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Changes in nutrient intakes of conditioned men during a 5-day period of increased physical activity and other stresses

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Summary. Nutrient intakes and selected blood and urinary constituents of 16 Navy servicemen were obtained before and during a period of 113 hours of physical activity, sleep deprivation, and psychological stress, to document the dietary adaptation of physically conditioned men to an extended period of hard physical work and other stresses. Food intakes were monitored by 1-day diet records prior to and by direct observation during the period. The factorial method was used to calculate energy expenditure. Carbohydrates provided 45 and 43% of the total energy intake before and during the experiment. Protein intakes and intakes of all the vitamins and minerals studied exceeded the Recommended Dietary Allowances, both before and during the period. Total energy intake averaged 18.7 $MJ \cdot d^{-1}$ before and 24.4 $MJ \cdot d^{-1}$ during the experiment. Body weight increased significantly by 2.7 ± 0.4 kg (mean ± s.e.) during the experiment ($p < 0.0001$). There was a significant correlation ($r = 0.74$; $p < 0.001$) between the change in body weight and urinary sodium from before to after the experiment suggesting that increased dietary sodium may have contributed to the weight gain. A significant increase in plasma volume ($11.9 \pm 3.2\%$; $p < 0.0003$) provided further support that the observed weight gain was due to sodium intake rather than a positive energy balance. In conclusion, conditioned men increased food consumption adequately to meet increased energy demands.

Key words: Nutrition – Energy balance – Vitamins – Minerals

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Introduction

It is an axiom that proper nutrition will enhance performance. However, with the exception of investigations concerning the effects of carbohydrates on endurance exercise, there have been few formal studies delineating which foods or combination of foods enhance physical performance. On a more fundamental level, before specific recommendations relating to diet and performance can be made, current dietary practices must be documented. While there have been surveys to assess dietary patterns in conditioned subjects (Steel 1970; Ferro-Luzzi and Venerando 1978; Laritcheva et al. 1978; Khoo et al. 1987) most dietary studies have been conducted during periods of relatively constant exercise intensity. To date no studies have documented dietary intakes during periods of increased activity to determine whether dietary habits change appropriately to meet the increased energy demands.

The specific objective of this study was to document the dietary adaptation of trained men to an extended period of physical activity and exposure to other specific stresses. The subjects were U.S. Navy Sea, Air, and Land (SEAL) trainees and the study was conducted during a 5 day period known as Hell Week (HW). This particular period occurs after 5 weeks of strenuous physical conditioning and consists of approximately 113 h of psychological stress, cold exposure, physical activity, and sleep deprivation. Psychological stresses included verbal confrontations, performance anxiety, and activities with no-win situations. The major physical activities during HW were simulated combat situations, calisthenics, and foot and boat races. Approximately 5 h of formal rest were allowed during this time. Those trainees who completed HW endured stresses not found in usual research paradigms. More detailed descriptions of the SEAL training program have been published (Rahe and Arthur 1967; Barnes and Strauss 1986).

Methods

The study was approved by the Human Use Review Committee at the Uniformed Services University of the Health Sciences (USUHS) and was conducted at the Naval Amphibious Base in Coronado, CA from September 18 to September 27, 1986. After being informed of the risks and benefits, 88 healthy adult males volunteered to participate in the study. Of the 88 men who started HW, only 38 completed it. No significant differences in anthropometric characteristics, physical fitness parameters, or selected urinary and blood biochemical indices were found before the start of HW between those men who completed HW and those that chose to withdraw from the program (Data not shown). For the purposes of this study, only trainees who successfully completed HW and who had complete diet, urinary, and serum measurements were included in the statistical analyses. Subjects were dropped from the study if they had missed any urinary collections during the 24 h period or if the creatinine content of the 24 h collection was less than 17 mg $\cdot$ kg^{-1} $\cdot$ d^{-1}. Thus, the number of subjects was reduced to 16.

Energy expenditure. The factorial method was used to estimate energy expenditure during HW. HW commenced at 2000 h on September 21 and ended at 1500 h on September 26. Three groups of observers, rotating in 12 h shifts, recorded all activities of the trainees for 96 continuous h. The last 14 h of HW were not monitored.

