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EFFECTS OF DEHYDRATION ON PERFORMANCE IN MAN: ANNOTATED BIBLIOGRAPHY

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ABSTRACT

This report is a compilation of studies of the effect of dehydration on human performance and the related physiological mechanisms. The annotations are listed in alphabetical order by first author and cover material through June 1973.

INTRODUCTION

The purpose of this report was to gather studies that investigated the effect of dehydration on human performance. Fluid and electrolyte shifts occur under most stressful environments; these include weightlessness, bed rest, heat, cold, altitude, and physical exercise. An understanding of the mechanisms of fluid changes in response to environmental extremes will help to extend man's performance and also his tolerance.

When it was necessary for clarity, a detailed annotation is provided under the subheadings: (a) purpose, (b) experimental conditions, and (c) results and conclusions. The annotations are listed in alphabetical order by first author and cover material through June 1973.

ADOLPH, E. G.
Tolerance of man toward hot atmospheres.
Public Health Reports, supp. 192. Washington: U.S. Government Printing Office, 1946, 38 pp.

Author's Summary:

A practical limit to tolerance for heat is signalled by the premonition of collapse (heat exhaustion) experienced by acclimatized men. The collapse represents an inadequate circulation of the blood, with or without high bodily temperatures. At temperatures below this practical limit, considerable physiological strain and discomfort prevail. They indicate definite disadvantages for human activities. No amount of morale can compensate for the physiological strains imposed by a hot atmosphere. The wet-bulb temperature is a useful index to intolerable conditions. Temperatures above 90° F [32.2° C] can rarely be endured indefinitely. During work the intolerable temperatures may be as low as 80° F [26.7° C] or less. The effective temperatures (sensibly, equivalent temperatures) are an accurate index of physiological stress, insofar as those temperatures have been determined at particular physical activities and in scant clothing. Initial acclimatization is in the majority of persons nearly complete after four exposures of 2 hours each to limiting temperatures. There is suggestion of additional slower acclimatization requiring a month or more. The variability in heat tolerances among individuals is reduced by their acclimatization. The range of the remaining variability is still vast, and may at present be put to advantage only by assay of individuals at the assigned tasks. Factors that help men to endure high temperatures are: shade, breeze sufficient to keep the skin dry, no clothing if already shaded, acclimatization to heat, plenty of water and salt, physical fitness, and adequate sleep. Factors known to threaten endurance are radiation, heavy or impermeable clothing, heavy work, alcohol, diarrhea or vomiting, lack of appetite for food, and wounds or infection.

ADOLPH, E. F.
Signs and symptoms of desert dehydration.
In: E. F. Adolph and Associates. Physiology of Man in the Desert.

Author's Summary:

The difficulties that may be encountered by men who are deprived of water in the desert are indicated by the functional abnormalities that appear progressively. In field tests, men who had lost up to 8 per cent of their body weights were observed; in the hot room, up to 11 per cent; more extreme (accidental) dehydrations have been described by others.

Qualitative signs and symptoms become marked at 4 to 6 per cent deficit. Thirst sensations are then less distressing than headache, dyspnea, and tingling. Men lag when walking, and may faint if asked to stand still. The range of deficits at which each sign first appears is a useful correlative. The most prominant signs and symptoms are listed in Table 14-D.

Quantitative changes that have been studied are those of plasma volume, salivary flow, urinary flow, blood concentration, pulse rate, ventilation rate, and body temperature. These change progressively with the amount of dehydration; while rate of oxygen consumption, visual acuity, auditory acuity, manual coordination, and some other functions do not change appreciably.

The interrelations among these bodily changes are partly understood; they indicate peripheral failure of the blood circulation. Stages of dehydration may be judged by the conjunctions of signs or changes; dehydration exhaustion is one such stage, occurring at 5 to 10 per cent deficit of body weight.

It seems probable that deficits of 15 to 25 per cent are fatal, the former at air temperatures above 85 F, the latter in cooler temperatures.

ADOLPH, E. F. and J. H. WILLS.
Thirst.
In E. F. Adolph and Associates. Physiology of Men in the Desert.
New York: Interscience, 1947. pp. 241-253.

Authors' Summary:

Some curious facts regarding thirst which have come to our notice during our work in the desert seem worth listing. These are:

Some species of mammals after dehydration drink at once, all or nearly all the water necessary to remove the deficit. Roughly, the amount drunk is just enough to place body fluids on the threshold of diureses (diuresis being a sign that an excess of water is present in the body). In other words, all the water that the body will retain is ingested and is metered through the pharynx. It has been shown to be true of the dog, rabbit, and burro (Physiological Regulations. Lancaster, Pa., Cattell, 1943). A rat in contrast, is somewhat more deliberate in its drinking, requiring 15 minutes to complete 80 per cent of its recovery drinking. And a man characteristically requires 30 minutes or more to accomplish 80 percent of the ingestion. No one has found any special relation of this species difference to any other property of man or rat. If the man is forced to drink the whole amount of his water deficit all at once, neither injury nor diuresis results; forced drinking, however, is uncomfortable.

The frequency of thirst sensations is lessened as a man acclimatizes to the desert. Upon arrival, he is continually taking small drafts of water; after a few days, he is quite content to allow an hour or two between drafts, and each draft is somewhat larger. On the whole, he may then allow less deficit of body weight to accumulate. This fact suggests that while large amounts of fluid are unwelcome to the alimentary tract, it can become adjusted so that large drafts can be taken with pleasure.

Thirst sensations are less intense during exercise. At the same water deficit and in the same environment, the man at work and sweating rapidly is more content without drink than the man at rest and sweating slowly. As soon as the exertion stops, the man makes up for part of his delayed drinking with alacrity. The deficit which thus accumulates we term "voluntary dehydration" (Chap. 16). In such cases thirst sensations are so modified that for a time a man does not drink nearly all the water he can retain; his water deficit may amount to 4 or 5 per cent of his body weight. It is not known what operates to suppress the urge to drink in this state.

Sensations of hunger do not seem to interfere with sensations of thirst. Most people feel them as two distinct sensations. Furthermore, food ingestion does not suppress thirst sensations, but rather enhances them. The

moist pharynx and the full alimentary tract do not discourage drinking. The enhancement of drinking apparently comes before the food has had time to be digested, and possibly before digestive juices have begun to flow in quantity. All this is puzzling, when we consider a[illegible] present hypotheses with regard to thirst.

Profuse salivary flows do not inhibit the urge to drink. This is shown by tests in which dehydrated men, whose salivery flows had already diminished to 10 per cent of their flows when hydrated, were given pilocarpine; the drug augmented the flow of saliva without diminishing the sensation of thirst (Fig. 15-1).

The urge to drink becomes intense in men who force themselves to ingest large quantities of water day after day. Two independent studies of this sort have been reported. (Ztschr. f. Exper. Path. u. Therap. 18:139, 1916; Arch. f. Exper. Path. u. Pharmakol. 170:701, 1933). Regnier took 6 to 7 liters daily for 11 days. Kunstmann swallowed 7 to 18 liters daily for 127 days; his thirst became so intense that he got out of bed at night in order to drink. When forced drinking was stopped, the thirst laste for some days longer. Such exaggeration of the thirst sensation is also evident in diabetes insipidus occurring with lesions of the hypothalamic region, and occasionally in psychopathic individuals. (Psychiatric Quart. 12:767, 1938). By forcing himself to drink (whatever the liquid), a man can become a hydromaniac for a time. Fortunately, this state does not prevail after a man leaves the desert where he has been drinking large volumes; drinking stops with noticeable suddenness, and the man is amazed at the novel absence of the former urge to drink.

It was believed that drugs might possibly provide some alleviation of thirst and perhaps of physical exhaustion in dehydrated men. The drugs were selected upon two premises: (1) Sensations of thirst could be diminished either by promoting salivary flow or by shifting body water from tissues into plasma. (2) The syndrome of dehydration might be postponed either by increasing blood pressure and peripheral blood flow, or by shifting water into the plasma from other parts of the body.

Men were exposed, both indoors and outdoors, to high temperatures (100 to 125 F.) and low relative humidities (6 to 20 per cent). In order to estimate any relief obtained, body weight, rectal temperatures, and heart rate were determined periodically. The refractive index of the serum was determined with a dipping refractometer. Thirst was studied first by querying the men about their sensations after dehydration. Half the men were then given a drug and the rest a placebo, the subjects being kept in ignorance of what they were given. After 30 to 90 minutes, the men were questioned again, and were then allowed to drink whatever amount of cool water (58 F.) they desired. This we did to obtain an additional, objective measure of thirst. In some tests the men without drink walked in the sun only before the drug was given, in others they continued walking for another 90 minutes. All drugs were administered orally, in the following doses: aminophylline, 100 milligrams; benzedrine sulfate, 5 to 10 milligrams; caffeine citrate, 65 milligrams; cortin, in the form of desoxycorticosterone acetate, 2 milligrams, sublingually; and pilocarpine hydrochloride, 7.5 to 10 milligrams. The results of these tests are considered under the measurements made.

Table 15-B gives the average effects of the various drugs on the rate of loss of body water by sweating, on pulse rate, and on rectal temperature of men who by marching in the desert had lost an average of 2.1 per cent of their initial body weights before the drugs were administered. Control groups of like numbers were given placebos.

TABLE 15-B
EFFECTS OF DRUGS ON WEIGHT LOSS, PULSE RATE, AND RECTAL TEMPERATURE OF MEN IN THE DESERT

DRUG	Nbr. of men in treated & control Grp.	Difference between treated and control group		
		Weight loss p/h, % initial wt.	Pulse rise beats/min.	Rectal temperature rise p/h, °C
Aminophylline	7	-0.03	-2	0.0
Benzedrine	14	-0.03	-3	-0.1
Caffeine	12	-0.03	0	0.0
Cortin	4	-0.35	0	0
Pilocarpine	6	-0.02	-4	-0.

Cortin was the only one of the five drugs that was tested only in the hot room and was the only one to have any effect on the quantities measured. In each of the four men who were given cortin sublingually, the rate of loss of body weight was less after taking the drug than before. While it is possible that this result, obtained on two separate days, is significant, we do not stress it, since the rectal temperature did not rise, as it might be expected to do with the supposed suppression of sweating.

When benzedrine was given during a march, the men became more alert and talkative about 40 minutes after taking the drug than they had been previously. They complained less than before about having to walk without water to drink, and there was even some singing, despite the fact that by that time the men had lost 3 to 4 per cent of their body weight. Caffeine and other drugs were not found to have any such exhilarating effect.

The effect of benzedrine and lack of effect of caffeine, as noted by us, on men approaching dehydration exhaustion, differ from the results obtained by Foltz and co-workers (J. Lab. & Clin. Med. 28:603, 1943) on men doing rapidly exhausting work without significant dehydration. They found that only caffeine was potent in improving physical performance; however, since we used only one thirteenth of the dosage used by Foltz, that fact may account for the absence of effect of caffeine in our tests. Benzedrine, in their tests, had no stimulating effect on the physically exhausted men, while in our dehydrated men this drug had a definitely exhilarating action at a time when the men were not exhausted but unpleasantly thirsty and tired.

