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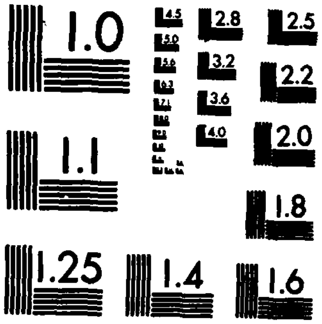
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REPORT NO. T2/84

EFFECTS OF RESTRICTED WATER INTAKE ON PERFORMANCE IN A COLD ENVIRONMENT

US ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

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NO. T 2/84

EFFECTS OF RESTRICTED WATER INTAKE ON PERFORMANCE IN A COLD ENVIRONMENT

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1 May 1984

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The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 in Use of Volunteers in Research.

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ABSTRACT

Eighteen male subjects were housed for 10 days in an environmental chamber maintained at 70°F for the first 3 days and then lowered to -10°F for the next 5 days and maintained at 70°F for the last 2 days. Subjects received a standard ration containing 4500 kcal and either 1.5L (Group 1) or 3.0L (Group 2) of water per day beginning on the first cold day. Their daily routine included walking on treadmills with or without packs (16 miles/day), psychological testing, weighing (BW), blood and urine collection and either endurance testing (cycle ergometer at 75% $\dot{V}O_2$ max for 30 min) or cold stress testing (sitting in a 32°F cold chamber for 90 minutes. All subjects were slightly dehydrated (2% BW) prior to cold exposure. After exposure, the weight loss for Group 1 was 3.49 ± 0.35% BW ($p < .05$) while Group 2 regained most of their initial loss and was down only .14 ± 0.35% BW. There was no significant difference in the groups' ability to perform endurance tests, but Group 1 showed a significant degree of hand cooling ($p < .01$). These data indicate that exercise can be performed satisfactorily even when subjects are not well hydrated, but their response to environmental conditions is adversely affected. The data further indicate that a person can function and remain hydrated on 3.0L water/day under severe conditions.

Dehydration, exercise, cold

INTRODUCTION

Dehydration has long been recognized as a frequently occurring problem during military operations in hot environments but has received little attention in cold weather operations. Buskirk (1) showed that work performance (max $\dot{V}O_2$) decreased with a dehydration of five percent body weight (BW) which occurred even in well conditioned subjects. Craig (2) showed that dehydration of 4.3 percent BW produced a 48 percent decrease in walking time and a 27 percent reduction in max $\dot{V}O_2$ while even a mild dehydration of 1.9 percent BW produce a 22 percent drop in walking time and a ten percent reduction in max $\dot{V}O_2$. Saltin (6,7) has reported that both work time and blood lactates decreased after exercise dehydration.

The Canadian Armed Forces have examined the problem of dehydration during their New Viking Exercises (4). During early exercises, findings indicated that dehydration has been a major contributing cause of casualties and loss of effectiveness of troops. It was found that troops showed a six to ten percent body water deficiency when diagnosed as dehydrated and often required evacuation (4). Dehydration was controlled somewhat in later exercises by greater Command awareness of the problem and by fluid forcing.

Roberts (5) has presented data indicating that dehydration results in a decrement in the ability of subjects to withstand cold. Personal observations under field conditions (Alaska, 1981) have shown that troops dehydrate within a short time (2-3 days) if efforts are not made to force fluid intake.

Studies by the Naval Submarine Medical Research Laboratory (8) have established that a person can exist in a cold environment on the standard arctic combat ration using only 2.8 L water/day. With continued use of this ration, which contains almost 20 gm of NaCl, some salt loading was present after ten days. The long term implications of this are not known but the newer versions of the ration will have 12.75 gm NaCl.

Based on Canadian Armed Forces data and related information, it is evident that dehydration poses a serious problem for troops operating in any environment in which fluid availability is limited. This is a problem of major importance since dehydration can occur as readily in the cold as in the heat, can decrease troop effectiveness, and may predispose to greater threat of injury.

The combination of the possibility of military operations occurring for long periods in cold climates and the logistical problem of supplying high quality water in large amounts under cold conditions prompted this study to examine the effect of reduced fluid intake on certain performance characteristics. We chose to look at tasks that resemble those needed by troops to function in a field environment.

The study plan was to expose two groups (9 each) of active duty troops receiving different amounts of water to an environment in which we could control or measure their performance. The troops would spend their day time in the cold (-10°F) doing work and their night time in an environment similar to a field tent (32°F).