The energy cost of each activity performed during HW was obtained from a review of the literature (Durnin and Passmore 1967; McArdle et al. 1986). If the activity had not been described in the literature an energy cost value most closely approximating the activity was used. Energy expenditure for each activity was calculated by multiplying the energy cost $\cdot$ kg^{-1} of body weight, the average body weight of the group, and the duration of the activity. If the activity was a race, the average time which the group took to complete the race was used. Values were determined on group activities because it was impossible to identify and follow single individuals. Daily total energy expenditures were calculated by summation of the energy expended in all activities performed during a 24 h period.

Throughout HW the weather was cool with average day and night temperatures of 18.4°C and 16.5°C, respectively. The trainees wore fatigue clothing which was often wet from frequent immersions in the surf. At times, considerable shivering was noted by the observers; however no estimation of energy expended for shivering was included in the final calculation of the daily total energy expenditure.

Energy intake. Dietary intakes were obtained twice: before the start of HW (pre-HW) and throughout the first 96 h of HW. Before the start of HW, 1-day diet records were completed by the trainees on a weekday. A dietitian reviewed the records with each trainee to ensure accuracy and completeness.

During HW, dietary intakes were estimated by the direct observation technique. The trainees were served 4 meals daily, with the exception of the first 24 h period during which the trainees did not eat a midnight meal. The meals were eaten at approximately 0700, 1200, 1800, and 2400 h. All meals, with the exception of 5 meals eaten during field exercises, were prepared by Navy cooks and served in a cafeteria-style dining hall. No attempt was made by the research team to change food preparation in any way. The trainees could select foods from several entrees and vegetable dishes, in addition to a salad and dessert bar. They were not permitted to have any food from outside sources, alcohol, or vitamin supplements during HW.

To avoid any delay in meal service and to minimize interference with HW operations, data for each meal were collected on a random sample of trainees. Sample sizes varied from 10 to 22 trainees for any given meal. The food intakes of these individuals were used to estimate the average group intake for each meal. Trained investigators recorded portion sizes as each designated trainee went through the food service line. After the meal, the designated meal trays were checked carefully for waste. Waste portion size was estimated to the nearest 0.1 portion and recorded. No attempt was made to calculate the discretionary table salt that may have been added by the trainees.

All food consumption data were reviewed by a dietitian. Nutrient analyses of all foods consumed before and during HW were determined with the Intake Nutritional Analysis System (version 1, Med Q Corporation, Kensington, MD). The Intake database consists of over 6000 food descriptors, 4210 of which are from the revised USDA Handbook 8 (Revised Agriculture Handbook No. 8). Analysis for each meal included total energy intake, protein, fat, carbohydrate, vitamins and minerals. The percents of total energy intake contributed by carbohydrate, fat, and protein were calculated using energy equivalents of 0.02 MJ (4 kcal), 0.04 MJ (9 kcal), and 0.02 MJ, respectively (Shils 1978).

Laboratory analyses. Blood samples were obtained before and after HW. Due to the large number of subjects at the beginning of HW, pre-samples were obtained on 2 separate days. Samples were collected either 2 or 3 days prior to the start of HW between 0500 and 0600 h after an overnight fast and before commencing any physical activity. Post-samples were collected as the trainees successfully completed HW: 4 trainees were sampled at 0900 h, 4 at 1100 h and 8 at 1500 h. Blood samples were collected by venipuncture without stasis while the trainees were seated. The blood was aliquoted into an EDTA tube for measuring hematocrit (hct) and hemoglobin (hb) and another tube without anticoagulant for serum analyses. The serum tubes were allowed to stand for 30 minutes and then centrifuged to separate the serum. The serum was frozen for later analyses. Hct was determined in duplicate after centrifugation at 15000 g for 5 min, and hb was determined by the cyanomethemoglobin method on a hemoglobin analyzer (Coulter Electronics Inc., Hialeah, FL). Serum sodium concentration (Na (S)) and serum osmolality (osm (S)) were determined at the Clinical Pathology Laboratory (DSCM), USUHS, Bethesda, Md, by ion exchange (Nova Biomedical, Waltham, MA) and by freezing point depression (Advanced Instruments, Inc, Needham Heights, MA), respectively.