INFLUENCE ON THIRST. The effects of the five drugs on the amount of water drunk in the first 30 minutes after dehydration are shown in Table 15-C. The results demonstrate that none of the drugs decreased the

TABLE 15-C
EFFECTS OF DRUGS ON DEHYDRATION OF MEN IN THE DESERT.

DRUG	Nbr of men in treated & control group.	Water drunk by treated men, % body wt. deficit	Water drunk by control men, % body wt. deficit
Aminophylline	7	76	52
Benzedrine	14	61	72
Caffeine	12	67	62
Cortin	3	37	37
Pilocarpine	6	68	59

amount of water drunk during rehydration. A third of the men given pilocarpine thought that their thirst sensations were lessened by the drug. None of the other substances diminished the thirst sensations, as reported by the subjects.

Pilocarpine can markedly increase the salivary flow of dehydrated men, as is shown by the results of the ingestion of 10 milligrams of the drug by two subjects (Fig. 15-1). Therefore, if the local theory of thirst (Proc. Roy. Soc. London, Ser. B, 90:283, 1918), is the only correct one, administration of pilocarpine to dehydrated men should reduce the desire for water. But as can be seen from Table 15-C, pilocarpine, despite its stimulation of the salivary flow, did not decrease the amount of water drunk at the end of dehydration. This indicates that water drinking is controlled by more than localized dryness of the pharynx. (Am. J. Physiol. 92:221, 1931; Am. J. Physiol. 132:517, 1941). We obtained a similar result with chewing gum; it, too, produced rapid salivary flow but did not decrease ingestion of water.

Although these studies are not as extensive as might be desired, they do indicate clearly that at the present time no drug can be recommended for administration to men whose supply of water is insufficient. Of the drugs tested, cortin and benzedrine gave hints of beneficial action, and two of six subjects reported that pilocarpine alleviated some of the discomfort caused by lack of water. As this drug may produce temporary abdominal pain, it must be used with caution. At present, the evidence of its beneficial action is not strong enough to outweigh its inconveniences. Cortin, sublingually, caused an apparent diminution of sweating rates in the hot room, but it has not been tested in the field. It has been reported to improve heat tolerance indoors when administered intramuscularly, but not when it is taken by mouth. (Klin. Wchnschr. 20:506, 1941). Benzedrine apparently conferred exhilaration without removing any of the signs of dehydration or of thirst.

ÅSTRAND, P.-O.
Diet and athletic performance.
Federation Proceedings 26:1772-1777, 1967.

Author's Summary:

1. The nitrogen excretion does not differ significantly on days of inactivity from days including vigorous activity.

2. The heavier the exercise in relation to the work capacity of the muscle groups involved, the higher is the relative energy yield from carbohydrate, the metabolic RQ approaching or reaching 1.00 during maximal exercise.

3. The diet can markedly influence the interrelation between fat and carbohydrate metabolism. After days of an extreme fat diet, an energy yield from fat will dominate combustion even during exercise. The maximal work capacity is, however, reduced. A high-carbohydrate diet shifts the metabolism toward relatively high energy release from carbohydrate, and improves the capacity for prolonged heavy exercise.

4. The diet on the days before a competition in endurance events may be of the utmost importance for success. The proper preparation for the competition or performance, with a work time exceeding 30-60 min, would be to exercise the same muscles to exhaustion about 1 week in advance. Then the diet should be almost exclusively fat and protein for some 3 days which procedure keeps the glycogen content of the exercising muscles low. Thereafter, a carbohydrate-rich diet should be taken for the remaining days before the performance. The longer the work time, the more important is this preparation (e.g., marathon running, cross-country skiing, bicycling, hiking, mountaineering, or military operations).

ÅSTRAND, P.-O. and B. SALTIN.
Plasma and red cell volume after prolonged severe exercise.
Journal of Applied Physiology 19:829-832, 1964.

Authors' Abstract:

On six subjects plasma volume (Evans blue space) was determined before and 1 hr after an 85-km race in cross-country skiing. The total water loss during the 5- to 9.5-hr competition was estimated to be 5.9 liters, and at the time of measuring the reduction in body weight was 3.9 kg or 5.5% of the weight. The plasma volume was increased 0.41 or 11% ($0.01 > P > 0.001$). A similar study was undertaken with measurements of red cell volume (Cr^{51}) on five subjects. The decrease in red cell volume was 0.08l or 3.2%. These findings are discussed in light of the small reduction in aerobic work capacity in combination with a marked decrease in total work output after the race. In five workers in a steel mill (three at a hot bank and two at a smelting furnace) the total water loss during an 8-hr shift in a hot environment was 3.9 liters and the reduction in body weight was 1.1 kg or 1.9% of the weight. The blood volume (I^{131}) was increased by 0.23 liters or 3.5%.

BALKE, B., G. P. GRILLO, E. B. KONECCI and U. C. LUFT.
Work capacity after blood donation.
Journal of Applied Physiology 7:231-238, 1954.

Purpose:

To measure the influence of the effects of 500 ml blood loss on work capacity both immediately after blood loss and during the following ten days.

Experimental Conditions:

Fourteen men (22 to 45 years) volunteered as subjects. Each man walked on a treadmill at 3.5 mph, but the slope was increased by 1/2 per cent of belt travel per minute at the end of each minute. Measurements taken at rest and during exercise were pulse rate, blood pressure, oxygen uptake, pulmonary ventilation, alveolar gas tensions, and hemoglobin concentration. The exercise test was performed without blood withdrawal and one hour after loss of 500 ml of whole blood. Following blood donation, seven of the subjects were tested on the second and tenth days and the remaining seven on the third and eighth recovery days. Room temperature was $25^{\circ} \pm 2^{\circ}C$.

Results and Conclusions:

(a) Immediately after blood loss:

Maximal oxygen uptake decreased 12%
Pulmonary ventilation increased 10%
Heart rate increased 8 to 10 beats/min.
Hemoglobin concentration dropped from 15.3 g/100 ml to 14.1 g/100 ml (8%).

(b) After 8 to 10 days recovery:

Maximal oxygen uptake increased 5% over control values.
Pulmonary ventilation returned to control levels.
Heart rate decreased 8 to 10 beats/min below control values.
Hemoglobin concentration was 14.6 g/100 ml, 4.6% below control values.

Loss of 500 ml of blood, the customary quantity taken in blood donation, imposes significant limitations on the physiological adjustments to severe exercise within the first few hours following venesection. There is rapid recovery of work capacity in two to three days and full restoration of function after one week.

BEAN, W. B. and L. W. EICHNA.
Performance in relation to environmental temperature. Reactions of normal young men to simulated desert environment.
Federation Proceedings 2:144-158, 1943.

Authors' Results and Conclusions:

Performance in hot environments depends greatly on the state of acclimatization. A man acclimatized to heat works in the heat with a lower body temperature, lower heart rate and a more stable blood pressure than when not acclimatized. Nevertheless, acclimatization to heat cannot be measured by these criteria alone, as they do not necessarily correlate with the man's behavior and ability to work. The man as a whole must be considered and evaluated. Acclimatization to heat begins with the first exposure, progresses rapidly and is well developed by the third or fourth day. Subjects in good physical condition acclimatize more quickly and are capable of a greater work output in the heat than are men in poor physical condition. Continued training in cool environments beyond that necessary to attain good physical fitness does not further increase the ability to work in the heat nor shorten the period of acclimatization. Resting for three or four days in the heat, with activity limited to that required for subsistence, results in definite, but only partial acclimatization. Some work in the heat is necessary for complete acclimatization. Full acclimatization (the ability to perform a maximum amount of strenuous work in the heat) is attained most quickly by graded, progressively increasing work in the heat. Strenuous work on first exposure to the heat is not well tolerated and will often result in disability. If such work is maintained for several days many men will become incapacitated and those who continue to work do so ineffectively and inefficiently. Tolerance to heat on first exposure, even to the point heat exhaustion, does not retard the rate of acclimatization or lessen the degree which is finally attained, provided work is discontinued when symptoms appear, water and salt are given, and subsequent work is within the capacity of the subject. Three or four exposures to heat of 3 or 4 hours duration, with two one-hour work periods during each exposure will produce a considerable degree of acclimatization. These exposures may be separated by intervals of two days in a cool environment. The pattern of acclimatization is the same for short severe exertion as for moderate work of long duration. Inadequate rest at night results in less work or less efficient work on the ensuing day, even by the well acclimatized man. Acclimatization is well retained for one to two weeks, after which it is lost at a variable rate. Most men lose the major portion of their acclimatization in one month - a few are able to retain it for two months. Men who remain in good physical condition retain their acclimatization best. Repeated exposures to heat are required at intervals not exceeding one month, if a high degree of acclimatization is to be maintained for long periods of time. The amount of work accomplished on first exposure to heat can be increased by drinking water in amounts equal to the weight (sweat) lost during work. The rate and final degree of acclimatization attained are not influenced by the water intake (forced, moderately restricted, or taken as desired) during the first two or three days of work in the heat, provided that after this initial period men are permitted as much water as desired. Suddenly restricting the water intake of men working in the heat leads to a deterioration of morale and motivation, reduces greatly the efficiency with which work is performed, decreases the total work output and causes disabling symptoms in many men. This hold for even the well-acclimatized man. Gradual reduction of water intake induces changes similar to sudden restriction, differing only in that they are produced more slowly. Acclimatization to hot dry (desert) environments increases markedly the ability of men to work efficiently and effectively in hot moist (jungle) environments.

BEETHAM, W. P., JR. and E. R. BUSKIRK.
Effects of dehydration, physical conditioning, and heat acclimatization on the response to passive tilting.
Journal of Applied Physiology 13:465-468, 1958.

Purpose:

To investigate the effects of dehydration on the cardiovascular response to orthostasis and to determine if physical conditioning and heat acclimatization would improve the response to passive tilting after dehydration.

Subjects:

Fifteen healthy young American men, divided into three groups: AC, acclimatized and conditioned; C, conditioned, physical exercise in a cool environment; and S, sedentary.

Dehydrated overnight -46.1 DBT and 26.7 WBT at 15% RH on two occasions to about 5.5% of their body weight.

Authors' Results and Conclusions:

Dehydration was associated with the following modifications of the 'normal' orthostatic response: An essentially unchanged systolic pressure, a consistent rise in diastolic pressure and a moderate decrease in pulse pressure. The pulse rate increased more rapidly with time in the upright position after dehydration than when hydrated. Physical conditioning, either with or without heat acclimatization produced no apparent improvement in the pulse rate or blood pressure response to passive tilting after dehydration.