METHODS

Eighteen volunteers were recruited from the US Marine Corps for this study. The volunteers were briefed, given physicals, and randomly assigned to one of two groups (1.5 L water/day, 3.0 L water/day). The only exception to the random assignment was to assign an NCO to each group.

Subjects lived in an environmental chamber for 10 days beginning on a Thursday. The first three days were spent on training and obtaining baseline measures which were performed at an ambient temperaure of 65-70°F. During the next five days, the chamber temperature was -10°F from 0530 to 1530 and then allowed to warm up. The highest temperature reached was 32°F. During the last two days the chamber was again warmed to 65-70°F and post experiment measures were taken.

The subjects were issued a full complement of arctic clothing and allowed to wear what they needed. Prior to cold exposure, subjects were briefed on wearing standard cold weather gear and the layering method of dressing. Dry socks were supplied several times a day to prevent foot problems. Subjects were also instructed on the importance of preventing sweating by proper ventilation of garments.

The subjects were fed the current low-salt version of the Marine Corps Arctic ration containing approximately 4500 calories/day and 12.75 gms of NaCl. They were provided with food and water six times daily over a 12.5 hr. period. Water was provided to each subject according to his experimental grouping. Details on food consumption and feeding schema have been described by Naval Submarine Medical Research personnel (9). Each day began with a resting blood sample (prone) followed by a prone and standing blood pressure measurement. All urine and feces were collected, volumetrically measured and an aliquot stored for subsequent analysis. Body temperature was taken during waking hours by oral thermometer and while sleeping by a rectal thermometer. During the warm phase, this was done every four hours, and during the cold phase, every two hours.

Body weights were taken in the chamber each morning before breakfast while wearing long underwear. The subjects were removed from the chamber several times during the study to take nude weights to allow measurement of water loading of their underwear.

During daytime hours subjects performed a series of tasks which simulated normal military procedures. The subjects performed on treadmills either walking (3 mph), pulling against a weight, carrying packs, or running (6 mph). These work periods (15 minutes) were alternated with rest periods (15 minutes) during which the subjects completed a battery of psychological tests. The total distance walked each day was approximately 16 miles. There were several additional procedures that were performed on an irregular basis.

MAX $\dot{V}O_2$ MEASUREMENT

Each subject completed a maximal oxygen uptake test on a cycle ergometer during the second day under thermoneutral conditions. This was an interrupted test consisting of pedaling at a rate of 60 rpm at one intensity of 120 W. Intensity was increased in increments of 30 W until a plateau in $\dot{V}O_2$ occurred with increasing intensity. Expired gas was collected during the last 60 seconds of each exercise level and analyzed for volume ($\dot{V}_E$), CO_2 content, and O_2 content. $\dot{V}O_2$ was calculated from the minute ventilation and the composition of the expired gas. A ten second ECG strip was recorded during each bag collection (3) and used to determine heart rate and to check for abnormal wave patterns.

ENDURANCE TESTING

An endurance test was performed which involved riding the cycle ergometer at 75% of max $\dot{V}O_2$ for 30 minutes. An expired gas sample and heart rate (ECG) were taken each 10 minutes. This test was performed once during the pretesting phase on Tuesday and Thursday during cold exposure, and during the post testing phase on 1/2 of the test subjects. Following each 30 minute endurance test a blood sample was taken and the lactic acid level determined. This was compared to lactic acid levels determined from resting blood samples taken on the morning of the test.

COLD TESTING

A thermocouple was attached to each finger proximal to the fingernail on the right hand of each subject. A rectal probe was used to measure core temperature. Subjects were dressed in arctic clothes (parka with liner, wool shirt, field pants with liner, vapor barrier boots, helmet liner, scarf, and arctic mittens with liners) and sat in a chair (non-metalic) in an environmental chamber at zero degrees centigrade with arms supported at heart level. The temperatures were measured using a Leeds & Northrup Numatron and transmitted to a PDP-11 computer for storage. Each temperature was updated once per minute. After 15 minutes equilibration time, the mitten from the right hand was removed and exposed to the cold air. Subjects remained in the chamber with hand exposed for 90 minutes or until any skin temperature reached and remained at 40°F. Temperature curves for each digit were obtained from the computer and the area under the cooling curve was calculated and divided by the time spent in the chamber to obtain the area/unit time for statistical analysis. This was performed once during the pre-cold phase and twice during the cold phase.