Pre-HW blood volume (BV_b) was estimated from height and weight using the formula of Allen et al. (1956). Pre-HW plasma volume (PV_b) was calculated as follows:

$$PV_b = (100 - hct_b)(BV_b)/100.$$

The percent change in PV (CPV) was calculated from changes in hb and hct as described by Dill and Costill (1974). Post-HW PV (PV_r) was calculated as:

A-1 20

$PV_p = (PV_b)(CPV/100) + PV_b$.

It was assumed that red cell volume did not change significantly from pre-HW to post-HW.

Two 24 h urine collections were obtained. The first was collected prior to HW on the day the diet records were kept and the second 24 h collection was obtained upon the completion of HW. The total urinary volume of each collection was recorded and samples from each collection were frozen in 3 polypropylene tubes for future analyses. Urinary sodium concentrations were determined by a KNA1 Sodium Potassium Analyzer (Radiometer America Inc., Copenhagen). Urine osmolality (osm (*U*)) and creatinine were measured at DSCM by the freezing point depression (Advanced Instruments, Inc, Needham Heights, MA) and the Jaffe reaction (Baker Instruments, Allentown, PA), respectively. Total urinary excretion of sodium (Na (*U*)) was calculated by multiplying total volume by urinary sodium concentration.

Statistical analyses. Data were analyzed by the Statistical Analysis System (SAS) computer package (SAS Institute, Cary, N.C.). Daily means were calculated on the dietary intake variables. Pearson correlation coefficients were calculated to determine associations between variables. Comparisons between pre- and post-HW serum and urinary variables were made with paired *t*-tests. The level of significance was set at 0.05.

Results

Subjects

The average age and height of the subjects were 21.9 ± 2.9 yrs (mean ± S.D.) and 1.76 ± 0.07 m, respectively. At the beginning of HW the subjects weighed 72.9 ± 7.6 kg with an average percent body fat of 11.0 ± 2.4% as measured by Navy standards using girths and height measurements (Hodgdon and Beckett 1984). At the end of HW, the mean weight was 75.6 ± 8.2 kg with an average weight gain of 2.7 ± 1.4 kg during HW.

Energy balance

Pre-HW energy expenditures were not determined. Energy expenditures during HW averaged 22.4 $MJ \cdot d^{-1}$ with observed values of 25.1 MJ (5988 kcal), 23.6 MJ (5650 kcal), 21.0 MJ (5024 kcal), and 20.1 MJ (4792 kcal) on Day 1, 2, 3, and 4, respectively. These values may be underestimated since the additional energy cost of shivering was not included.

The average energy intake before HW was 18.7 $MJ \cdot d^{-1}$. Energy intake during HW increased to 24.4 $MJ \cdot d^{-1}$ with intakes of 18.2 MJ (4346 kcal), 24.7 MJ (5895 kcal), 24.8 MJ (5934 kcal), and 29.9 MJ (7146 kcal) observed on Day 1, 2, 3, and 4, respectively. Thus, as HW progressed, daily energy intake increased even though less activity was performed per day. At the conclusion of HW, the cumulative energy intake had been 7.8 MJ (1867 kcal) more than the total energy expenditure.

Table 1. Mean daily intake and percent of total energy intake of fat, carbohydrate, and protein before and during Hell Week

	Pre-Hell-Week[a]		Hell Week[b]	
	Daily intake	Percent of energy intake	Daily intake	Percent of energy intake
Fat (g)	177	36	260	40
Carbohydrate (g)	494	45	625	43
Protein (g)	189	17	260	18

[a] Determined by one-day diet record
[b] Determined by direct observation over a 4-day period

Diet composition

The amount and relative contributions of fat, carbohydrate, and protein to total energy intakes are presented in Table 1. Energy intake increased 133% during HW, with increases of 147, 127, and 138% observed in the total dietary amount of fat, carbohydrate, and protein, respectively.