BLYTH, C. S. and J. J. BURT.
Effect of water balance on ability to perform in high ambient temperatures.
Research Quarterly 32:301-307, 1961.

Authors' Abstract:

To determine the effects of water balance on ability to perform in high temperatures, 18 male subjects were subjected to exhaustion runs on the treadmill under three experimental conditions: normal water balance, dehydration, and superhydration. All three runs were performed in an ambient temperature of 120°F. No statistical difference was found between performance under conditions of superhydration and normal water balance, but performance in the dehydrated state was significantly reduced. The performance of a subgroup of 11 athletes under the condition of superhydration was significantly superior to their corresponding performance under the condition of normal water balance. The seven non-athletes did not exhibit this tendency.

BOSCO, J. S., R. L. TERJUNG and J. E. GREENLEAF.
Effects of progressive hypohydration on maximal isometric muscular strength.
Journal of Sports Medicine and Physical Fitness 8:81:86, 1968.

Authors' Summary:

A selected group of nine male college students, between the ages of 20 and 29, who had had previous athletic experience and were physically active, were hypohydrated for 2 one-week periods. A prescribed, nutritionally adequate diet, differing only in water intake (week one, 1500 ml/day; week two, free water intake; week three 900 ml/day), resulted in a mean weight loss of 2.2 per cent, 1.5 per cent, and 3.1 per cent for each respective week. There was no significant decrease in maximal isometric strength of knee extension, dominant and nondominant hand grips, leg extension, back extension, total strength (sum of both grips and leg and trunk extensions), and the ratio of total strength divided by body weight. However, paralleling a 2.5 per cent mean weight loss, elbow flexion strength significantly ($p < 0.05$) decreased 5.8 kg (10.7 per cent). During the third week of the diet (900 ml water/day), a general decrease was evident in all the isometric strength measures, except knee extension. This decrease paralleled a mean weight loss of 2.5 per cent (range 1.2 to 5.2 per cent). In general, the maximal strengths exhibited decreasing trends but only elbow flexion was significantly decreased to 3.1 per cent hypohydration.

BUSKIRK, E. R., P. F. IAMPIETRO and D. E. BASS.
Work performance after dehydration: effects of physical conditioning and heat acclimatization.
Journal of Applied Physiology 12:189-194, 1958.

Authors' Abstract:

Three groups of five men each were dehydrated overnight in the heat (115°F) on two occasions (D_1 and D_2) to approximately 5.5% of their starting body weight. During the 3-week period between D_1 and D_2, one group (AC) was acclimatized to heat and physically conditioned, the second group (c) was physically conditioned and the third group (S) remained sedentary. The response to work after dehydration was assessed by the following criteria: pulse rate (P), rectal temperature (T_r) and maximal oxygen intake (Max. $\dot{V}O_2$). Pulse rates during and after walking and after running were elevated with dehydration. This elevation was reduced in groups AC and C at D_2 as compared to D_1, but not in group S. An elevation in T_r with walking also occurred with dehydration, but this elevation was not significantly different at D_2 as compared with D_1 in any group. Physical conditioning elicited an elevation in Max. $\dot{V}O_2$ (group AC and C), but the elevation was no greater in group AC than in group C. Dehydration was associated with an equal decrement in Max. $\dot{V}O_2$ at D_1 and D_2 in all groups, but the conditioned men (AC and C) maintained a relatively higher Max. $\dot{V}O_2$ than group S. Thus, physical conditioning was associated with enhanced work performance during dehydration (assessed by the above criteria), whereas, acclimatization to heat did not appreciably supplement this effect.

FOLTZ, E., A. C. IVY and C. J. BARBORKA.
The use of double work periods in the study of fatigue and the influence of caffeine on recovery.
American Journal of Physiology 136:79-86, 1942.

Purpose:

To determine if rate of recovery after double work periods is a better measure of the effects of the work than single work periods, and to determine the effects of caffeine on voluntary muscular effort in the presence of fatigue.

Experimental Conditions :

Six medical students were used as subjects. Food intake was controlled and their diet was adequate in all known components. The double work periods on a bicycle ergometer occurred on Monday, Wednesday and Friday afternoons between 2:00 and 4:00 P.M. The work rate was 1,235 kg-m/min. In the drug experiments two subjects, who had been trained for three months, and two who had trained about 1.5 months were injected at random, intravenously with a placebo (2 ml of sodium chloride solution), 2 ml of 0.5 gram caffeine-sodium benzoate or 0.25 gram caffeine immediately after the first work period. Ten minutes after the end of the first work period, the subjects worked to exhaustion again.

Summary:

Caffeine-sodium benzoate (0.5 grams) injected at the end of the first work period significantly increased the work output during the second work period only in the two subjects that were subjectively less fatigued during the rest period. It had no effect on the other two subjects who were not subjectively affected; in these subjects the dose had to be increased to 1.0 gram to produce objective and subjective effects. Caffeine increased hand tremor after the second work period. Caffeine had no effect on a breath-holding test.

GRANDE, F., J. E. MONAGLE, E. R. BUSKIRK and H. L. TAYLOR.
Body temperature responses to exercise in man on restricted food and water intake.
Journal of Applied Physiology 14:194-198, 1959.

Authors' Abstract:

Rectal temperatures (T_R) of 12 clinically healthy soldiers were measured in a room at 25.5°C and 40-45% relative humidity during a 1-hour walk on a motor driven treadmill at 3.5 mph and 10% grade, during control with adequate food intake and water ad libitum, and during a period of food and water restriction. The daily water intake during the water restriction period was 900 ml for six of the men, Low Water Group (L.W.), and 1800 ml for the other six, High Water group (H.W.). The restriction of water began at the same time as the restriction of food and lasted 5 full days for the L.W. group and 10 full days for the H.W. group. Food was restricted to 1000 calories from carbohydrate, 4.5 gm of NaCl and a multivitamin pill/day for 16 days. Water ad libitum was given throughout the experiment except for the period of water restriction. The L.W. group showed a progressive increase of T_R at the end of the walk during the water restriction period with average T_R 1.51°C, higher at peak dehydration than in ontrol. In the H.W. group the greatest average increase, 0.46°C, was observed on day 5 of restriction. Administration of water ad libitum brought the work T_R back to the control level in the L.W. group, but failed to produce any important change in the H.W. group. The relationship between dehydration, elevation of T_R during work and changes in sweat rate is discussed.

GREENLEAF, J. E.
Some observations on the effects of heat, exercise and hypohydration upon involuntary hypohydration in man.
International Journal of Biometeorology 10:71-76, 1966.

Author's Comments:

Four male subjects at a high level of physical fitness were put on a controlled diet 4 days prior to a 4-hr exposure in a hot room (49°C) in separate experiments at rest or with exercise on a treadmill and free access to drinking water. The experiments were repeated at 24°C. Each experiment was followed by a recovery period of 8 hr. The water intake during the heat exposure was roughly proportional to the work load. The rate of water consumption during the recovery period was independent of the level of hypohydration. Previously hypohydrated men took longer to regain their water debt than previously hydrated men. During the recovery periods when the stresses were removed, the increased fluid consumption in both the hydration and hypohydration experiments occurred when meals were eaten. Since the water intakes of the hydration experiments were equal to or larger than those in the hypohydration experiments, the stress conditions inhibited recovery consumption, other things being equal. It appears that the heat, exercise and hypohydration were associated with the immediate (fast) drinking response explained by the effective osmotic pressure hypothesis of Gilman, but another mechanism must be operative during the recovery (slow) period. Perhaps the latter is governed by slower acting changes in the ECF volume through variations in the oncotic pressure rather than directly by the ECF tonicity. Thus, thirst is associated more with the severity of the total stress rather than with the degree of water deficit.

GREENLEAF, J. E., W. van BEAUMONT, E. M. BERNAUER, R. F. HAINES, H. SANDLER, R. W. STALEY, H. L. YOUNG and J. W. YUSKEN.
Effects of rehydration on $+G_z$ tolerance after 14-days' bed rest.
<u>Aerospace Medicine</u> 44:715-722, 1973.

Authors' Abstract:

To determine if rehydration increases $+G_z$ tolerance following bed rest deconditioning, eight male volunteers (21-23 yrs) were subjected to acceleration levels of 2.1G (740 sec), 3.2G (327 sec) and 3.8G (312 sec) presented in random order; the rate of acceleration was 1.8 G/min. Acceleration tolerance was determined by either loss of peripheral vision (greyout) or by loss of central vision (blackout) to a white light with a luminance of 1.2×10^{-2} candles/cm (35.3 foot-lamberts). The experimental design consisted of a 3-week ambulatory control period (C), 2 weeks of bed rest (BR1), followed by a 2-week ambulatory recovery period (R), then 2 weeks of bed rest with rehydration prior to centrifugation (BR2) and a final week of recovery. $+G_z$ tolerance was measured immediately before and at the end of each bed rest period. The subjects ate a calorically controlled, nutritionally balanced diet and exercised 1/2 hr each day on a bicycle ergometer at 50% of their maximal oxygen uptake (approx. 450 kcal/day) during the entire study. The subjects were rehydrated with 1.0 to 1.9 liters of a drink, containing 143m Eq/l Na, 31 mEq/l K and a total osmolarity of 620 mOsm/l, given over a 3-hour period before centrifugation in BR2.

There were significant ($p < 0.05$) reductions in average $+G_z$ tolerances following both bed rest periods at all three G-levels. Compared with control values, following BR1, average ramp plus plateau tolerances decreased 36% at 2.1G, 30% at 3.2G and 44% at 3.8G. Compared with recovery values, following BR2, average tolerances decreased 23% at 2.1G, 29% at 3.2G and 34% at 3.8G. Rehydration increased tolerance ($p < 0.001$) only at 2.1G, but tolerance was not completely restored to control values. Compared with control values, average tolerances at all three G-levels were lower after the recovery period, suggesting that 2 weeks of recovery is not long enough to permit tolerance to return to pre-bed rest levels. After bed rest the time full visual capability can be maintained at plateau during these acceleration profiles can be estimated from the equation: Tolerance (sec) = 345 − (1605/G-level). In relaxed deconditioned men without protective garments, tolerance at 2.0G is 7.6 min and the level of instant blackout is about 4.7G. It is concluded that 2 weeks of bed rest results in a significant decrease in centrifugation to tolerance which occurred despite the use of moderate daily isotonic exercise. Compared to nonhydration control values, rehydration significantly improves $+G_z$ tolerance only at 2.1G but did not return tolerance to ambulatory control levels.

GREENLEAF, J. E. and B. L. CASTLE.
Exercise temperature regulation in man during hypohydration and hyperhydration.
Journal of Applied Physiology 30:847-853, 1971.