DEHYDRATION

Each subject was normally hydrated upon arriving at the lab on day 1 by undergoing water loading over a 24 hour period. On the day before the cold exposure, each subject was dehydrated by 2% of his normal body weight through a combination of exercise and withholding fluid. Both groups (high and low water) started the 5 days of cold exposure at the same hydration level. Group 2 then received 3.0 L water/day which was shown in an earlier study to satisfy the body requirements for this experimental design, while Group 1 received only 1.5 L water/day. This water was issued throughout the working day during meals and breaks.

RESULTS

Table 1 lists the characteristics of the subjects and the data collected during maximum aerobic testing. These data were used to adjust the work level for the 30 minute endurance test.

Table 1. Anthropometric and Maximal Exercise Data.

	SUBJ	MAXIMUM VO_2 L/min	MAXIMUM HR	WEIGHT Kg	AGE
LOWER WATER	G1	3.35	180	80.26	34
	G2	3.58	192	79.12	21
	G3	3.02	185	97.84	19
	G4	2.71	190	73.86	19
	G5	2.74	189	63.06	21
	G6	3.77	188	94.62	19
	G7	2.94	191	79.94	19
	G8	2.96	189	68.39	20
	G9	3.18	179	87.46	21
	$\bar{X}$ ± SEM	3.14 ± 0.12	187 ± 1.6	80.51 ± 3.81	21.4 ± 1.6
HIGHER WATER	Y1	3.82	181	95.58	28
	Y2	3.01	193	60.32	19
	Y3	3.81	199	78.78	21
	Y4	3.78	185	82.72	20
	Y5	3.62	195	69.25	23
	Y6	3.93	187	86.91	20
	Y7	3.29	196	67.09	21
	Y8	3.97	180	82.90	19
	Y9	3.04	179	62.56	19
	$\bar{X}$ ± SEM	3.59 ± 0.13	188 ± 2.5	76.23 ± 4.00	21.1 ± 1.0

The data for the daily weight changes and consequent level of dehydration are shown in Table 2 and graphically depicted in Fig. 1. Both groups show a weight decline on the forced dehydration day prior to cold exposure.

Table 2. Daily Weights for the 9-Day Experiment.

0600HR WEIGHTS (KG) IN UNDERWEAR

				COLD CHAMBER						
	SUBJ	SAT	SUN	MON	TUE	WED	THUR	FRI	SAT	SUN
LOWER WATER	G1	81.3	80.7	77.8	78.7	78.4	80.6	80.2	78.5	79.0
	G2	79.8	79.8	77.6	77.9	77.7	77.2	77.3	77.2	80.2
	G3	80.9	80.4	78.5	78.0	77.3	77.2	76.8	76.7	78.9
	G4	74.8	74.5	72.5	72.6	72.2	72.3	72.1	71.8	72.9
	G5	69.9	68.5	67.7	67.2	66.8	66.4	66.1	66.0	66.7
	G6	63.7	63.9	62.7	62.6	62.9	62.8	62.6	62.3	63.4
	G7	94.7	94.8	92.0	90.9	91.2	90.6	89.9	90.9	92.8
	G8	80.8	80.8	78.7	78.9	78.5	78.5	78.5	78.3	80.0
	G9	88.2	87.9	85.0	84.5	84.2	84.6	84.6	84.1	86.1
	$\bar{X}$	79.3	79.0	76.9	76.8	76.6	76.7	76.5	76.2	77.8
	± SEM	3	3	3	2	3	3	3	3	3
HIGH WATER	Y1	96.5	95.7	93.5	94.4	94.0	95.5	95.2	94.3	94.0
	Y2	61.4	61.9	60.0	61.1	61.2	61.0	61.6	60.5	60.2
	Y3	79.7	79.6	77.2	79.2	79.8	80.0	79.7	78.0	77.8
	Y4	83.6	83.2	81.8	83.4	83.8	83.7	82.8	82.7	82.4
	Y5	70.2	70.2	68.3	69.5	70.3	69.8	70.3	68.5	68.7
	Y6	87.7	87.2	85.5	86.6	87.1	86.6	87.0	86.4	86.5
	Y7	67.9	68.7	66.8	68.1	67.7	67.1	67.0	66.8	66.1
	Y8	63.4	63.5	63.1	63.8	63.8	64.6	64.9	63.7	63.1
	Y9	83.7	84.2	81.6	83.0	82.9	83.2	83.2	81.7	81.6
	$\bar{X}$	77.1	77.1	75.3	76.6	76.7	76.8	76.9	75.8	75.6
	± SEM	4	4	4	4	4	4	4	4	4

Group 2 returned to normal by day 2, while Group 1 continued to decrease slowly during cold exposure, but showed a sharp increase on the last day when water was provided. Group 2 tended to decrease slightly on the last two days.

