EFFECTS OF HYPOHYDRATION ON WORK PERFORMANCE AND TOLERANCE TO $+G_z$ ACCELERATION IN MAN

J. E. Greenleaf, Ph.D., M. Matter, Jr., M.D., J. S. Bosco,* Ph.D., L. G. Douglas, B.S., and E. G. Averkin, M.A.

ABSTRACT

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Nine men were water depleted up to 6.9% of their body weight during controlled 5-day dietary periods and then subjected to various physical performance tests, including grayout tolerance while undergoing $+G_z$ - 3.0G/min. acceleration, to define set points (the % hypohydration where functional deterioration begins). Hypohydration refers to the primary water-loss type of dehydration. The following set points were observed: total body reaction time - 0 to 1%; isometric muscular strength - greater than 4%; Harvard step test - 4 to 4.5%; submaximal O_2 intake - greater than 4%; and $+G_z$ - 3.0G/min. centrifugation - greater than 4%. 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.

National Aeronautics and Space Administration, Life Sciences Division, Ames Research Center, Moffett Field, California.

*Associate Professor of Physical Education, San Jose State College, San Jose, California.

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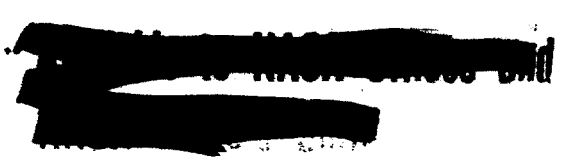
INTRODUCTION

At the completion of orbital missions,[20,25,26,27] where astronauts were exposed to a variety of environmental stresses including acceleration, heat, isolation, and weightlessness, they were all in weight deficit: Glenn 3.1% (156 g/hr), Carpenter 3.9% (180 g/hr), Schirra 3.1% (132 g/hr), and Cooper 5.3% (102 g/hr). The bulk of the weight loss was assumed to be water. It was very likely that they also experienced voluntary dehydration; that is, a delay in complete rehydration following water loss with water available ad libitum due, presumably, to inhibition of the normal stimuli for drinking caused by exogenous and endogenous stress.[14]

In studies on voluntary dehydration it has been postulated that there is a range of body water plus or minus some arbitrary set point within which functional deterioration does not occur.[14] This set-point hypothesis has been inferred by others.[1,8,13,15,17,21] Furthermore, some water deficit might be beneficial when man is exposed to a stressful environment in which he must perform.[14,15] Since it has been observed that the water content of the body is inversely related to the rectal temperature,[8,28] it was postulated that a 2 to 3% (of body wt) dehydration might be beneficial for physical performance by augmenting the "warm-up effect."[8] On the other hand, numerous studies suggest that any amount of dehydration is deleterious.[3,5,7,9,29]

In 1961 Webb[37] commented that work needed to be done concerning the influence of dehydration on grayout tolerance during centrifugation. The only other published study on this problem indicated a decreased tolerance to $+G_z$ - 18G/min. acceleration in subjects acutely dehydrated in the heat about 1 to 3% of their body weight.[36] Similar decreases following dehydration were observed in our laboratory (unpublished observations).



Some of the factors that might influence the set point are: 1) the degree of acclimatization to heat, 2) the degree of acclimatization to physical exertion (level of physical fitness), and 3) the rate of incurrence of the water debt - this would be closely associated with the environmental temperatures, pressures, and the water-intake regimen. It is very possible that different stresses or combinations of stresses would have different set points and ranges.

Some confusion exists in the literature regarding the meaning of the word dehydration. It is often used to mean a depletion of body water with no reference to the changes in osmotic substance. Whenever water is lost from the body by sweating, micturition, or through the gastrointestinal system, osmotic substance is lost simultaneously (insensible water and water vapor in exhaled air are probably pure water). Since body water and osmotic substance are closely interrelated, both must be considered as a unit. For that reason, three types of dehydration have been recognized: 1) dehydration caused by primary loss of water, 2) dehydration that is secondary to the loss of salt, and 3) a combination of the two above.[4,22] More recently the term hypohydration has been suggested in place of primary loss dehydration (R. E. Johnson - personal communication).

In this investigation, the effects of chronic hypohydration on the responses to various tests of bodily functions were studied in an attempt 1) to define some set points and ranges, and 2) to elucidate some of the possible mechanisms involved in changes in work performance.

PROCEDURE AND METHODS

Nine healthy male college students (ages 21 to 29) were used as subjects. Table 1 Anthropometric and physiologic baseline data on them are presented in Table I.