Authors' Abstract:

The purpose of this study was to investigate the changes in body temperature during exercise under various hydration regimes and to determine if these changes were due to alterations in sweating. Rectal (T_{re}) and mean skin ($\bar{T}_s$) temperature and sweat losses were measured in eight men while performing upright exercise on a bicycle ergometer at 49% of maximal $\dot{V}_{O2}$ ($\bar{X}$ = 4.55 L/min), in an ambient temperature of 23.6° C, relative humidity of 50% and at three hydration levels: hyperhydration (Δ body wt = + 1.2%), ad libitum (Δ body wt = -1.6%), and hypohydration (Δ body wt = -5.2%). Equilibrium levels of T_{re} were: hyperhydration 37.64°C, ad libitum 37.89°C, and hypohydration 38.51°C ($P < 0.001$). Compared with hyperhydration values, hypohydration a) $\dot{V}_{O2}$ and heart rates were increased, b) equilibrium levels of $\bar{T}_s$, $\dot{V}_{E_{BTPS}}$, and respiratory water loss were unchanged, and c) sweating and evaporative heat loss were reduced. Equilibrium levels of T_{re} are elevated 0.1°C for each 1% of body weight loss. With a constant T_{db}, equilibrium levels of $\bar{T}_s$ and $\Delta\bar{T}_s$ are constant and independent of the level of hydration between +1% and -5%. With constant $\Delta\bar{T}_s$, T_{db}, work load, and respiratory water loss, it is concluded that the excessive rise in T_{re} with hypohydration is due to inadequate sweating.

GREENLEAF, J. E., L. G. DOUGLAS, J. S. BOSCO, M. MATTER JR. and J. R. BLACKABY.
Thirst and artificial heat acclimatization in man.
International Journal of Biometeorology 11:311-322, 1967.

Authors' Abstract:

The purpose of this study was to investigate the relationship between serum osmotic changes, water intake and water balance in four, fit young men during and after exercise in the heat, before and after artificial heat acclimatization. During exercise, before steady-state conditions were reached, voluntary water intakes generally paralleled but were not proportional to the serum osmotic pressure. In steady-state conditions, drinking was approximately proportional to the ef[illegible]ive osmotic pressure of the serum. During the post-exercise recovery [illegible]d, when serum osmolarity returned to normal levels, water intake a[illegible]ded even though there was a total body water (wt) deficit of abo[illegible] Body weight did not return to control levels until 62 to 86 hr fo[illegible]ng the exercise. This slow recovery could not be accounted for by a loss of water associated with glycogen utilization during exercise or by sweat electrolyte depletion. In general, the results supported Dill's hypothesis but plasma volume changes, in addition to osmotic factors, are very likely operative in the initiation and satiation of drinking under these conditions. Perhaps slower acting volume control mechanisms mediate the slow recovery of total body water.

GREENLEAF, J. E., M. MATTER, JR., J. S. BOSCO, L. G. DOUGLAS and E. G. AVERKIN.
Effects of hypohydration on work performance and tolerance to $+G_z$ acceleration in man.
Aerospace Medicine 37:34-39, 1966.

Authors' Abstract:

Nine men were water depleted up to 6.9 per cent of their body weight during controlled 5-day dietary periods and then subjected to various physical performance tests, including grayout tolerance while undergoing $+G_z$ at 3.0 G/min. acceleration, to define set points (the per cent hypohydration where functional deterioration begins). Hypohydration refers to a depletion of body water. The following set points were observed: isometric muscular strength - greater than 4 per cent; modified Harvard step-test - 4 to 4.5 per cent; submaximal O_2 intake - greater than 4 per cent; and $+G_z$ centrifugation - greater than 4 per cent. Total body reaction time decreased with hypohydration. The concept of free circulating water was suggested as a possible explanation for the diversity of results regarding the effects of water depletion on bodily deterioration and work performance.

GREENLEAF, J. E., M. MATTER, JR., L. G. DOUGLAS, S. A. RAYMOND, J. S. BOSCO, E. G. AVERKIN and R. H. ST. JOHN, JR.
Effects of acute and chronic hypohydration on tolerance to $+G_Z$ acceleration in man: I. Physiological results.
NASA Technical Memorandum X-1285, 1966. 39 pp.

Authors' Summary:

Two groups of male subjects were hypohydrated approximately 3.6 per cent of their total body weight either by means o. sauna bath (acute group) or a 48-hour water restriction period (chronic group). Following hypohydration each group underwent four centrifugation runs at an acceleration build-up of +3.7 G/min - held at 6.0 G until blackout occurred. The results indicated (a) no significant difference in mean tolerance times between the acute and chronic group; (b) a significant decrease ($p < 0.005$) in mean tolerance times between the normohydration and hypohydration groups; and (c) a significant decrease ($p < 0.001$) in mean tolerance times over the four successive runs. The mechanisms of reduced tolerance to $+G_Z$ acceleration when hypohydrated are complex because there was very little relationship between percent body weight loss, red cell volume, plasma volume, and total blood volume and tolerance time. The concept of free circulating water was advanced as a possible explanation for the conflicting results regarding the effects of water depletion on tolerance to $+G_Z$ acceleration.

GREENLEAF, J. E., E. M. PRANGE and E. G. AVERKIN.
Physical performance of women following heat-exercise hypohydration.
Journal of Applied Physiology 22:55-60, 1967.

Authors' Abstract:

Twelve healthy women, ages 22 to 33, underwent a 5-month physical training period before being divided into two groups, a control group and a hypohydrated (water-depleted) group. Hypohydration was achieved with the subjects alternately resting and walking (4.8 km/hr) at 49 C until they lost about 3.3% of their body weight. They were then given various physical performance tests to assess the effect of the hypohydration. Statistically significant changes ($P < 0.05$) in the hypohydrated group were observed in a) resting pulse rates, b) recovery pulse rates following a modified Harvard step test, and c) the pulse rates and systolic and diastolic blood pressures during a standard 70° tilt table test. No significant decrements were noted in submaximal O_2 intakes, submaximal VE, total body reaction times, and maximal isometric muscular strength. The submaximal ventilatory exchange ratio was unchanged. It was concluded that there was some deterioration in the cardiovascular system response but there was no gross deterioration in physical performance following 3.3% hypohydration in fit, young women.

GREENLEAF, J. E. and F. SARGENT II.
Voluntary dehydration in man.
Journal of Applied Physiology 20:719-724, 1965.

Authors' Abstract:

The effects singly and in combination of heat, exercise, and hypohydration upon voluntary dehydration were studied in four acclimated, physically fit, young men. Voluntary dehydration is the delay in complete rehydration following water loss. Hypohydration refers to the state of decreased water content while the osmotic concentration of the body is maintained. Ad libitum drinking during the heat experiments was 146% greater than it was in cool experiments. Hypohydration increased drinking 109% over the corresponding hydration experiment, exercise increased water intake 41% over resting. Hypohydration and exercise were less effective than heat in stimulating drinking. During the 4-hr experimental periods, the subjects did not or could not drink enough to compensate for the water lost. Regardless of the magnitude of the water deficit at the beginning of the recovery periods, the rates of rehydration were the same. The more stressful the experiment, the greater the water consumption and, in general, the longer it took to regain the lost water.

HENSCHEL, A.
Diet and muscular fatigue.
Research Quarterly 13:280-285, 1942.

Author's Comments:

The use of coffee, tea, and "cokes" to combat fatigue is a common practice. One might be tempted to think that the popular mid-morning coffee and afternoon tea habit might reflect something a bit more fundamental than accidental habit. Caffeine (J. Pharm. and Exper. Therap.43:457, 1931) has been shown to prolong the onset of fatigue and increase the total work output of an isolated frog muscle. In the normal non-coffee-drinking human it took from 0.5 to 1.0 gram of caffeine intravenously to produce any subjective or objective effect on fatigue (Amer. J. Physiol. 136:79, 1942). With such high doses the recovery rate from fatiguing work and the total amount of work that could be done before complete fatigue were increased. If it takes about 1 gram of caffeine intravenously to be effective, it hardly seems logical that the average coffee drinker would get enough caffeine to have any alleviating effect on fatigue.

HENSCHEL, A. F.
Vitamins and physical performance.
The Journal - Lancet 63:355-357, 1943 (Review article).

Author's Summary:

All acceptable evidence agrees that the supplementation of an "adequate" diet with any or all of the vitamins known to be required by humans does not increase physical performance, work output or recovery from fatiguing work. Hard physical work can be performed without physical deterioration for months on diets that contain about one-half the recommended daily intake of B complex vitamins. Hard physical work apparently does not greatly increase B complex vitamin requirements beyond those due to the increased caloric output. In the normal young man 0.30 mg. of thiamine per 1,000 calories is sufficient for at least some months to prevent deficiency symptoms and to allow maximum physical performance. Larger thiamine intakes have no effect on work capacity. The riboflavin requirements for maximum physical efficiency is probably not appreciably more than 1 mg. daily. Available information does not allow a precise estimation of the niacin requirements for maximum physical performance. However, 15 to 20 mgs. per day will probably prove sufficient. Daily intakes of 25 mgs. of ascorbic acid over long periods of time have not been accompanied by signs of scurvy or by physical deterioration. Claims about the possible reduction in work output by the current vitamin levels in the American diet are not justified from the present state of knowledge.

HENSCHEL, A.
Minimal water requirements under conditions of heat and work.
In: Thirst, edited by M. J. Wayner. New York: Pergamon, 1964. pp. 19-30.

Author's Summary:

In summary we may try to answer the question, "What is the minimal water requirements for man?" Obviously, there is no such thing as a minimal water requirement, because the requirement differs for individuals and for environmental and work conditions. Absolute minimum for inactive man under conditions of no sweat production is about 1 l. a day. When sweating occurs, then additional water must be provided to prevent serious dehydration. However, on an hour-to-hour basis, the body water lost in sweating need not be entirely replaced. Indeed, it may have some advantage not to replace it all during the actual hours of working. A deficit of 2 l. appears to be reasonable, but with deficits greater than that increased physiological strain may result. With 24 hr sweat productions of 8 to 12 l. or even higher under really hot environments, minimal water requirements, over a period of days, would be not less than sweat production. It has been suggested that minimal water requirements is the amount needed to provide urine excretion of 900 cc per day. This would require from 1 to 20 l. per day.

HENSCHEL, A., H. L. TAYLOR, J. BROZEK, O. MECKELSEN and A. KEYS.
Vitamin C and ability to work in hot environments.
American Journal of Tropical Medicine 24:259-265, 1944.