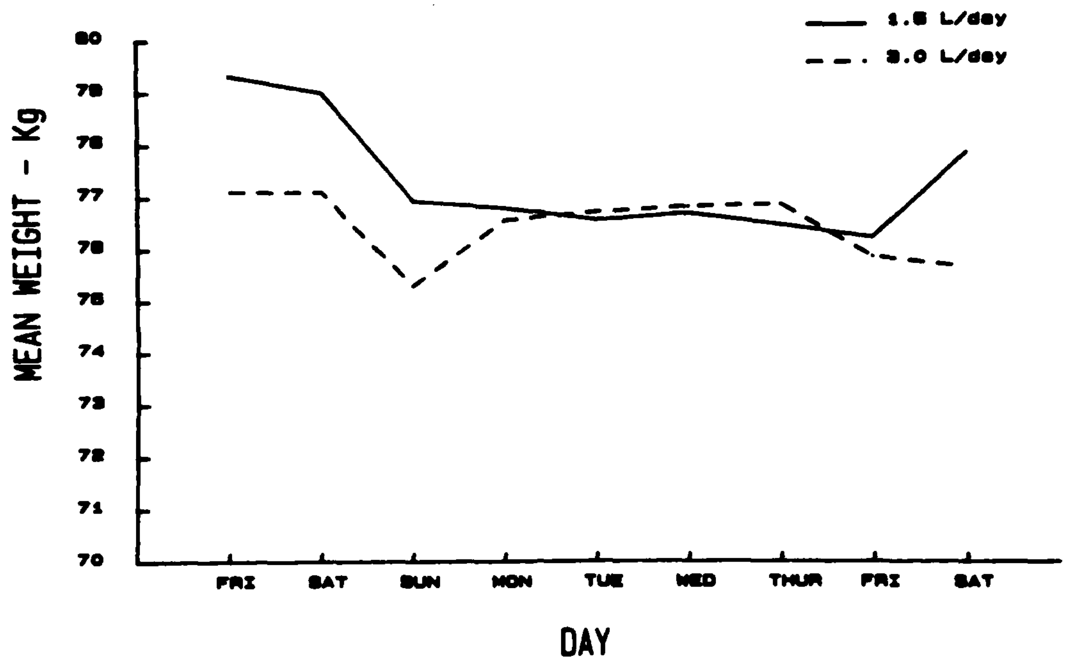

Figure 1. Comparison of mean body weights for both groups during the 9-day study.

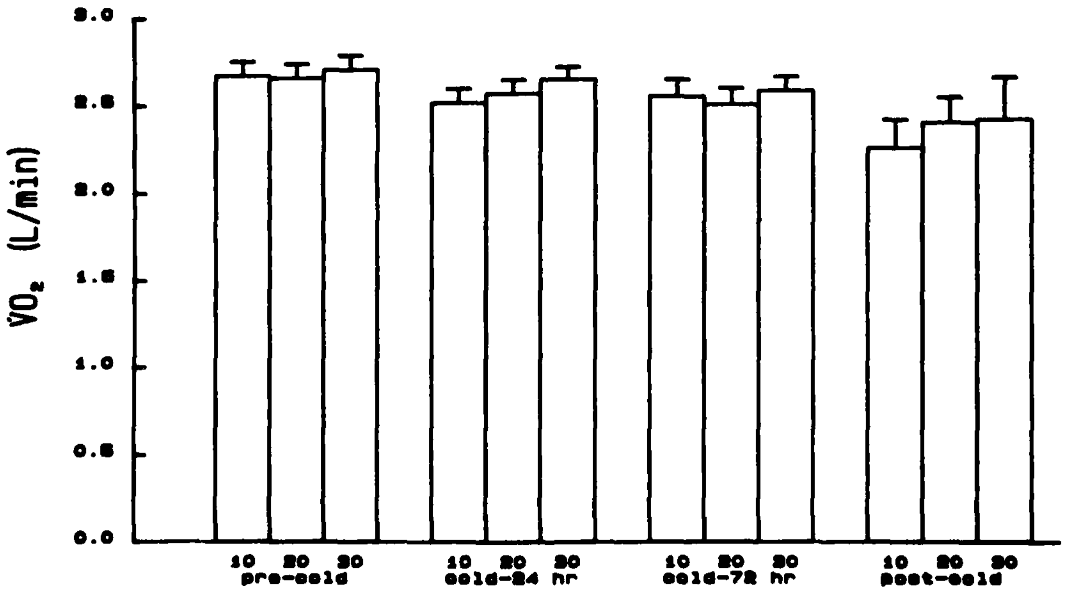

Figure 2. Mean $\dot{V}O_2$ data for 3.0 L water/day group at 10, 20, and 30 minute intervals for the endurance tests.