The study was divided into three experiments during three consecutive weeks. Each experiment consisted of a 5-day controlled dietary period and programmed water intake, during which time the subjects proceeded with their normal activities. The sixth day was devoted to various physical and psychomotor testing plus centrifugation (Table II). The results of the psychomotor tests will be reported elsewhere. The programmed water intake during the 5-day dietary periods was: week 1 - 1500 ml./day, week 2 - ad libitum, and week 3 - 900 ml./day.

Table 2

The subjects reported to the laboratory the evening of day 5 and slept there overnight. Two subjects were tested each day. On the morning of the test day (day 6) the subjects ate about 1/3 of their daily allotment of Sustagen, 1 g of NaCl, and 200 ml. of water. No more food or water was allowed until the end of the tests on day 6. Regardless of the water-intake regimen, the results were compared on the basis of the change in body weight between day 1 and day 6 just before centrifugation. Nude body weight was measured each morning before breakfast on a balance accurate to ±5 g after the subject emptied his bladder. In some subjects there was a greater loss of weight during week 1 - 1500 ml. H_2O/day [mean daily high (MDH) = 27.2 C, mean daily low (MDL) = 8.9 C] than during week 3 - 900 ml./day (MDH = 20.0 C, MDL = 10.0 C) due, in part, to the warmer weather. The tests were conducted in October and November 1964 and it was unlikely that the subjects were acclimatized to heat. The average daily high temperature for the entire 3-week period was 23.3 C, and the average low was 10.0 C (range 6.1 to 31.1 C). The subjects were given sufficient practice in taking the various tests to assure us that very little additional learning would occur thereafter.

Biochemical Analyses: Venous blood and urine specimens were collected before and after the battery of physical tests and before and following centrifugation

(Table II). Evans blue space (plasma volume) was measured just prior to centrifugation, utilizing one 10-min., post-dye blood sample.[24] A correction factor of 0.96 was used for trapped plasma in the capillary micro-hematocrit determinations using venous blood.[19] The following additional measurements were made: urinary and serum Cl,[11] urinary and serum Na and K (Baird flame-photometer Model KY-2), urinary and serum total osmolarity (Fiske osmometer - Mark III), urinary and serum endogenous creatinine,[6] and serum glucose using glucose oxidase.[35]

Table 3

Diet: The weight-sustaining controlled diet (Table III) was composed of Sustagen (Mead-Johnson), saltine crackers (Premium), oleomargarine (Blue Bonnet), and either bouillon cubes (Wylers) or an equivalent amount of enteric coated NaCl pills (Lilly). Subjects EG, JL, AM, and SR consumed the 2900 kcal diet, and RW, FK, JC, DM, and DR the 2500 kcal diet.

Physical tests: The tests performed were: 1) tilt table, 2) isometric muscular strength, 3) modified Harvard step test, 4) total body reaction time, and 5) submaximal O_2 intake, in that sequence. The results of the tilt table tests will be reported elsewhere.

Isometric muscular strength was measured with dynamometers following the method of Mathews.[18] Total strength was the sum of the right-hand, left-hand, back, and leg strengths.

The modified Harvard step test utilized a 43-cm (18 in.) bench and the index was calculated according to the following formula:[16]

$$\text{PFI} = \frac{\text{duration of exercise in seconds} \times 100}{2 \times \text{sum of recovery pulse counts from 1 to 1-1/2, 2 to 2-1/2, and 4 to 4-1/2 min.}}$$

Total body-reaction time was measured by having the subjects jump off a platform in response to a light only, a buzzer only, and the light and buzzer presented simultaneously (combined). The platform was positioned about 2 m from the light and buzzer. Five trials were taken for each stimulus and the average times used in the calculations.

The subjects ran on a motor-driven treadmill (11.3 km/hr, 7% grade) for 3 min. with no warm-up other than that given by the previous four tests. The Tissot tank was flushed during the first 2 min. and exhaled air was collected during the third min. This effort represented 2/3 to 3/4 maximum O_2 intake. Oxygen and CO_2 percentages in the exhaled air were analyzed on a Beckman Model E2 and a Beckman Model LB-1, respectively.

Centrifuge: The centrifuge employed was the Ames Research Center's five-degree-of-freedom motion simulator.[12] The single-place cab, supported inside a gimbal structure that allowed three degrees of freedom plus vertical translation, was mounted on a centrifuge with a 30-ft radius. The subjects were seated in a standard aircraft seat and restrained with a lap and chest harness. The helmet was secured so the subject's head would not be displaced. The roll of the cab was controlled by electronic computers so the line of force would be maintained parallel to the long axis of the body.

Measurements taken during the centrifugation included the EKG, blood pressure, and O_2 saturation utilizing an ear oximeter. The subject's face was observed on a closed-circuit TV monitor. An intercommunication system was also used.