The mean daily intakes and nutrient densities of selected vitamins before and during HW are presented in Table 2. Nutrient densities of the vitamins were similar from pre-HW to HW and all vitamin intakes before and during HW exceeded the Recommended Dietary Allowances (RDA) (National Research Council 1980).

Mean daily intakes and nutrient densities of minerals and electrolytes before and during HW are presented in Table 3. Pre- and post-HW nutrient densities of the observed minerals and electrolytes appeared similar. Mean daily intakes of the minerals and electrolytes exceeded the RDA both before and during HW. Sodium intake before HW was 178% above the upper limit of the estimated safe and adequate intake (ESAI) range (National Research Council 1980) and increased to 260% above the upper limit during HW.

Serum and urinary constituents

Hct dropped significantly from 0.43 ± 0.01 (mean ± S.D.) pre-HW to 0.36 ± 0.01 post-HW ($p < 0.0001$). Measures of hb, Na (*S*), and osm (*S*)

Table 2. Mean daily intake and nutrient density of selected vitamins and their Recommended Dietary Allowances before and during Hell Week

	RDA[a]	Pre-Hell-Week		Hell Week	
		Daily intake (U)	Nutrient density (U · 4.2 MJ^{-1})[b]	Daily intake (U)	Nutrient density (U · 4.2 MJ^{-1})[b]
Vitamin A (μgRE)	1000	1413	346	2615	449
Vitamin E (mgTE)	10	20	4.4	21	3.6
Vitamin C (mg)	60	211	50	362	62
Thiamin (mg)	1.5	3.4	0.8	4.7	0.8
Riboflavin (mg)	1.7	3.5	0.8	5.7	1.0
Niacin (mgNE)	19	45	10.5	49	8.4
Vitamin B_6 (mg)	2.2	3.0	0.7	4.3	0.7
Folacin (μg)	400	480	111	553	95
Vitamin B_{12} (μg)	3.0	11	2.4	11	1.8

[a] Recommended Dietary Allowances for males, ages 19-22 years, from the National Academy of Sciences-Research Council, revised 1980
[b] U · 1000 kcal^{-1}

Table 3. Mean daily intake and nutrient density of selected minerals and electrolytes and their Recommended Daily Allowances before and during Hell Week

	RDA[a]	Pre-Hell Week		Hell Week	
	(mg)	Daily intake (mg)	Nutrient density (mg · 4.2 MJ^{-1})	Daily intake (mg)	Nutrient density (mg · 4.2 MJ^{-1})
Sodium	1100-3300[b]	5869	1337	8587	1473
Potassium	1875-5625[b]	5084	1167	7600	1304
Calcium	800	1630	369	2845	488
Phosphorus	800	2948	675	4174	716
Magnesium	350	501	114	648	111
Iron	10	25.9	6.0	35.4	6.1
Zinc	15	19.0	4.4	23.6	4.0

[a] Recommended Dietary Allowances for males, ages 19-22 years, from the National Academy of Sciences-Research Council, revised 1980
[b] Estimated safe and adequate intake range

Table 4. Means and standard errors of selected laboratory parameters before and after Hell Week

	Pre-Hell Week	Post-Hell Week
Hemoglobin (g · l^{-1})	145 ± 1	138 ± 5
Serum sodium (mmol · l^{-1})	149 ± 1	148 ± 2
Serum osmolality (mmol · kg^{-1})	301 ± 3	306 ± 4
Urine osmolality (mmol · kg^{-1})	771 ± 46	688 ± 45

were not statistically different from pre- to post-HW (Table 4). Pre-HW blood volume was estimated to be 5.5 ± 0.1 L. Calculated PV increased significantly by 11.9% from 3.1 ± 0.1 L at pre-HW to 3.6 ± 0.1 L post-HW ($p < 0.0003$). Post-HW urinary volume and Na (*U*) increased significantly from pre-HW values by 38% and 92%, respectively (Fig. 1). Osm (*U*) was not statistically different from pre- to post-HW (Table 4). There was a significant positive association between the change