During the 30 minute endurance test expired gas was collected at the end of each 10 minutes and $\dot{V}_E$ and $\dot{V}O_2$ calculated. The data for $\dot{V}O_2$ are presented in Figures 2 and 3. Figure 2 shows the data for Group 2 at each time period for the four days.

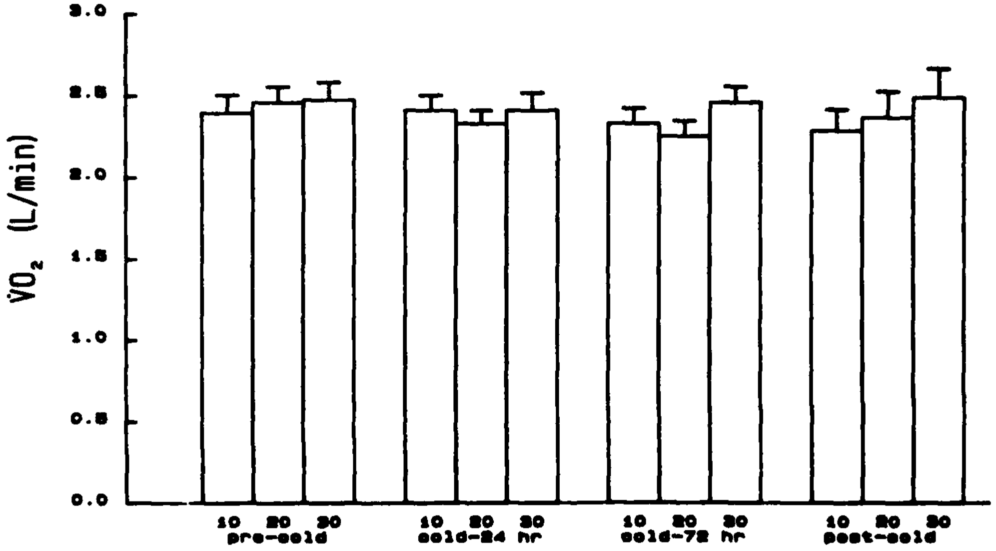

Figure 3. Mean $\dot{V}O_2$ data for 1.5 L water/day group at 10, 20, and 30 minute intervals for the endurance tests.

The post-cold phase includes data on only 4 subjects while all other data are for all 9 subjects in that group. There was no significant change in $\dot{V}O_2$ for this group across time. Figure 3 shows the data for Group 1. The post-cold data includes 5 subjects while all other graphs include all 9 subjects. The $\dot{V}O_2$ appears to be less in Group 2 during during cold exposure, particularly for the first 10 minute phase on the 24 hr test and for all three phases of the 72 hr test when compared with