On the test day each subject had 3 runs at an acceleration of 3.0G/min. with 1 to 1-1/2 min. rest between each run. A run was the period of time from a standing start to grayout. Sphygmomanometric blood pressures were measured

automatically during the rest periods. At the end of each run the cab stopped with the subject on his right side. The cab was rolled back slowly to prevent nausea, etc. None of the subjects became ill during or after the centrifugation. Prior to the start of the experiments each subject had had at least 8 runs for practice and orientation, and was instructed to ride passively without counter-muscular effort. Each subject had about 5 min. to become accustomed to the dark in the cab before starting an experiment.

Grayout was the end point of each run. Lights of three luminances, approximately 1.03, 0.39, and 0.30μ lamberts, were presented to the subjects, beginning with the lowest intensity. The lights were positioned directly in front of the subject's eyes and the duration of each light flash was about 1 to 2 sec. The subjects were instructed to depress a turn-off switch whenever they saw a light flash. Failure to turn off a light would cause the light of the next highest intensity to come on. The run was stopped by the medical monitor when the subject failed to turn off the highest intensity light. The luminance of the latter was adjusted so grayout would occur at about 5G.

Statistical procedures: The subjects were grouped according to loss in body weight. Group 1.3% consisted of 9 subjects, range 0 to 1.69%; group 2.3% - 10 subjects, range 1.70 to 2.99%; and group 4.3% - 8 subjects, range 3.00 to 6.90%. The 1.3, 2.3, and 4.3% were the means for the three groups. Each subject was tested three times.

The dependent variables were adjusted according to the percentage of body-weight loss by means of the following formula:

$$Y_{ij} = \mu + \alpha_i + \beta X_{ij}$$

i = groups 1, 2, 3

$j = 1, 2, \ldots, n_i$; where

n_i = number of observations in the ith group

where Y_{ij} is the jth observation in the ith group of the variable under consideration; X_{ij} is the jth observation in the ith group of the amount (%) of body-weight loss; μ is the over-all mean of the dependent variable; α_i is the specific response of the dependent variable in the ith group; and β is the correlation coefficient between weight loss and the dependent variable under study.

No statistical tests of significance were performed, since some individuals were included twice in the same group, thereby giving a biased error estimate for testing group means. Tables IV and VI give the unadjusted means ($\bar{X}$), the adjusted means ($\bar{X}_a$), and the standard error (SE) of the adjusted means for selected metabolic variables under study.

RESULTS AND DISCUSSION

Physical performance tests: Total body reaction times - sound, light, and combined - all progressively decreased with increasing hypohydration (Fig. 1). Average values for each variable were used in all the tables and figures.

Fig. 1

The step-test PFI (Fig. 1) increased slightly with increasing hypohydration, a higher score indicative of better performance. Since all the subjects were able to complete the 5 minutes of stepping, the increase in the mean PFI was a reflection of lower pulse rates at the end of the exercise and/or a greater drop in the pulse rates during the 4-1/2 min. recovery period. The effect of water loss on the pulse rate during exercise is variable, depending upon the test conditions. Slightly lower pulse rates have been observed in one man walking in moist heat and drinking water ad libitum rather than drinking water equal to his weight (sweat) loss.[23] On the other hand, Rothstein and Towbin[28] concluded that dehydration alone accelerated the pulse rates of working subjects. However, in the latter studies there was no significant increase in the working pulse rates

(190 kg - m/min. at 49 C) in hydrated subjects drinking water ad libitum versus dehydrated subjects drinking no water until a weight deficit of about 4% was attained. Thus it appears that a 3 to 4% body-weight (BWt) loss does not always influence the pulse rates of subjects working in the heat. Our data on men working in a cool environment support this observation. Also, a reduction of 10.6% in total blood volume (TBV) and 5.8% red cell volume (RCV)(Table V) was associated with the slightly increased PFI. The set point for pulse-rate deterioration in water-depleted subjects seems to be about 4% of total body weight.

Table 5

Isometric muscular strength increased slightly with increasing hypohydration (Fig. 1). It must be kept in mind that these various strength measures were taken during a very short period of time - the time necessary for one maximal contraction of the particular muscle group. During the step test the subjects commented that their leg muscles were progressively more fatigued with increasing hypohydration. While muscular strength was not affected in the 0 to 4% weight-depletion range, it is very likely that muscular endurance would be adversely affected. Saltin[30] observed that work times at maximal exercise decreased significantly after dehydration. Further, a very slight increase in maximal isometric strength (elbow flexion and knee extension) occurred in subjects dehydrated approximately 3.8% in a sauna bath (80 C) and 3.6 to 4.0% by exercise.[30] It may be concluded that maximal isometric muscular strength was not affected in the 0 to 4% range of hypohydration.