Authors' Summary:

The performance of muscular work in dry heat -- up to 122°F. -- was studied in 44 normal young men under rigidly controlled environmental, dietary and work conditions. The stay in the heat varied from 3 hours to 4 days. Comparisons were made between performances on a diet restricted in ascorbic acid intake and a diet supplemented by 500 mg. ascorbic acid daily. The dietary differences were maintained for periods of 4 to 7 days. Pulse rates in rest and in work, rectal temperatures, vasomotor stability tests, rates of sweating, general observations and subjective reports all failed to demonstrate any significant advantage for the men receiving supplements of ascorbic acid. Psychomoter tests and strength tests likewise generally failed to show any advantage in the ascorbic acid supplementation. There apparently was a slight gain in flicker fusion frequency related to the extra intake of vitamin C. Daily sweat losses were of the order of 5 to 8 liters but the total loss of vitamin C in the sweat is entirely negligible. Heat exhaustion occurred with equal frequency in the vitamin C restricted and supplemental groups.

HYDE, I. H., C. B. ROOT and H. CURL.
A comparison of the effects of breakfast, of no breakfast and of caffeine on work in an athlete and a non-athlete.
American Journal of Physiology 43:371-394, 1917

Purpose:

To compare the pulse rate, blood pressure and finger and trunk ergometer work in a male athlete (29 yrs) and a male non-athlete (26 yrs) under the following conditions: (a) a dose of caffeine without breakfast; (b) breakfast without caffeine; (c) neither breakfast nor caffeine; and (d) at different intervals of time following ingestion of caffeine or breakfast.

Experimental Conditions:

The experiments were conducted in the morning. Breakfast consisted of one soft boiled egg, two ounces of wheat bread and 3/4 ounce of butter. Caffeine was ingested in 7 ounces of Coca-Cola (1.42 grams). "Analysis of Coca-Cola syrup: sugar 53%, caffeine 1.42%, water 44%, citric and phosphorus glycerine and alcohol qualitative test. One ounce of syrup equals about 7 fluid ounces of Coca-Cola." Additional work experiments were conducted with 2.84 grams and 3.58 grams of caffeine given 30 minutes before the work commenced.

Authors' Summary:

The working power of the untrained flexor muscles in a trained athlete may be increased at least three and one-half times, and the same muscle in a non-athlete three times in one month of daily training. From the first the athlete did one and one-half, in less time, and later at the same stage of training, twice as much work as was done by the same muscles in the non-athlete.

The lack of breakfast had at first a slightly less favorable effect upon the amount of work done, although the athlete always felt less fatigued working without breakfast than when working one hour after the meal. Both subjects were able to do more work on the ergograph when the muscles were in training after eating breakfast, and more one hour than one and one-half hour following the meal. After taking 1.42 grain of caffeine, both subjects did more than twice as much work than they were able to do after eating breakfast. The after effect, however, was a heightened degree of irritability especially noticeable in the athlete. The ergographic work had practically no effect on blood pressure and only a fsight effect, if any, on the pulse rate, when working either without or after eating breakfast. The normal pulse rate was practically the same, but the normal blood pressure was higher at all times in the athlete than in the non-athlete.

After both subjects had had equal preliminary training for one month of the arm and trunk muscles on the ergometer, the athlete did more than twice the work done by the non-athlete in one and one-half the time without, and more than one and one-half as much work, after eating breakfast. The efficiency of both subjects grew in proportion as the interval between the meal and beginning of the work increased from one to two and one-half hours. The non-athlete did one-half and the athlete one-third more work two and one-half hours after than they were able to do one hour after the meal.

The increase above their normal blood pressure after working either with or without breakfast was the same for both subjects, notwithstanding that the athlete did more work. But under the same conditions the pulse rate in the athlete was practically double that in the non-athlete. The increase in heart rate was least in both subjects when working two and one-half hours after eating breakfast, that is, the time when the greatest amount of work was accomplished.

A weak dose of 1.42 grain of caffeine, without work or breakfast, gradually increased the pulse rate during the first hour, but in the non-athlete, as a rule, only after a slight initial fall. In both subjects the pulse returned to the normal rate within three hours. With the larger dose, 2.24 grains, under the same conditions, the increase in pulse appeared more promptly, but in thirty minutes was depressed below normal in the non-athlete, and accelerated above the normal rate in the athlete. The blood pressure rose above the normal level in one hour and frequently had not returned to the level in three hours after taking either of the doses of caffeine.

The effects of caffeine taken at different intervals before work, varied with the dose and the individual. In the athlete the maximum influence of a dose of 1.42 grain was manifested in three-quarters of an hour, and in the non-athlete three hours after the dose was taken. The athlete did but little more work forty-five minutes after than he did twenty minutes after taking the drug. But the non-athlete did two and one-half times as much work three hours after as he did twenty minutes after taking the dose.

Power and endurance for work, and cardiac activity and increase in blood pressure do not keep pace with increase of dosage. The maximum power for work in both subjects was attained with the dose of 2.24 grains of caffeine. With this dose both subjects did two and a half times as much work as they were able to do one hour after eating breakfast. In the athlete with this optimum or with the weaker dose of caffeine, the blood pressure was no greater than after the maximum work done either with or without breakfast, and the heart rate only slightly more accelerated. In the non-athlete the pulse rate was increased almost three times as much but the blood pressure was no higher than it was after the maximum work following the meal. A stronger dose of 3.58 grains depressed the muscular power for work in both men, but very markedly so, as well as the blood pressure and pulse rate in the non-athlete. In the athlete the blood pressure was no different, but the heart rate was less after the work following the weaker dose. When the dose was taken in proportion to body weigt, e.g., 0.2 grain of caffeine per 9.3 kilo body weight, or a stronger dose of 0.2 grain per 5.9 kilo weight, the results presented another viewpoint to those obtained when the dose was taken irrespective of body weight. The facts showed that of these two doses thirty minutes before beginning work, the weaker dose and not the stronger stimulated the working power in the athlete most. But in the non-athlete the reverse was the case. With the stronger dose the athlete did one-fourth less and the non-athlete one-fourth more work than with the weaker dose. At the same time the pulse rate was enormously increased in the non-athlete and less so in the athlete who did double the work done by the non-athlete. On the other hand, the blood pressure fell slightly in the non-athlete, and fell also or remained unaltered in the athlete after work and after taking the stronger dose. Therefore, for each subject there was a definite optimum dose which, when increased, proved depressing for muscular work, blood pressure and pulse rate.

One hour's rest did not remove the sense of fatigue produced by the ergometer work, but when caffeine was taken the fatigue of the previous hour's work was inhibited and both subjects did more work then, and even twenty-four hours after taking caffeine, than they did before taking the drug. With the same dose of caffeine and also without eating breakfast, the power for muscular work in the athlete was greater at 4:20 p.m. and in the non-athlete at 8:20 p.m. than at 8:20 a.m. That is, the athlete did his best work eight hours after taking the caffeine and four hours after luncheon, and the non-athlete did his best work twelve hours after taking the dose, and two hours after dinner. At these respective periods, the pulse rate and blood pressure increased greatly in the non-athlete, and the pulse but not the pressure in the athlete. The after effect of the larger dose was a heightened condition of irritability that persisted many hours after the drug was taken. The power and endurance for work were increased, and the cardiac activity greatly affected, but the blood pressure less so than with the stronger dose. It was not possible to state how long the after effect would endure, because the experiments were suddenly interrupted by the paralysis of the rectus muscle of the left eye in the athlete and the nervous condition of the non-athlete.

KARPOVICH, P. V.
Ergogenic aids in work and sports.
Research Quarterly 12:432-450, 1941.

Author's Comments:

Caffeine acts upon the blood vessels, heart, and nervous system. It causes general vasoconstriction with simultaneous dilation of the coronary artery, and increases the contractile power of the heart. It stimulates the central nervous system, accelerating the respiratory rate and shortening the reaction time. In small doses, it acts beneficially upon psychic processes.

Experiments by Mosso (Arch. Ital. de biol., 21:293, 1893) showed that caffeine increased muscular performance in finger ergograph tests. Schirlitz (Arbeitsphysiol., 2:273, 1930) found that 0.3 grams caffeine-sodium-salicylate caused a slight increase in work output of subjects riding bicycle ergometers. Schumburg (Arch. f. Anat., Phys., Phys. Abt. 1889, Suppl. -- Bd. p. 289) observed that tea was beneficial in prolonged marching.

Caffeine and cola-nuts (also containing caffeine) were used in a well-controlled experiment by Graf (Arbeitsphysiol., 10:376, 1939). Subjects riding ordinary or stationary bicycles were given chocolate, either plain or with the addition of caffeine or cola. He found that chocolate with cola had more noticeable effect than caffeine, raising the work output 20 per cent to 30 per cent. Toda (Arch. f. d. ges. Physiol., 224:403, 1930) demonstrated that caffeine produces a temporary improvement in muscular contractility, followed by a longer period of fatigue. Matthias, (München med. Wchnschr., 81:555, April 13, 1934), from observing the effect of coffee on subjects running 800 meters, concluded that coffee unnecessarily increases the work of the heart. However, his experiments are rather difficult to interpret. Herxheimer (Münch. med. Wochenschr., 69:1339, 1922) gave 0.25 grams of caffeine-sodium-benzoate to 46 subjects running a 100-meter race, and could observe no effect on performance. Cheney (Arch. Internat. de Pharmacodyn. et de Therapie, 42:173, 1932) showed that the beneficial effect of caffeine upon the muscles may be independent from its effect upon the central nervous system.

The bulk of evidence shows that caffeine does delay the onset of fatigue and increases work output. Yet the concensus of medical opinion is that the use of caffeine should be prohibited to athletes. It is futile, however, to attempt to prohibit the moderate use of coffee and tea by all, and yet one cup of coffee or tea may contain 1 1/2 - 3 grains of caffeine, the equivalent of one therapeutic dose. All of which leaves an insolvable dilemma.

LADELL, W. S. S.
The effects of water and salt intake upon the performance of men working in hot and humid environments.
Journal of Physiology 127:11-46, 1955.

Author's Summary:

The effects of drinking water or saline, of not drinking at all and of taking salt alone, on fully acclimatized men working in a hot and humid environment were investigated in a number of experiments; in some tests the amount of water drunk, and/or of salt taken, was equated to the amounts of these substances lost in the sweat; in others saline of fixed strength was given in varying amounts. Subjective effects were more marked than objective effects. The chances of failure to complete a given task in the heat increased with increasing water deficit. Fatigue, usually sudden in onset, was more pronounced when the water debt was high. Sweat rate tended to be lower in men drinking saline. Abstention from water had no effect on the sweat rate, until water debts of more than 2.5 liters had been incurred. In this respect sweat secretion behaves similarly to urine excretion and salivation during dehydration. Thermal equilibrium was established at a higher level in men who abstained from drinking than in those who did drink, and in those not taking salt than in those taking salt. The heart rate in recovery increased with rectal temperature less rapidly when the subjects were taking salt or saline, than when they were not drinking or drinking only water. In those taking salt the heart rates were faster at low rectal temperatures, and slower at high rectal temperatures, than in those taking water only. Exercise tolerance was better maintained by subjects when they drank water or saline than when they did not drink or took salt only. The chloride content of the sweat was higher when salt was taken. The changes in thermal equilibrium and in heart rates may be predicted from the changes in intracellular fluid volume (ΔI) which can themselves be predicted with reasonable accuracy from the water and salt losses using the equation given. Apparently contradictory responses to given conditions by different times, can be traced to variations in sweat rate and especially to differences in the sodium chloride losses in the sweat, which shift the water and salt balance in different ways. Further modifications of the response to heat may be the result of alterations in adreno-cortical activity or of changes in renal function.

