold water;
3) cold, sweetened tea with lemon juice;
4) cold water with an addition of lemon or apple syrup;
5) pasteurized milk;
6) soda water;
7) "a light citrus drink" containing 7% orange or grapefruit pulp ("juice");
8) "Solo" (similar to "Tempo") (Translator's remark: two carbonated soft drinks similar to "Seven-Up.");
9) "Malton" -- a type of sweet, dark beer;
10) light beer with 3% alcohol content;
11) light beer with 1 1/2% alcohol content, prepared specially for the trip.

Cold water was tried out seven times during this test to determine the importance of temperature as an aid to fluid intake. The temperature of the wagon water was between 25-30°C, which was accomplished by covering the water wagon with thistle branches

(poterium) that were wetted from time to time. On the first day (8.3.1959), when the water wagon had not yet been covered, the water temperature reached 40°C. Al the other beverages were cooled in the canteen to a temperature of 10-15°C.

Twice during the trip free choice days were arranged during which each of the marchers could drink an unlimited amount of the beverage of his choice at any time, the available choice being:

1) water from the wagon;
2) soda water;
3) citrus drink'
4) Solo;
5) Tassas (carbonated beverage);
6) "Malton;"
7) Beer with 1 1/2% alcohol content.

In addition, each marcher was questioned about his favorite type of beverage during a period of effort.

The marching schedule for this trip was based on two hours of marching in the morning, followed by a 30 minute rest period. Afterwards, there were three more marching periods of 60-70 minutes each, with rest periods of 15-20 minutes. Once, for the sake of comparison, a marching period of 50 minutes, followed by a rest period of 10 minutes, was tried each time.

All sources of fluid intake were carefully inspected by the members of the medical team, 24 hours a day. A record of the beverages, when they were drunk and how much was drunk of each, was kept by the medical team and also by the marchers themselves. Every evening, comparisons were made between the records to check on inaccuracies that might have occurred. There was good cooperation on the part of the marchers and good agreement between the two sets of records.

The condition of dehydration of the men was checked each day by weighing them in the morning after urinary excretion and before breakfast. The degree of dehydration at each stage was also determined by weighing at fixed intervals, according to the test requirements. The weighing was performed on medical scales with an

accuracy of ± 100 g. Before each weighing, the scales were calibrated. Ten men were equipped with personal flasks and a quantitative collection of their urine was made during the entire trip. Measurements of creatinine in the urine during a 24 hour period served to assure that the urine collection was complete.

Various meteorological measurements were made during the entire trip to permit evaluation of the heat stress during the hours of effort and during the entire day [6].

Results

A) Daily Fluid Balance.

The daily average changes in the weights of the men are shown (in kg) in Table 1. The figures in the Table show that daily changes in body weight are minimal and are acceptable within physiological boundaries. Exceptions to this general condition are:

a) the high weight loss on the first day of the trip (8.3.1959) which was caused by insufficient fluid intake, for reasons that will be explained further on;

b) the addition of weight on the following day (8.4.1959) to balance the loss;

c) the relatively large loss of weight on 8.11.59 as the result of diarrhea, which some of the men contracted after the milk drinking experiment.

During the morning weighing, at the start of the trip in Eilat, the average weight for the men was 62.75 kg and the average weight on the last day was 62.94 kg. Such data are proof that they generally drank a sufficient amount of fluids and, except for the first day, were not in a state of dehydration. For this we find additional proof in Table 2 which gives the average urinary excretion for each day of the journey. Except for the first day (8.3.59) on which a significant decrease in daily urine quantity appeared (see above), and for 8.24.59, where a slight decrease in the daily average of urinary excretion is noted, all other days showed urinary excretion within accepted limits [2].

Table 1

Daily changes in weight (average in kg)

Date	Daily Change	Date	Daily Change
8.3.59	—2.000	8.15.59	+0.67
8.4.	+1.30	8.16.	+0.47
8.5	—0.25	8.17.	—0.27
8.6.	—0.15	8.18	—0.40
8.7.	—0.67	8.19	—0.85
8.8.	+1.00	8.20.	+1.17
8.9	—0.20	8.21.	—0.70
8.10	0	8.22.	+0.62
8.11	—1.25	8.23.	—0.50
8.12	+1.07	8.24.	+0.35
8.13	—0.35	8.25.	0
8.14	—0.15	8.26.	+0.27

Table 2

Daily urine quantity (average in liters)

Date	Daily Urine	Date	Daily Urine
8.3.59	0.635	8.15.59	1.269
8.4	1.098	8.16.	1.349
8.5.	1.778	8.17.	1.422
8.6.	1.364	8.18.	1.141
8.7.	1.479	8.19.	1.122
8.8.	1.162	8.20.	1.377
8.9.	1.674	8.21.	1.577
8.10.	1.339	8.22.	1.394
8.11.	1.183	8.23.	0.980
8.12.	1.555	8.24.	0.870
8.13.	1.195	8.25.	0.970
8.14.	1.223	8.26.	0.980

B) Type of Preferred Beverage.