Submaximal O_2 consumption (Fig. 1) was not significantly changed with increasing hypohydration. However, the RQ in group 4.3% was significantly higher when compared with group 1.3%. Saltin[31] observed no change in submaximal O_2 intakes in subjects previously dehydrated (3.5%) at 80 C who sustained a 10 to 20% decrease in their plasma volume.

Table 4

Exercise serum and urine variables: In general, the pre- and post-exercise serum and urine variables (Table IV) reflected the effects of water depletion. Small variations in the individual serum ions were noted but the serum osmolarity increased 2 to 3 mOsm/l in group 4.3% compared to group 1.3%. The post-exercise osmolarity increased about 4 to 5 mOsm/l. Both exercise and water depletion contributed to the diminution of urinary excretion. Creatinine clearances were reduced about half during the exercise period. Post-exercise urinary creatinine appeared to be highly dependent upon body weight; while the raw mean values were sufficiently different, the adjusted mean values were essentially equal. The urine osmolarity was highest in group 4.3% coinciding with greater water depletion and the urinary Na, K, and Cl, and the urine/serum osmotic ratio also reflected this change. The exercise reduced the urinary osmolarity and the urinary ion concentrations as well. This reduction was not influenced by the degree of hypohydration.

Blood volume: The plasma volume (PV) sustained the greater part of the water loss from the blood (Table 5). Compared with group 1.3%, PV decreased 3.3 and 13.8% in groups 2.3 and 4.3%, respectively. The corresponding RCV changed +0.6% and -5.8%, respectively. The TBV was essentially unchanged in group 2.3% (-1.7%), but was reduced 10.6% in group 4.3% when compared with group 1.3%. It appeared that PV and TBV changes were not proportional to BWt loss (Table V). They both remained essentially constant to about 3% BWt loss and then decreased in group 4.3%.

The relationship between PV loss and BWt loss is determined, in part, by the net effect of water and osmotic intake and outgo, both of which are influenced by the environmental conditions and work load. The PV increased 11% while the BWt decreased 5.5% in participants in an 85-km. cross-country ski race.[2] On the other hand, Saltin and Stenberg[32] observed a decrease in the TBV of less than 5%

associated with a 3 to 5% BWt loss in men exercising at 24 C. Conversely, the PV decreased up to 25% in men dehydrated 3.5% BWt in a sauna bath (80 C).[31] Thus, there seems to be no consistent relationship between PV, TBV, and BWt loss. The critical factors appear to be the rate of water loss and the ensuing lag in restoring the lost water into the circulatory system.

Centrifugation tolerance: Grayout tolerance during the three runs was not affected appreciably from 0 to 4.3% hypohydration (Fig. 2). A slight decrease in tolerance may be observed in group 4.3% during run 3, but this point is most likely not the set point because the terminal pulse rates decreased slightly during successive runs which would not indicate deterioration. The set point for centrifugation tolerance would be greater than 4.3% hypohydration an acceleration of 3.0G/min.

Fig. 2

Centrifugation serum and urine variables: In contrast to the exercise results, centrifugation increased the urinary osmolarity, Na, K, Cl, and the urine/serum osmotic ratio (Table VI). The post-centrifugation urinary volumes were also increased, even though the subjects were water depleted. Stauffer and Errebo-Knudsen[34] found an increase in urinary specific gravity and a signficant reduction in urinary output following centrifugation in water loaded subjects. In general, increasing the load on the cardiovascular system usually causes a decrease in urinary output. Serum glucose increased following centrifugation in all three groups; 8.4, 6.8, and 13.3 mg/100 ml. in groups 1.3, 2.3, and 4.3%, respectively. This was an apparent increase due to fluid leaving the circulatory system because the hematocrit/glucose ratio remained essentially constant (range 0.52 to 0.50). The hematocrit increased 2 to 3 vol.% following centrifugation. The latter observation was consistent with Clark et al.[10] who observed that fluid shifted from the blood to tissues during the short-term $\pm G_z$ accelerations.

Table 6

SUMMARY AND CONCLUSIONS

There were no significant changes in maximal isometric strength, total body reaction time, the Harvard step test, submaximal O_2 intake, and tolerance to $+G_z$ - 3.0G/min. acceleration from 0 to 4% hypohydration. Concomitantly, a comparison of pre- versus post-exposure indicated that most of the various blood and urine variables were essentially unchanged as a result of the exercise and centrifugation. The only significant change in the physical test measurements was an increase in the RQ in group 4.3% during submaximal O_2 intake. This increase was associated with a 10.6% decrease in total blood volume. It would seem that group 4.3% was near the set point in submaximal O_2 consumption. The term "set point" refers to the level of hypohydration where deterioration begins.