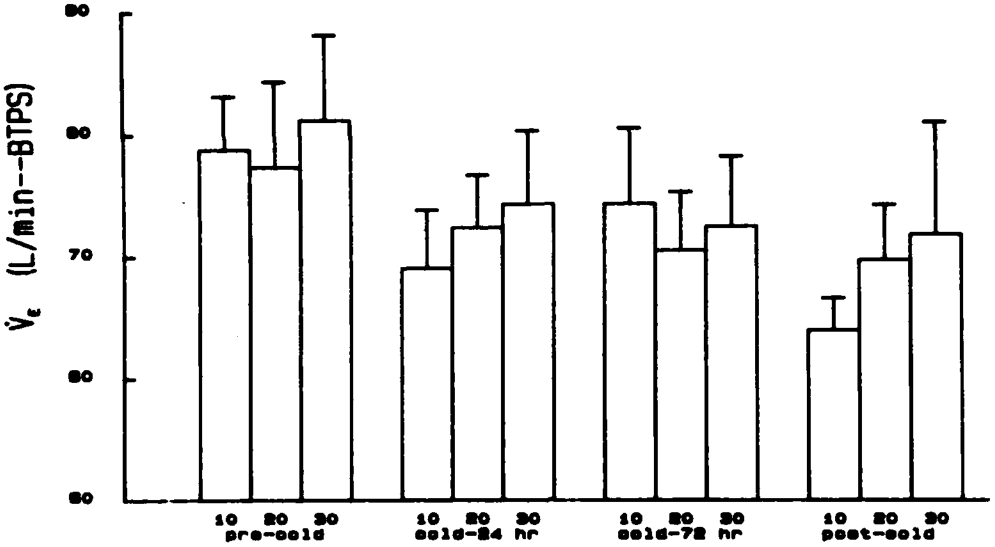

Figure 4. Mean ventilation data for the 3.0 L water/day group for 10, 20, and 30 minute intervals for the endurance tests.

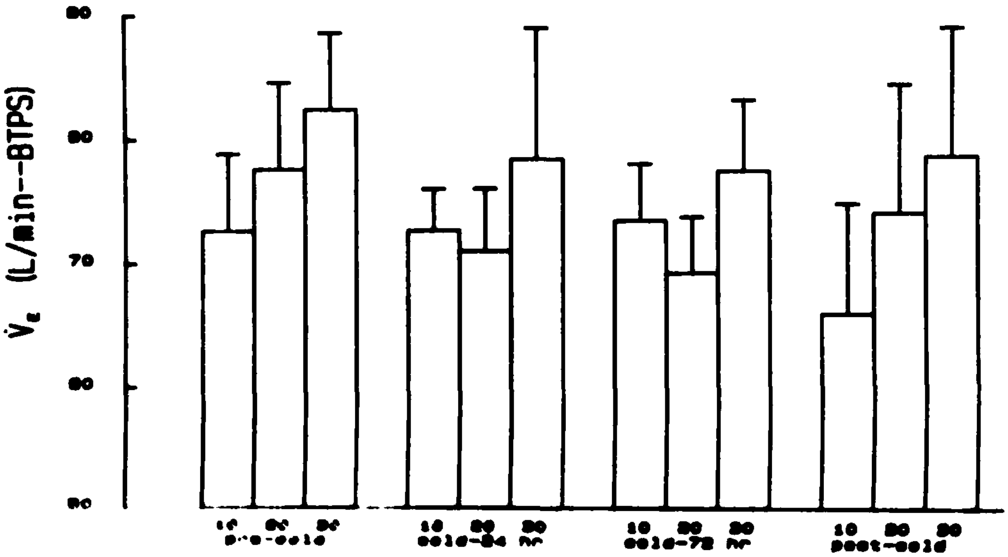

Figure 5. Mean ventilation data for the 1.5 L water/day group for 10, 20, and 30 minute intervals for the endurance tests.

precooling measurements. The post cold test shows a lower value, but a much larger error and is not statistically significant. The data in Figure 3 indicates no difference in the $\dot{V}O_2$ the exercise intensities at either level of dehydration.

The ventilatory data are shown in Figures 4 and 5. The $\dot{V}_E$ data is widely varied, and statistically not significant, but the trend is for ventilation to be lower during cold exposure in both groups.