Table 3 shows the degree of preference for beverages as they were consumed during the hours of effort in a test where the participants were divided into groups. The beverages appearing in the column for first choice are: "a light citrus drink" (juice), water with citrus syrup ("lemonade"), each of them three times; cold water and sweetened tea with lemon ("cold tea"), each of them twice and soda water, just once.

The outstanding fact is that in 10 days out of 11, the preferred beverage was noncarbonated and that in 8 instances, a sweetened beverage with citrus taste was preferred.

In the last column on preference (column 4), carbonated beverages appear 5 times (Solo, soda water and beer) and uncooled water from the wagon 4 times. Here we found the interesting phenomenon that men who belonged to groups who customarily drank carbonated beverages used to shake the bottles before drinking from them, so as to decrease the amount of gas in them since it prevented their drinking large quantities.

Table 3

Preference of beverages

Date	1	2	3	4
8.10.59	soda water	juice	water	Solo
8.11	juice	water	milk	Solo
8.12	lemonade	juice	water	soda water
8.13,	juice	lemonade	cold water	water
8.18	juice	Malton	water	beer
8.19	cold tea	cold water	1½% beer	water
8.20	lemonade	cold water	1½% beer	water
8.21	cold tea	1½% beer	water	cold water
8.23	cold water	lemonade	water	Solo
8.24	cold water	water	lemonade	cold tea
8.25	lemonade	1½% beer	cold water	water

Pasteurized milk was tried only once. Four out of five men, in a group that tried that beverage, contracted diarrhea after drinking 1.5-2 liter (the members of the medical team drank milk from the same source but in smaller quantities, which is understandable and did not suffer from such a problem). Regular light beer was also tried only once since it caused inebriation right after the first rest period when a number of men drank 2-3 bottles within a short time. The special beer containing only 1 1/2% alcohol which had been brewed specially for this trip, did not cause drunkenness but did not meet with much enthusiasm -- the men claimed it had a funny taste.

In Table 4 the results of drinking beverages of free choice are shown. The result is given in percentages of the entire liquid input during the time of effort on the two days when there was a free choice of beverages. Here, too, the superiority of the citrus drink and the relative inferiority of the carbonated beverages stands out. Under the given conditions, when the tired men had to drink large quantities of liquids during a relatively short span of time, they preferred to drink warm water from the wagon rather than carbonated drinks even though the latter were cooled.

Table 5 sums up the answers of the marchers to the question: What is the beverage that you like best to drink at a time of effort?" The answers confirm subjectively what the test already disclosed.

Table 4

Free choice drinking during the days 8.16 and 8.26 in percent of total liquid intake during the effort.

	8.16	8.26
Citrus drink	34.5	58.5
water from wagon	22.7	15.0
carbonated drink	18.0	8.2
Malton	8.8	6.2
soda water	3.6	2.3
1½% beer	0	2.8

Table 5

The preferred beverage during a period of effort (questionnaire)

Citrus drink (juice)	-	9	marchers
water with citrus syrup	-	8	"
soda water	-	1	marcher
carbonated drink	-	1	"

C) Desirable Beverage Temperature

On 8.3.59, the only source of liquid intake was the water wagon which had not been insulated from the effects of direct sunshine. The water temperature in the wagon reached a maximum of 41°C that day and the men refused to drink large amounts of water. As a result, after the period of effort, they attained a state of dehydration of 3.3 kg. Only on the following day did they succeed in replacing part of the missing water, even though on that day (8.4.59), the wagon was still the only source of water and the only difference between the two days was a lower temperature of the water wagon (25-30°C).

From Table 3 we learn that out of 7 days during which the drinking of cold water was compared to drinking water of 25-30°C, the preference was 6 times for the cold water. On 8.21.59, the men drank more water from the wagon. A look at the trip journal shows that on that day, a new marching order was carried out which required brief rest periods of only 10 minutes between marching periods. This caused considerable demand at the window of the mobile canteen which prevented the men of the cold water group from drinking a sufficient quantity of cold water so they drank from their own canteens and from the water wagon where there was not so much demand. On all other days, the rest periods were longer and so allowed each marcher to drink an amount sufficient for him.

D) The Marching Regimen

Table 6 explains the test in which two methods of marching were compared. The comparison was made on days that were not far apart, had similar weather and were relatively calm.

Comparison was made of the degree of dehydration which the men attained immediately after finishing their effort and before they had a chance to quench the thirst that was generated as a result of the latest marching period. On 8.21.59, when rest periods were long, a minimum dehydration of less than half a liter was reached which matched the latest marching period. On 8.20.59, when rest periods were short, dehydration reached an average of 2.08 liter.