Total body reaction time appeared to decrease progressively with increasing hypohydration. Thus its set point would be about 1.3%. The set points for isometric muscular strength and the step test were both greater than 4.3%; the set point for submaximal O_2 intake appeared to be about 4.3% when the rise in RQ in group 4.3% is considered.

Other factors in addition to acclimatization to physical exertion that must be considered when set points are discussed are: degree of acclimatization to the particular environment (heat, cold, altitude, etc.), the rate of incurrence of the water debt (see introduction), and the type of test or measure used to assess deterioration. It is suggested that deterioration measured by rather gross tests of bodily functions that can be accomplished quickly (e.g., isometric strength) would not be influenced as much by water depletion as tests that require a longer duration and rely more on the integrity of the circulatory

system (e.g., step test and O_2 intake). Acceleration tolerance as used in this experiment fulfills both of the above criteria; however, no significant deterioration was apparent up to 4.3% hypohydration after three runs. It is likely that greater fatigue would have been observed had a larger number of successive runs been employed.

Group 4.3% sustained a 13.8% decrease in Evans blue space and a 10.6% decrease in total blood volume without much deterioration in performance. It seems that there is a reservoir of extracellular fluid that can be drawn upon without compromising performance.

Ladell[17] has stated that " a man can lose 5% of his body weight when thirsting without showing gross physiological changes." Our blood, urine, and test results would essentially agree with that statement. Further, and more important, he suggested the concept of "free circulating water" (FCW). That is, the body has a reservoir of water (about 2 liters or 2-3% BWt) over and above its critical needs that can be drawn upon in time of need. Thus, bodily functions could continue unimpaired until the store of FCW was used up. It is likely that the free circulating water comprises part of the extracellular fluid compartment.

Part of the mechanism for the increase in physical performances in well-trained athletes might be due to an increase in their FCW since they consistently have greater blood volumes than comparable sedentary people.[33] It should be remembered that our subjects were in a higher state of acclimatization to physical exertion than the general population and therefore may be compared with our physically conditioned astronauts. This level of physical conditioning would most likely raise the set points for the various tests (i.e., if our group of subjects began to deteriorate at 4% hypohydration, a group of average subjects might begin to decline at 3%).

Some of the confusion regarding the effect of dehydration on performance, as suggested in the introduction could be explained, in part, by the FCW concept. Most of the studies on performance in the heat indicated that any amount of dehydration was deleterious (set point 0-1%) while those studies conducted in cooler environments suggested set points from 3 to 5% body weight loss. The FCW could be reduced or eliminated very quickly if dehydration were induced by heat and/or exercise, and the ensuing performance would then immediately begin to decline. There is always the possibility that part of the performance decrements caused by heat dehydration could be attributed to the heat per se. The same argument would apply to exercise dehydration. On the other hand, hypohydration induced by water deprivation over periods of 3 to 4 days might not deplete the FCW enough to diminish performance.

It is recognized that many interrelated physiological and psychological mechanisms are involved in the phenomenon of the determination of work capacity or performance. The use here of the free circulating water concept is suggested not only as one possible explanation for the relationship between water depletion and performance but also to provide a framework to help unify the apparent diversity of information regarding the effects of water depletion on bodily deterioration and work performance.

Since there were essentially no decrements in the various tests utilized here in the 0 to 4% range of hypohydration, it may be concluded that performances by physically well-conditioned subjects would most likely not be adversely affected if the water depletion were incurred rather slowly (4 to 5 days). However, short-term dehydrations induced by heat and/or exercise are usually associated

with decrements in physical performance and grayout tolerance. The key factor in the determination of the relationship between water depletion and performance appears to be primarily the rate at which water is lost and secondarily, the level of dehydration attained.

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TABLE I. ANTHROPOLOGIC AND PHYSIOLOGIC BASELINE DATA ON THE SUBJECTS

SUBJECT	AGE yr	HT cm	WT kg	SA m^2	PFI	TOTAL STRENGTH UNITS	PV liters
FK	29	176	75.0	1.90	85	1671	3.66
JC	22	178	69.3	1.86	85	1962	2.75
AM	26	173	79.9	1.94	87	1471	3.15
EG	22	164	53.6	1.56	152	1193	3.02
JL	22	161	59.2	1.60	97	1019	2.90
SR	21	186	69.3	1.92	85	1853	4.00
DM	22	182	85.8	2.08	75	1626	3.39
RW	22	171	72.9	1.83	91	1948	3.47
DR	22	182	76.9	2.00	81	1516	3.58