LEE, D. H. K. and G. P. B. BOISSARD.
The effect of exercise in hot atmospheres upon the pulse rate.
Medical Journal Australia 2:664-668, 1940.

Authors' Purpose:

To investigate pulse rate responses to various levels of water replacement and exercise in hot-wet and hot-dry environments.

Subjects:

Seven healthy males between 18 and 45 years of age.

Three levels of water and saline administration were given: (a) none, (b) half replacement, and (c) full replacement.

Authors' Results:

Afternoon exercise gives rise to a greater heart rate than morning exercise, attributed partly to accumulated fatigue and also to eating lunch. Acclimatization with half water replacement had only a minor effect on the pulse rate reaction to exercise in the hot-wet atmosphere and a somewhat greater increase in nonacclimatized subjects in the hot-dry environment. During exercise full water replacement affords no definite improvement over half replacement. Half replacement gives some improvement over no water in the hot-wet and pronounced improvement in the hot-dry environment - an improvement that becomes proportionately greater as the day progresses. In marching, half replacement with saline gives some improvement in hot-wet atmospheres but appears to be a disadvantage in the hot-dry environment. In both environments a 2-hr delay in half fluid administration leads to increased pulse rates in all exercise and rest conditions. When saline was given the recovery is delayed or transient. Weight lifting tends to result in somewhat nigher pulse rates compared to marching in the hot-wet environment at all levels of fluid intake. In the hot-dry environment, weight lifting is less exacting than marching particularly when water is withheld. While there is no difference between the effects of the two atmospheres when ample water is given, the hot-dry atmosphere has some heightening of effect when only half quantities are given, especially with the longer periods of marching. When no water is given, the greater effect of the hot-dry atmosphere is very apparent. The administration of saline solution shows up the preponderant effect of the hot-dry atmosphere more than does the corresponding administration of water. There is a certain margin of reserve of body water than can be traded upon if necessary.

LEE, D. H. K., R. E. MURRAY, W. J. SIMMONDS and R. G. ATHERTON.
The effect of exercise in hot atmospheres upon the salt-water balance of human subjects.
Medical Journal Australia 2:249-258, 1941.

Purpose:

To investigate the effects of exercise and three levels of water and saline replacement in a hot-wet and a hot-dry environment on the salt-water balance.

Subjects:

Seven healthy males, 18 to 45 years of age. Three levels of water and saline replacement were given: (a) none, (b) half replacement, and (c) full replacement. Frequent administration was compared with the same total amount at longer intervals.

Results:

The rate of sweating was increased (a) by increasing the rate of water intake in the hot-dry environment from nil to ample, (b) by substitution of the hot-dry for the hot-wet environment, (c) by exercising, and (d) in the afternoon. The rate of sweating was decreased by drinking saline instead of water in the hot-dry environment. The rate of sweating was not appreciably affected by (a) acclimatization, or (b) the substitution of larger amounts of fluid given infrequently for smaller amounts of fluid given frequently. The Queensland subjects were probably long-term acclimatized to heat when the study began: their sweat chloride concentrations were rather low. The sweat chloride concentration was increased (a) by the substitution of the hot-dry for the hot-wet environment, and (b) in the afternoon. The sweat chloride concentration was decreased by (a) an increase in the rate of water administration, and (b) the drinking of saline rather than water in the hot-dry environment. The sweat chloride concentration was not affected by (a) acclimatization, (b) the frequency of fluid administration, or (c) the rate of sweating. Saline was more beneficial than water in the retention of body water. Frequent drinking of small amounts was more beneficial than infrequent drinking of large amounts, particularly in the hot-dry environment. Urine volume tended to be reduced with heat acclimatization. Urine chloride concentration and the rate of chloride loss were reduced by heat acclimatization, following saline administration, and when fluid administration was delayed.

LEITHEAD, C. S. and A. R. LIND.
Heat Stress and Heat Disorders.
Philadelphia: Davis, 1964. pp. 147-149.

Authors' Comments:

The earliest symptom of progressive or involuntary water-depletion heat exhaustion is thirst, and it is one with which the patient becomes obsessed. The tongue and mouth become dry, eating and swallowing are difficult, and appetite for solid food is lost. Thereafter there is increasing fatigue, weakness, and weight-loss, accompanied by a sense of discomfort and foreboding. At a time when it is often important to think clearly, some upset or dulling of the mental capacity is common, and judgment is impaired. In the late stages, tingling or other paraesthesiae develop in the extremities, restlessness and hysteria are common, and the patient experiences giddiness and incoordination of limb movements so that he finds it difficult to walk properly or even to stand. Finally, there is delirium, coma, and death. The survival time in water depletion depends almost entirely upon the surrounding temperatures and the amount of energy expended by the patient. For example, obligatory losses in a temperature climate are such that complete water-deprivation may not cause death until 7 to 10 days have elapsed; whereas, marching without water across a hot desert usually results in death within 48 hours and occasionally within 12 hours (p. 143).

Urine of small volume and high concentration is excreted from the outset, and in men accustomed to work in heat it is at first a more constant and reliable index of water depletion than is thirst. The lips, mouth, and tongue are dry, and the voice may be husky. There is often not much else which is significantly abnormal in the individual case, although in fact the increase in pulse rate and drop in pulse pressure when the patient stands up from a recumbent posture are both greater than average values obtained in fully hydrated subjects. As water depletion advances, however, the resting pulse rate becomes rapid, the body temperature is elevated, and subcutaneous dehydration develops. The rise in temperature may be sudden and pronounced, and there is no doubt that severe water-depletion heat exhaustion predisposes to heatstroke, and the two disorders often coexist. In the later stages the skin is inelastic, the cheeks hollow, and the eyes sunken; the tension of the eyeballs may in skilled hands be helpful in estimating the degree of water-depletion. Breathing is fast and laboured, and cyanosis appears. As a result of hyperventilation, tetany may occur. Hypotension and circulatory failure are accompanied by extreme oliguria or anuria, and the disorder terminates with a high temperature and as noted above with signs of severe cerebral dysfunction.

Marriott (1950) divided water depletion into three clinical grades, and with modifications relevant to water-depletion heat exhaustion, these are as follows:

(1) Early: A deficit of approximately 2% of body weight, equivalent in a 70-kg. man to 1.5 litres; associated usually with thirst as the only definite indication of water debt, but often without any symptoms in those accustomed to work in the heat.

(2) Moderately severe: A deficit of approximately 6% of body weight, equivalent in a 70-kg. man to 4.2 litres; associated with intense thirst, dryness of the mouth, scanty urine, rapid pulse, and an increase in rectal temperature of about 2°C. (3·5°F.) (Adolph, 1947).

(3) Very severe: A deficit of more than 7% of body weight, equivalent in a 70-kg. man to 5 to 10 litres; associated with all the above manifestations and in addition, marked impairment of mental and physical capacities. Cyanosis, circulatory failure, coma and death occur when the water debt amounts approximately to 15% of body weight or 20% of body water.

Voluntary water depletion is limited by the onset of thirst to a deficit of approximately 1 to 2% of body weight. It is symptomless and therefore cannot be described as a heat disorder. Some authorities indeed regard it as natural and therefore beneficial. Many observers have reported, however, that pulse rates and rectal temperatures increase as voluntary water depletion develops, and urine output is below what is usually considered to be a satisfactory amount. Of 137 24-hour urine volumes collected in summer months from a group of British servicemen in Bahrein, 48% were below 500 ml. and 10% were little more or less than 300 ml. (Leithead and Pallister, 1960). The same authors found that sweat rates fell progressively with body weights and reviewed the literature on this vexed question; the weight of the evidence favours the view that thermal sweating is diminished in water depletion. These measurable features of physiological disturbances suggest that voluntary water depletion, however symptomless, is potenitially harmful and undesirable; it is also difficult to believe that water-depleted men are wholly efficient at the work.

MACPHERSON, R. K. (Ed.)
Physiological Responses to Hot Environments.
Medical Research Council Special Report Series No. 298. London: Her Majesty's Stationery Office, 1960.

Author's Summary:

The ninth series of experiments at Singapore (Series IX) dealt with three topics: the effect of water intake on men working in the heat, the upper tolerable levels of warmth for acclimatized men in the tropics, and the incapacitation of men at rest in hot humid climates.

The experiments on water intake were performed during the artificial acclimatization of the subjects in which they were exposed to increasing degrees of heat stress in preparation for the investigation of the upper tolerable levels of warmth. The men were supplied with cool drinking water at the rate of 550, 700 or 850 ml per hour during exposure to hot conditions, and their sweat losses, body temperatures and pulse rates were observed.

The results showed that those receiving the greatest amount of water produced the greatest amount of sweat, and those receiving the least water, the least sweat. The effect became more marked with the passage of time. During the first hour there was no difference between the groups but during the second hour a difference became apparent and this became more marked during the third and fourth hours. A comparable effect on body temperature was observed -- those receiving the least water had the highest rectal temperatures and those receiving the most water had the lowest rectal temperatures. A similar, but less well marked, effect was observed on the pulse rate, those receiving the most water exhibiting the lowest pulse rates.

The results also showed that the amount of sweat secreted is in part dependent on the amount of water drunk, and emphasized the importance of the provision of adequate amounts of cool water for men exposed to heat.

In the third part of Series IX, in order to determine the lengths of time for which men at rest could tolerate very humid warm air and to ascertain whether drinking cool water might prolong endurance to such conditions, nine men were exposed to a series of climates with very high water-vapour pressures in which they sat at rest stripped to the waist. The air speed was 150 ft/min.

When the dry-bulb temperature was 99.4°F and the wet-bulb 99°F, the average length of endurance was 144 min. The first man retired at 79 min; the last man withstood the conditions for 240 min, and then was able to complete 10 min step-climbing.

When the dry-bulb was 130°F and the wet-bulb 105°F the average endurance time was 37 min (range 30-55 min). At the same dry-bulb but at wet bulb 100°F the average endurance was 55 min (range 34-129 min).

In the first and third experiments the endurance time of the subjects were closely related to the rise of their rectal temperatures. In the first experiment there was also a close relation between the rates at which they were able to drink cool water, their endurance times and the rate of rise of their rectal temperatures.

The main symptoms of approaching collapse and the changes observed in skin and rectal temperature are described. It was observed that serious impairment of judgement, reasoning and perception frequently preceded physical incapacitation, and it is stressed that adequate allowance must be made for this mental impairment when assessing the permissible levels of environmental warmth to which men may be exposed.