Table 6

		Method A			Method B		
Date		8.21			8.20		
Cumulative Discomfort Index (Cum.D.I.) Effort km per day		4.8 27.0	Minutes walked	Minutes rested	6.2 27.0	Minutes walked	Minutes rested
Start		07:15			07:00		
March	1	08:10	55	-	09:00	120	-
Rest	1	08:20	-	10	09:30	-	30
March	2	09:10	50	-	10:30	60	-
Rest	2	09:20	-	10	11:00	-	30
March	3	10:10	50	-	12:00	60	-
Rest	3	10:20	-	10	12:20	-	20
March	4	11:10	50	-	13:30	70	-
Rest	4	11:20	-	10			
March	5	12:25	65	-			
Rest	5	12:40	-	15			
March	6	13:25	45	-			
Total		370	315	55	390	310	80
Loss of weight at end of effort			2.08 kg			0.5 kg	
Rectal temperature differences Δt_R			1.5 ° C			1.25 ° C	

Discussion and Conclusions

In spite of the trip having been planned for the hottest month of the year and of the participants' loss of daily quantities of 5-10 liter perspiration, there was no dehydration from day to day, as proven by the daily changes in weight and the daily amounts of urine. This was accomplished by the supply of liquids in suitable quantities and quality during all hours of the day and, particularly, at mealtimes. Dehydration -- even a mild case -- interferes with the regulation of body heat, decreases a person's work efficiency, diminishes his beneficial enjoyment of rest and reduces the appetite.

Also well known is the high incidence of kidney stones in warm regions which some ascribe to dehydration and the resulting decrease in urination that results from it [3, 4, 5].

To maintain a working man in optimum condition while he is working, care should be taken to keep him from voluntary dehydration during the time of effort. The problem is how to arrange the intake of a large amount of fluid in a short time and we observed that the supply of tasty, cool beverages (desired temperature 10-15°C) and the arrangement of rest periods, for 15-20 minutes between periods of effort, permitted people to drink sufficient amounts to cover their losses under nearly all conditions.

Of importance, in addition to the temperature of the beverage, is the mode of drinking. Data collected during the summer of 1960 [7] show that comparison between drinking from a cup or from a jet, straight from the refrigerator into the mouth -- under equal conditions of heat and effort -- shows a significant advantage in favor of the cup. This advantage increased as the water temperature decreased and the jet stream became painfully cold to the teeth. It has therefore become clear that wherever there is need for a lot of liquid intake during intervals between efforts (as in factories and outside work places in the hot parts of the country), drinking from a cup is preferable to drinking straight from a jet of liquid.

Accurate arrangement of the test for determination of the preferred beverage ran into a number of difficulties: climatic conditions and the general amount of liquid intake were not identical during the test days and there is no equality in fluid intake between the different groups on a specific day. Also, not all beverages were tried out an equal number of times. In spite of these drawbacks which were caused by factors beyond our control, or by unexpected developments during the testing process, a rather clear picture of the preferred drink was obtained.

When we talk about a preferred beverage, distinction must be made between a tasty beverage that people like to drink in small quantities with their meals or during leisure periods and a beverage that is appropriate to be drunk in large quantities during periods

of effort. Quite a few people like light beer with their meal at noon but when a test was performed during which large quantities of beer were offered at a period of effort, it became immediately clear that this beverage was totally unsuitable since: a) it produces inebriation when large quantities are consumed in a short time; b) even those who always took beer with their meals did not want to drink any during periods of effort.

Milk turned out to be unsuitable to be drunk in large quantities since it produces diarrhea.

Carbonated beverages were also found to be unsuitable since the gas that they contain inhibited their consumption in large quantities. Cold water and even water from the water wagon which was not cooled were preferable to carbonated beverages during periods of effort.

The most suitable beverage was found to be a noncarbonated cold one, sweetened and fruit-flavored (citrus). Into this category fell sweetened tea with lemon, cold water with lemon or apple syrup, or a light citrus drink. The latter known as "Mitz" (juice) contains only a small amount of natural citrus juice. No tests were conducted with undiluted citrus juice since such juice causes heartburn to many people, particularly when taken in large amounts; special tests would be required to determine the desirable percentage of juice content.

Summary

During an experimental trip from Eilat to Metullah, the daily positive fluid balance was preserved by providing a wide choice of beverages during the hours of the day.

Voluntary dehydration during the period of effort was prevented by the supply of appropriate beverages that were cooled to 10-15°C as well as by maintenance of a marching regimen that permitted relatively long rest periods between legs of the march.

It was found that the beverage most suitable for drinking in large quantities during periods of effort was a cold drink with sweetened (citrus) fruit taste. Carbonated drinks, including beer, were found unsuitable for this purpose.

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