PFI = PHYSICAL FITNESS INDEX
PV = EVANS BLUE SPACE

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TABLE II. TYPICAL EXPERIMENTAL PROTOCOL

TIME	PROCEDURE
5 DAYS	CONTROLLED DIET
0700	BLOOD-URINE-WT (PRE-EXERCISE) BREAKFAST PSYCHOMOTOR TEST
0900	TILT TABLE TEST STEP TEST STRENGTH TEST REACTION TIME TEST SUBMAXIMAL O_2 INTAKE TEST
1000	BLOOD-URINE-WT (POST-EXERCISE) PSYCHOMOTOR TEST
1130	URINE (PRE-CENTRIFUGE) REST
1200	EVANS BLUE SPACE (PRE-CENTRIFUGE) CENTRIFUGATION HOOK-UP
1330	CENTRIFUGE RIDE BLOOD-URINE (POST-CENTRIFUGE)
1430	PSYCHOMOTOR TEST

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TABLE III. DIET COMPOSITION

Kcal	PROTEIN gm	CHO gm	FAT gm	Na gm	H_2O gm	NaCl gm/day
2900	103 (18%)	342 (60%)	125 (22%)	4.9	430	12.3
2500	79 (17%)	274 (58%)	121 (25%)	4.7	315	11.6

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TABLE IV. PRE- AND POST-EXERCISE SERUM AND URINE VARIABLES

	PRE-EXERCISE						POST-EXERCISE					
	GROUP 1.3 PERCENT		GROUP 2.3 PERCENT		GROUP 4.3 PERCENT		GROUP 1.3 PERCENT		GROUP 2.3 PERCENT		GROUP 4.3 PERCENT	
	$\bar{X}$	$\bar{X}a$	$\bar{X}$	$\bar{X}a$	$\bar{X}$	$\bar{X}a$	$\bar{X}$	$\bar{X}a$	$\bar{X}$	$\bar{X}a$	$\bar{X}$	$\bar{X}a$
		±S.E.		±S.E.		±S.E.		±S.E.		±S.E.		±S.E.
SERUM Na meq/l	145.7	145.3	142.5	142.4	145.9	146.4	146.1	146.9	145.3	145.5	147.8	146.7
		1.8		1.2		2.1		2.2		1.5		2.5
SERUM K meq/l	4.21	4.14	4.14	4.12	4.18	4.27	4.26	4.17	4.15	4.13	4.14	4.27
		.10		.07		.12		.13		.09		.15
SERUM Cl meq/l	102.6	102.1	101.8	101.6	102.6	103.2	101.9	102.4	102.0	102.1	102.8	102.1
		.96		.65		1.10		1.17		.80		1.35
SERUM OSMOLARITY mosm/l	286.8	288.0	284.6	285.0	291.3	289.6	291.7	292.4	291.5	291.7	294.0	293.0
		3.6		2.4		4.2		3.3		2.2		3.8
SERUM GLUCOSE mg/100 ml	76.8	76.4	78.8	78.7	79.0	75.5	73.2	74.1	75.1	75.3	82.0	80.8
		4.5		3.0		5.2		5.2		3.5		6.0
HEMATOCRIT VOL PERCENT	42.6	42.5	43.4	43.4	43.3	43.3	44.0	43.8	45.0	45.0	45.4	45.7
		1.2		.8		1.4		1.2		.9		1.4
SERUM CREATININE mg/100 ml	1.05	1.06	1.07	1.07	1.07	1.06	1.25	1.25	1.28	1.28	1.31	1.31
		.06		.04		.07		.07		.05		.08
URINE CREATININE mg/100 ml	238.4	215.2	259.4	253.4	339.0	370.4	208.0	229.1	225.0	230.5	259.7	231.1
		41.0		27.9		47.3		25.0		17.0		28.9
URINE VOLUME ml/min	.86	.93	.87	.89	.71	.63	.69	.68	.60	.60	.56	.56
		.10		.07		.11		.06		.04		.07
CREATININE CLEARANCE ml/min	196.6	199.7	193.8	194.5	211.4	207.2	109.6	119.8	102.0	104.7	108.8	94.9
		16.4		11.1		18.9		8.7		5.9		10.1
URINE Na meq/l	158.9	152.5	172.9	171.3	155.8	164.5	150.5	151.0	146.0	146.1	140.9	140.2
		26.4		17.9		30.4		19.6		13.4		22.7
URINE K meq/l	80.1	76.9	76.4	75.5	106.6	111.0	66.9	62.8	67.5	66.4	94.3	99.8
		9.1		6.2		10.5		8.7		5.9		10.0
URINE Cl meq/l	162.9	160.6	167.8	167.2	178.0	181.2	155.2	157.1	150.2	150.7	159.3	156.6
		20.4		13.9		23.6		25.2		17.2		29.1
URINE OSMOLARITY mosm/l	990.5	944.4	973.8	961.9	1138.0	1200.4	927.8	923.0	933.6	932.4	1047.6	1054.1
		67.7		46.1		78.2		48.6		33.1		56.2
U/S OSMOTIC RATIO	3.44	3.26	3.41	3.36	3.90	4.15	3.18	3.15	3.20	3.19	3.56	3.60
		.20		.14		.24		.15		.10		.17