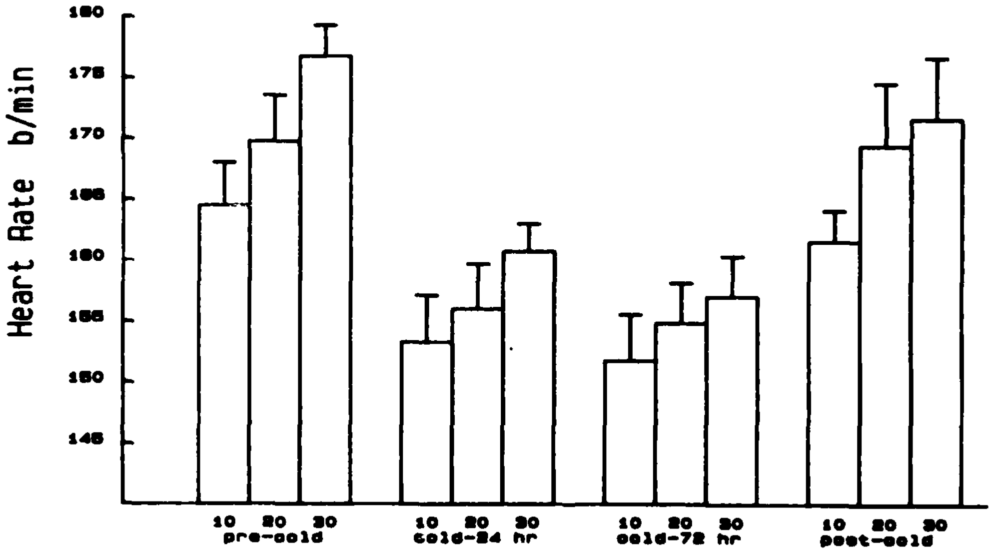

Figure 6. Mean heart rate data for the 3.0 L water/day group for 10, 20, and 30 minute intervals for the endurance tests.

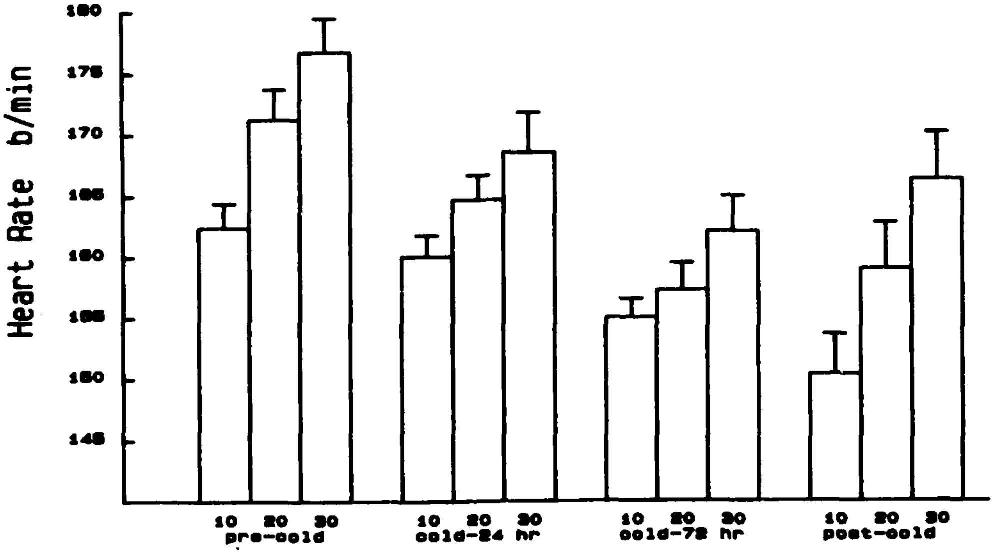

Figure 7. Mean heart rate data for the 1.5 L water/day group for 10, 20, and 30 minute intervals for the endurance tests.

The data for the heart rate are presented in Figures 6 and 7. The heart rate data appear to reflect the effect of cold and perhaps conditioning to a greater extent than the ventilation data. Group 2 appears to be able to maintain the exercise intensity at a lower heart rate during both cold tests while the decrease in Group 1 is not as dramatic.

The data for the blood lactates are shown in Table 3. The resting lactate values show no significant difference between warm and cold (72 hr) for either group. The exercise blood lactates were drawn 3 minutes after completion of the 30 minute endurance exercise test and while both groups show a decrease only Group 1 was statistically significant.

Table 3. Blood Lactate Concentration in Mg % at Rest and During Submaximal Exercise in a Warm and Cold Environment.

	WARM		COLD	
	RESTING	EXERCISE	RESTING	EXERCISE
1.5 L H_2O/day	8.6 ± 1.7	50.4 ± 6.4 *	9.3 ± 1.0	35.9 ± 3.4 *
3.0 L H_2O/day	7.7 ± 1.0	39.5 ± 3.3	6.1 ± 0.5	30.6 ± 2.7