MOROFF, S. V. and D. E. BASS.
Effects of overhydration on man's physiological responses to work in the heat.
Journal of Applied Physiology 20:267-270, 1965.

Authors' Summary:

The question was asked whether men could work in the heat with less physiological strain if they drank water in excess of expected fluid losses than if they merely replaced their losses as they worked. Thirty volunteer soldiers walked on 2 successive days for 90 min at 3.5 mph on a level treadmill, at a temperature of 120/80 F dry bulb/wet bulb. Each man drank 2[illegible],00 ml water before the walk on one day and no water before the walk on the other; 1,200 ml were drunk during the walk on both days. Overhydration resulted in significantly lower rectal temperatures and pulse rates and significantly higher sweat rates than did the control state. Two matched groups of six men each were then acclimatized to heat by daily 100-min walks under the conditions described above. One group was overhydrated during each day of the acclimatizing period; the other was not. Overhydration did not affect the pattern of acclimatization to heat; conversely, acclimatization to heat did not alter the above-described acute response to overhydration. The hypothesis that overhydration is beneficial to men working in the heat was supported by this study.

PITTS, G. C., R. E. JOHNSON and F. C. CONSOLAZIO.
Work in the heat as affected by intake of water, salt and glucose.
American Journal of Physiology 142:253-259, 1944.

Authors' Summary:

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. Replacement of salt hour by hour under such circumstances has no demonstrable advantage. Administration of glucose is of little if any advantage when compared with the great benefit of large amounts of water. 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.

ROTHSTEIN, A., E. F. ADOLPH and J. H. WILLS.
Voluntary dehydration.
In: E. F. Adolph and Associates. Physiology of Man in the Desert.
New York: Interscience, 1947. pp. 254-270.

Authors' Summary:

Men in the desert tend to become dehydrated even when water is available. This phenomenon is called voluntary dehydration. Men voluntarily dehydrate between meals and make up their fluid deficits during meals.

The voluntary dehydrations measured under field conditions in men walking, in ground crews, tank crews, and flying personnel, often exceeded 2 per cent of the body weight and may go as high as 5 per cent. Such dehydrations are sufficient to limit the physical performances of the men.

Voluntary dehydration can be minimized if no meals are missed, if ample palatable water is available, and if sufficient leisure is provided during and between meals so that men can satisfy their thirst. Voluntary dehydration is greater when men are sweating rapidly, so that unnecessary activity should be eliminated when permissible.

Since under the most favorable circumstances men dehydrate voluntarily, they should be encouraged to drink more water than they want, especially during periods of prolonged activity.

At the termination of dehydration in either the laboratory hot room or the desert, men drink copiously for the first 15 or 20 minutes. During this time they replace their total loss of water, if that loss is not greater than about 2 per cent of their initial body weight. After the first 15 or 20 minutes of drinking, water ingestion proceeds more slowly than at first.

The greater the deficit of body water, the greater the length of time required for complete removal of that deficit. There may be adaptation to water lack, rendering voluntary dehydration more insidious as the day passes.

SALTIN, B.
Aerobic work capacity and circulation at exercise in man.
Acta Physiologica Scandinavica 62:Supp. 230, 1964. 52 pp.

Author's Summary:

A determination of the oxygen uptake during work on a bicycle ergometer exhausting the subject within two to eight minutes actually gives a measure of the individual's aerobic work capacity. The dye dilution technique and the acetylene method for the determination of cardiac output agree well at rest and during work up to maximal level and the reproducibility of the two methods was good. There was a minor rate of increase in cardiac output when oxygen uptake gradually approached maximum. There was a higher stroke volume during light exercise in upright work position than at rest, but at a work load heavier than 40% of the aerobic work capacity there was no further significant increase. A dehydration caused by a high environmental temperature (thermal dehydration) affected the plasma volume and the extracellular volume much more than if the same degree of dehydration was caused by severe exercise (exercise dehydration). After six to ten hours' skiing no significant reduction in red cell volume was found. At submaximal work in upright position there was after dehydration an exaggerated heart rate response which was more marked after exercise dehydration than after thermal dehydration. In both situations, the stroke volume was decreased as there were only minor changes in the cardiac output. Only after the thermal dehydration was the reduction in stroke volume correlated to the decrease in plasma volume. At maximal work in upright position there was after dehydration no change in either the central circulation or the aerobic work capacity compared with normalcy in spite of a body weight decrease of up to 5.5%. The work time on the maximal work load was definitively reduced after dehydration and most markedly after the exercise dehydration. As mechanical efficiency and aerobic work capacity were unchanged after dehydration, the reduction in work time was accompanied by a lower peak blood lactic acid concentration. Reduced aerobic work capacity may be excluded as an essential explanation for the gradual decrease in physical work capacity during dehydration. The results may be interpreted to indicate that the explanation should be sought at the cellular level.

SALTIN, B.
Aerobic and anaerobic work capacity after dehydration.
Journal of Applied Physiology 19:1114-1118, 1964.

Author's Abstract:

Ten subjects performed standard exercise tests at two submaximal loads and one maximal load before and 90 min after dehydration caused predominantly by 1) a thermal, 2) a metabolic, and 3) a combined thermal and metabolic heat load applied for 2.5-4 hr. Each subject interrupted dehydration so that almost the same decrease in body weight was attained in the three situations (1.7-4.6 kg). Oxygen uptake, heart rate, and concentration of blood lactate were measured during the exercise. At the submaximal loads there was no change in oxygen uptake after dehydration but the heart rates were significantly higher (mean difference 13 beats/min) and blood lactates were lower (from 0.5 after (1) to 1.6 (2) mmoles/liter). At the maximal load there were no significant changes in oxygen uptake and heart rate but work times decreased markedly (6-4 min) as did blood lactates (14.0-10.4 mmoles/liter) especially after exercise dehydration.

SALTIN, B.
Circulatory response to submaximal and maximal exercise after thermal dehydration.
Journal of Applied Physiology 19:1125-1132, 1964.

Author's Abstract:

Data on cardiac output and stroke volume are given for four subjects at various levels of muscular work up to the individual's maximum. No significant difference was found between the dye-dilution and the acetylene methods. Three subjects were studied under normal conditions and after dehydration (exposure to heat with a reduction in body weight of up to 5.2%); circulatory data were measured at rest and during exercise at two submaximal and one maximal work load. The decrease in body weight was accompanied by a reduction in plasma volume of up to 25%. After dehydration, the major change in the hemodynamic response to work in a sitting position at the submaximal loads was a decrease in stroke volume and an associated increase in heart rate, so that the cardiac output remained almost unaltered. Both these changes were significantly correlated to the reduction in body weight and plasma volume. When after dehydration the submaximal work load was performed in a supine position, no increase in heart rate was noticed compared with that before dehydration. Dehydration produced no significant change in oxygen uptake, cardiac output, or stroke volume during maximal exercise in a sitting position. However, the maximal work time was much shorter and there was a marked decrease in maximal blood lactate.

SALTIN, B. and J. STENBERG.
Circulatory response to prolonged severe exercise.
Journal of Applied Physiology 19:833-838, 1964.

Authors' Abstract:

Four subjects worked on a treadmill or a bicycle ergometer for 180 min at oxygen uptakes of 75% of the individual's max $\dot{V}_{O_2}$; after 90 min rest, the exercise was resumed and a maximal work load was tried. Repeated circulatory studies were made. The body weight decreased 3.1 kg (3.2-5.2%), but the reduction in blood volume was less than 5%. During submaximal exercise the major change in the hemodynamic response was a decrease in stroke volume (from 126 to 107 ml). Oxygen uptake and cardiac output increased slightly. There was a decrease of about 10% in systolic, diastolic, and mean arterial blood pressure during the 180 min of exercise. When the work was performed in a supine position there was the same reduction in the stroke volume as in the sitting work position. At the maximal work oxygen uptake, cardiac output, heart rate, and blood pressure attained almost normal values but there was a marked decrease in both work time and blood lactates.

TAYLOR, H. L., A. HENSCHEL, O. MICKELSEN and A. KEYS.
The effect of the sodium chloride intake on the work performance of man during exposure to dry heat and experimental heat exhaustion.
American Journal of Physiology 140:439-451, 1943.

Authors' Summary:

The effects of 3 levels of NaCl intake on cardiovascular functions were studied in 49 "normal" men in work and rest during exposure to hot dry conditions. The salt intakes were, in grams NaCl per 24 hours, 6 $\pm$ 2 ("low"), 15 $\pm$ 2 ("moderate") and 30 $\pm$ 2 ("high"). Day temperature was 120^{o}F. dry bulb, wet bulb of 85^{o}F., night 85^{o} to 95^{o}F. dry bulb, 65^{o} to 75^{o} wet bulb. Control studies were at 80^{o}F. dry, 65^{o}F. wet bulb. Diet, exercise and other conditions were rigidly standardized. Water was allowed ad lib. Periods in the heat ranged from 2 to 8 days each.

Pulse rates, rectal temperature, sweat composition and rate of sweating were studied in work and in rest. Blood ptosis tests were made. Sweat production ranged from 5 to 8 liters per day.

No advantage in any of the variables measured was demonstrated for men on a "high" daily intake of 30 grams NaCl as compared to the "moderate" (15 grams) intake.

Men maintained on a "low" (6 grams) intake of salt had higher pulse rates and rectal temperatures in work than men on a "moderate" salt intake. The deleterious effect of the "low" salt intake was also reflected in poorer postural cardiovascular adjustment. The men on the "low" salt intake lost more than twice as much body weight, drank less water and sweated less than the men on the "moderate" salt intake.

The "low" salt intake resulted in an average net deficit of 13 grams NaCl for 3 days in the heat. The men on the "moderate" salt intake appeared to be in NaCl balance after 3 days in the heat.

Heat exhaustion and prostration, characterized by nausea, vomiting, tachycardia, hypotension, vertigo, dehydration and collapse, occurred in 25 per cent of the men on the "low" salt intake and in only 2.5 per cent of the men on the "moderate" salt intake. Rest in the heat, food (with salt) and water sufficed to restore all these men so that they could continue work in the heat in 8 to 24 hours.

Although pronounced hypochloremia was observed in many instances heat cramps did not occur.

There was little or no relation between the concentration of chloride in the sweat and the rectal temperature.

It is concluded that heat exhaustion and ability to work in the heat are almost wholly dependent on cardiovascular function and that a moderate salt intake is more important to preserve this function than to prevent heat cramps. Hypochloremia is not the only factor in heat cramps.

It is further concluded that the NaCl requirements of unacclimatized men who are sweating 5 to 8 liters a day is not greater than 13 to 17 grams daily. An increase in salt intake above this level results in increased loss of salt and water in the urine with no apparent advantage.

van BEAUMONT, W. and J. E. GREENLEAF.
Effect of hyperhydration on working men at sea level and simulated altitude.
Federation Proceedings 30:427, 1971.