TABLE V. BLOOD VOLUME CHANGES WITH HYPOHYDRATION

GROUP 1.3 PERCENT		GROUP 2.3 PERCENT		GROUP 4.3 PERCENT	
EVANS BLUE SPACE	3473.1	3358.7	(-3.3%)	2994.0	(-13.8%)
±S.E.	248.3	169.1		286.8	
RED CELL VOLUME	2304.1	2318.5	(+ .6%)	2170.9	(- 5.8%)
±S.E.	138.0	94.0		159.4	
BLOOD VOLUME	5777.2	5677.2	(- 1.7%)	5164.9	(-10.6%)
±S.E.	364.2	248.0		420.6	

ALL PERCENT CHANGES COMPARED TO GROUP 1.3 PERCENT

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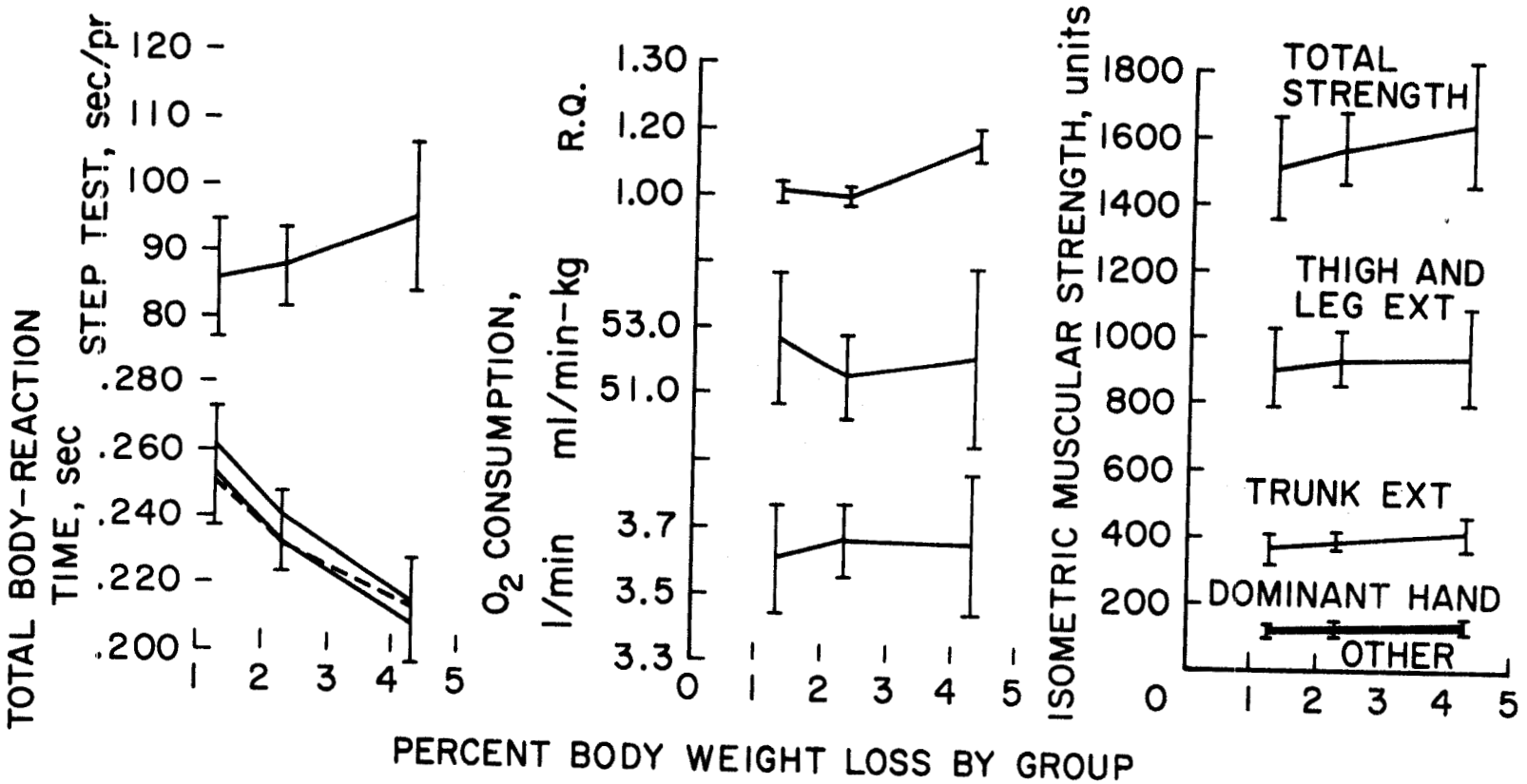

Fig. 1. Physical performance measures at three levels of hypohydration.