X ± SEM

P < .05

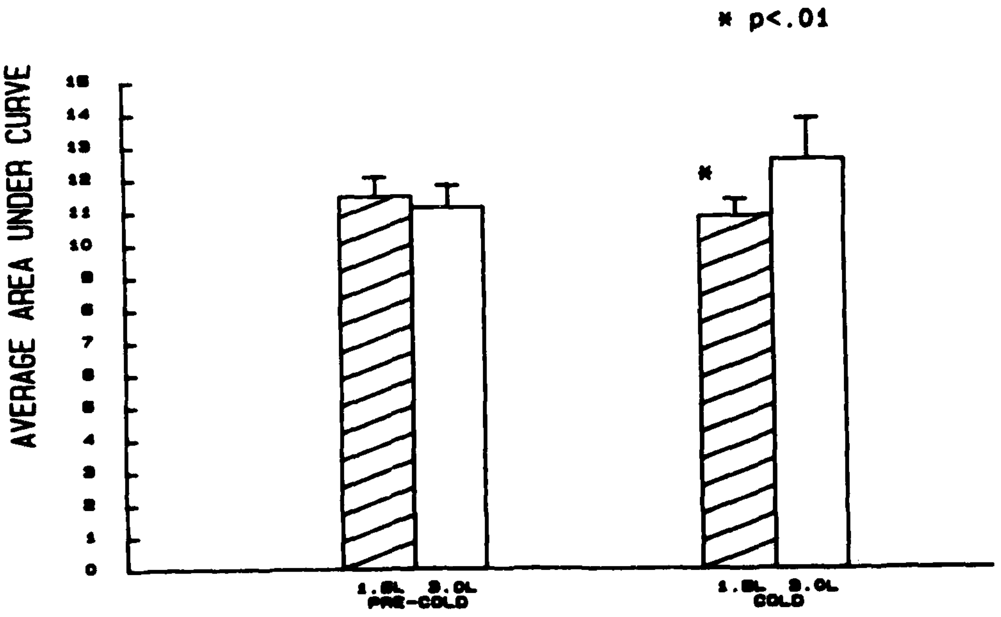

Figure 8. Mean data for the area per unit time for the hand cooling curves for both groups.

The data for the cold exposure tests are shown in Figure 8. There was no significant difference in the response of Group 2, but Group 1 shows a significant decrease in the average temperature per unit time. These data indicate that subjects receiving less water had colder hands.

DISCUSSION

Dehydration will continue to be a problem of major concern as long as troops serve in environments that make the supply of high quality water difficult. This is true in a hot desert or in a cold desert such as the arctic. When large numbers of troops are involved, the requirements for water far exceed the capacity to use local water i.e. snow, ice. It, thus, becomes necessary to know what the consequences to individual and unit functions are if water supply is inadequate.

This study attempted to look at what happens if the daily water supply is halved from what has been shown to be required. The Navy (8) has shown that when using the US Marine Corps Arctic Ration at least 3.0 L water/day is needed. Consequences of inadequate water intake include salt loading, loss of appetite, constipation, and sometimes loss of the will to continue.

One difficulty in dealing with reduced water intake is the problem of defining and measuring dehydration. We have used a loss of body weight as an index but this is only valid if caloric intake is constant, which, unfortunately, can change with low water levels. The measurement of fluid compartments is difficult and has a high margin of error. This leads to difficulty in comparing data from other studies or to build on existing data bases. We feel that the body weight loss in this study was fluid loss since the time to regain weight is consistent with fluid gain and not caloric gain (Fig. 1).

It is clear from other studies (1,2) that dehydration does have a detrimental effect on maximal levels of exercise, but under normal field situations, one rarely is called upon to perform at a maximal aerobic level as this cannot be sustained for any period of time. The data on the $\dot{V}O_2$ (Figs. 2,3) clearly indicate that an exercise intensity of 70 percent can be performed and maintained under conditions of dehydration and cold.

Saltin (6,7) has reported that blood lactates are decreased after exercise dehydration indicating a shift in metabolic function. In this study blood lactates from both groups were lowered after exercise in the cold (Table 3), but only the low water group was significantly different. It is not clear why this happened, since exercise has been shown to maintain the circulating fluid volume during dehydration by shifting protein into the vascular space. It may be a shift in the metabolism in order to produce more heat. The ability of the subjects to exercise in the cold at lower heart rates (Figs. 6,7) is probably related to the need to rid the body of heat during warm or hot weather exercise resulting in a more dilated condition during exercise in a warm environment.

The response to cold stress is similar to that reported in another study (5) in which dehydration (water withholding) occured to a greater extent (4.5% BW) but under warm conditions (room temperature) with little exercise. It is not clear what consequences this increased cooling would have under field conditions in which movement is allowed, however, the increased rate of cooling could be of considerable concern if troops were in a non-moving position exposed to cold.

In conclusion, while the data indicate that motivated troops can perform physical tasks under less than adequate water supplies, we feel that the increased risks of cold injury and lowered morale factors coupled with the medical sequellae of constipation and thirst should indicate to field commanders that water is of prime importance in maintaining a well-functioning military unit.

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