Authors' Abstract:

Overhydrated men working in the heat have lower heart rates and rectal temperatures than normohydrated men. (Moroff and Bass, J. Appl. Physiol, 20:267, 1965). Few additional data on the influence of hyperhydration on work performance are available. In the present series of experiments, 3 men worked at 32%, 64% and 100% of max. VO_2 at sea level and simulated altitude. When the men were kept hyperhydrated with a water load equal to 2% of their body weight, oxygen consumption, ventilation and respiratory rates were similar at all work levels and atmospheric pressure compared to normohydration. Hyperhydration reduced the heart rates during submaximal work at 3000 meters. During diuresis at sea level and altitude, urine flow was not reduced during work of 32% max. VO_2. During work rates of 64% max. VO_2 urine flow was progressively reduced, in spite of expanded blood volumes and normal plasma osmolarities. Apparently, exercise greater than 35% max. VO_2 has a direct effect on the renal fluid retention mechanism.

WEISS, B. and V. C. LATIES.
Enhancement of human performance by caffeine and the amphetamines.
Pharmacological Reviews 14:1-36, 1962.

Authors' Concluding Remarks:

The foregoing evidence indicates that a very wide range of behavior can be enhanced by caffeine and the amphetamines - all the way from putting the shot to monitoring a clock face. Moreover, the superiority of the amphetamines over caffeine is unquestionable.

Two questions are implicit in these conclusions. (1) How do these drugs enhance performance; can they actually produce superior performance or do they merely restore performance degraded by fatigue, boredom, and so on? (2) What is the "cost" of obtaining this enhancement; is it great enough to prohibit the practical use of these agents, particularly the amphetamines?

Davis (Brit. Med. Bull. 5:43, 1947), who studied amphetamines, and Barmack (J. Psychol. 5:125, 1938; J. Exp. Psychol. 25:494, 1939; J. Exp. Psychol. 27:690, 1940) who studied both amphetamine and caffeine, are among those who claim that these agents produce their effects not by an increase in capacity, but by making people more interested in the task, or as Barmack (J. Psychol. 5:125, 1938) states, because their effect is to allay the development of unfavorable attitudes toward the task. Davis' evidence is unconvincing, but Barmack supports his argument with data. One of his most cogent findings in this regard was the lack of effect of caffeine on subjects who had just started working versus its effects on subjects who had been working for 2 hours. Also, he found with amphetamines that the greatest differences between active drug and placebo (on adding 6-place numbers) occurred toward the end of the work-period and paralleled reports of boredom, irritation and inattention by the control subjects.

To support this contention we also have the data of Kornetsky et al., (J. Pharmacol. 127:46, 1959), who found that d-amphetamine affected performance only in subjects suffering from prolonged sleep-loss. Furthermore, Hauty and Payne (In: Vistas in Astronautics, ed. by M. Alpern and M. Stern, pp. 304, Pergamon Press, New York, 1958) showed that in highly motivated subjects, d-amphetamine did not produce the same superiority in performance relative to placebo that it produced in subjects who typically showed early decrement in performance. Finally, Mackworth's (Med. Res. Council, Special Rpt. Series No. 268, H. M. Stationery Off., London, 1959) results showed only a restoration by amphetamine to normal performance on a vigilance task, and no enhancement. Moreover, a number of experiments have failed to show any effects at all in non-fatigued subjects.

Opposing these data and their interpretation, however, are arrayed data at least equally convincing. Among the most cogent are those of Smith and Beecher (J. Am. Med. Assoc. 170:542, 1959) on athletic performance. Smith and Beecher (experiment 5) found that amphetamine significantly decreased the time to swim an event, even in college swimmers so highly motivated that they often exceeded, even with placebo, the best times that they had made in intercollegiate competition. Smith and Beecher also found (experiment 1) that the effects of amphetamine were more apparent in rested than in fatigued subjects. Furthermore, shot-putting and weight-throwing displayed the greatest proportionate modifications by the drug. It is difficult to see how fatigue, lack of interest, or boredom could be significant factors in such an acute expenditure of effort.

Some findings of the Randolph Field investigators also support the notion that drugs can have effects above and beyond a mere restoration of previously impaired performance. Their data frequently showed a sizeable increase in proficiency after the administration of d-amphetamine relative to the highest score achieved during the pre-drug period (J. Exp. Psychol. 49:60, 1955; J. Pharmacol. 119:385, 1957; J. Exp. Psychol. 47:267, 1954; J. Pharmacol. 115:480, 1955). Even though this increased proficiency may not be statistically significant when the studies are evaluated individually, the consistency of this finding suggests that the effect is a real one. Another consistent finding of these investigators is a difference in the kind of improvement produced by psychological and pharmacological variables; only drugs were able to forestall the decline in proficiency with time. Other investigators who have found performance improved beyond the control level in non-fatigued subjects include, Adler et al. (J. Aviat. Med. 21:221, 1950), Lehmann and Csank (J. Clin. Psychopath. 18:222, 1957), and Eysenck et al. (J. Ment. Sci. 103:645, 1957). The results of Adler et al. are particularly noteworthy. In their experiments, d-amphetamine not only restored to normal some kinds of performance degraded by exposure to a simulated altitude of 18,000 feet, but brought other kinds to levels better than that seen at ground level. And the two studies by Hauty et al. (J. Pharmacol. 119:385, 1957; J. Comp. Physiol. Psychol. 50:647, 1957) conclusively demonstrated on a monitoring task that d-amphetamine could prevent proficiency decline even with the added challenge of inadequate oxygen. Payne et al. (J. Comp. Physiol. Psychol. 50:146, 1957) also offered data that contradict Barmack's finding (J. Psychol. 5:125, 1938) that the difference between amphetamine and placebo is exaggerated toward the end of a long work period. They found an equivalent effect of a particular dose no matter when during the period it was given.

Actually, neither Barmack's data nor those of the other investigators who hold similar views can justify their position that drugs that enhance performance do so only by inducing favorable attitudes. It is quite likely that drugs such as the amphetamines produce at least two independent effects - performance changes and attitude changes. The fact that these parallel one another does not necessarily confirm a deterministic relationship; nor does it make it unnecessary to show that attitudinal variance can account for performance variance. Indeed, in the only investigations to take this crucial step, the subjective data argued against the hypothesis that the amphetamines improve performance merely by inducing favorable attitudes toward the task. Payne and Hauty (J. Exp. Psychol. 47:267, 1954) found that favorable dispositions toward tasks which arose from special instructions were not reflected in performance. They also demonstrated that very significant variation in drug response occurred independently of attitude variation. Pearson (USAF Rpt. 57-77, April 1957) obtained similar results; he could demonstrate no more than a very slight correlation between fatigue ratings and performance decrement. One can point to even more dramatic disparities; for instance, although alcohol may increase confidence in the ability to drive an automobile, we have every reason to doubt that this parallels an increased ability to perform the task.

The associated claim that only performance degraded by fatigue and similar states can be helped by drugs also suffers from a logical defect. Obviously, if one is working just below a task ceiling, the effect of an agent is more difficult to detect than if performance is well below that ceiling. One should not confuse ease of detection with mechanism of action.

There are strong indications, therefore, that the amphetamines, and perhaps caffeine as well, can do more than merely restore performance degraded by factors such as muscular fatigue, sleep deprivation, and boredom.

The evidence for answering the second question - is there a cost to the enhancement obtained? - is mostly negative. Both from the standpoint of physiological and psychological cost, amphetamines and caffeine are rather benign agents. Except for reports of insomnia, the subjective effects of the amphetamines in normal doses are usually favorable. Moreover, no one has ever presented convincing evidence that they impair judgment. Caffeine seems somewhat less benign. Hollingworth's (Arch. Psychol., N.Y. 3, No. 22, 1, 1912) subjects, after doses of about 240 mg and above, reported such symptoms as nervousness, feverishness, irritability, headache, and disturbed sleep. Caffeine also produces a significant increase in tremor. At dose levels that clearly enhance performance, the amphetamines seem not only more effective than caffeine, but less costly in terms of side-effects.

These statements refer only to the acute effects of caffeine and the amphetamines. Are additional costs incurred when these drugs are taken chronically to enhance performance? Do they lead to addiction? There appears to be no experimental evidence from which to answer this question. The clinical reports show that occasional individuals, usually persons with neurotic or psychotic symptoms, habitually take extremely high doses.

However, there is no evidence of physical dependence; abrupt cessation of the drug produces hardly any effect, apart, perhaps, from a transient somnolence (Amer. J. Med. 14:558, 1953; J. Nerv. Ment. Dis. 115:406, 1952; Psychiat. Neurol., Basel 135:227, 1958). Caffeine also does not produce physical dependence. Withdrawal in habitual coffee drinkers seems mainly to lead to an increased incidence of headaches for a day or two (In: Problems of Addiction and Habituation, ed. by P. H. Hoch and J. Zubin, PP. 37-48, Grune and Stratton, New York, 1958). Some degree of tolerance develops to both; neither is addicting in the sense that narcotics are. In view of the wide use enjoyed by these drugs, the incidence even of habituation, so far as one can tell from the literature, is quite low. [The sociological aspects of the use of these drugs, particularly the amphetamines, are discussed by Leake (The Amphetamines, Charles C. Thomas, Springfield, Ill., 1958)].

A final word is in order about our present state of knowledge. Strikingly few attempts have been made to determine the basic parameters of drug action and performance. Such work is essential if we are ever to develop broad principles. What little we have learned has had to be inferred from work rarely designed to yield unambiguous answers. The question of whether the effects of amphetamine are dependent upon the amount of degradation of performance existing at the time the drug is taken has been discussed above. Few other broad questions have stimulated even this amount of work. A few examples should suffice to make the point. (a) We suspect that amphetamine affects coordination and tracking tasks differentially depending upon the complexity of the task used (Sect. III). But task complexity has rarely been made the subject of explicit study. (b) Work with lower animals suggests that the effects of the amphetamines on response rate are in part dependent upon the rate at which the subject is responding when given the drug (Fed. Proc. 17:1024, 1958); almost no systematic work on human performance has been done (J. Exp. Anal. Beh. 1:359, 1958). (c) There is a hint that the mood changes due to any drug depend upon the environment of the subject; more specifically, there is some evidence that amphetamine leads to more profound changes when the subject is surrounded by others also on the drug. Little has been done to determine the variables operating here (J. Physiol. 106:42, 1947; Ann. N.Y. Acad. Sci. 65:345, 1956). (d) We have no information on whether tolerance develops to the effects of these drugs on performance as it does, say, to the anorexigenic effects of the amphetamines. It is clear that the notion of drug-behavior interaction, which is proving so important in behavioral pharmacology (Ann. N.Y. Acad. Sci. 65:282, 1956), should be applied more frequently to work on the human level.