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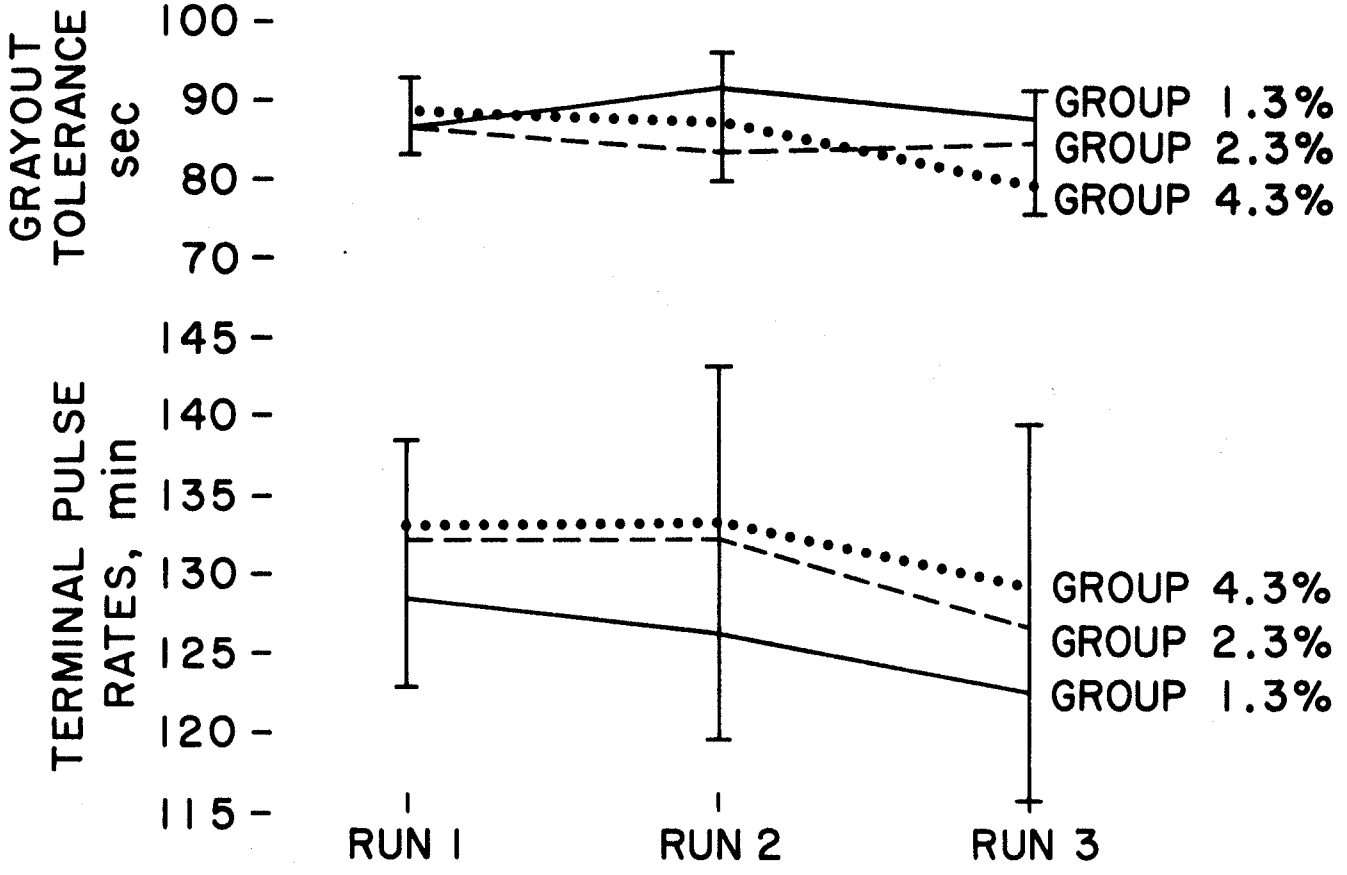

Fig. 2. Tolerance times and terminal pulse rates after configuration.

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