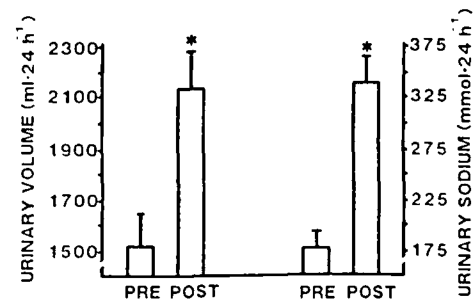

Fig. 1. Means and standard errors for urinary volume and urinary sodium excretion pre and post Hell Week (*$p < 0.05$)

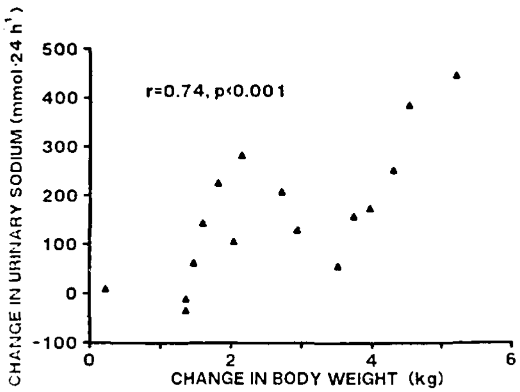

Fig. 2. The relationships between change in body weight and urinary sodium excretion from before until the end of Hell Week

in body weight and Na (U) from pre- to post-HW (Fig. 2).

Discussion

The major purpose of HW is to select men who will complete an assignment despite overwhelming physical, psychological, and /or environmental obstacles. Consequently, the conditions of HW are severe. Over the 5 day period, less than 5 h are allowed for sleep, and the trainees are almost continuously engaged in physical activities, usually in a cold, wet environment. Most of the physical exercise is at a low to moderate workload and consists of jogging, paddling, calisthenics, and swimming. However, interspersed in this regimen are timed activities that require maximal efforts, such as foot and boat races, an obstacle course and simulated combat exercises. Trainees who are not performing at their maximum are required to do additional exercises, such as pushups. Voluntary withdrawal is high, with an attrition rate ranging from 30 to 70% (Rahe and Arthur 1967). The present study was undertaken to identify any dietary patterns which might influence attrition. The results indicated that conditioned men increased their energy intake to approximate energy expenditure during a period of increased physical activity and stress. Further, the foods selected by the trainees provided sufficient vitamins and minerals to meet the RDA.

Energy can be derived from any combination of fat, protein and carbohydrates. During HW, SEAL trainees derived 40, 18 and 43% of their energy from fat, protein and carbohydrates, respectively. This dietary pattern is similar to that of the average American (National Research Council 1980). Although the precentage of dietary carbohydrates was lower than the amount recommended for endurance athletes (Costill et al. 1981; Brotherhood 1984), the total daily intake of carbohydrates during HW was greater than 620 $g \cdot d^{-1}$, an amount that should be more than adequate to replete the glycogen used during exercise or shivering. Thus, it is likely that the distribution of energy sources was adequate, especially when the intensity of the work is considered.

The energy data indicate that despite an increase in activity during HW, the trainees were able to match energy consumption with expenditure over a period of 4 days. The average daily energy expenditure during HW was 22.4 $MJ \cdot d^{-1}$. By the end of the study, the trainees had eaten a total of 7.8 MJ more than their calculated energy costs. This value probably overestimates net energy balance since the energy cost of shivering was not included in the calculation. Despite these limitations, the energy expenditure values appear reasonable when compared to values from other populations. The U.S. Army Rangers trainees expended 20.3 $MJ \cdot d^{-1}$ (4850 $kcal \cdot d^{-1}$) during the physical conditioning phase of training (Johnson et al. 1976). These values were determined from dietary intake and body composition changes. Other estimates from dietary studies suggest that athletes undergoing "arduous sports training" can maintain energy balance with intakes ranging from 15 to 26 $MJ \cdot d^{-1}$ (Ferro-Luzzi and Venerando 1978; Kirsch and von Amelm 1981; Brotherhood 1984). These values also compare favorably to the energy intakes of SEAL trainees during the physical conditioning phase of 18.7 $MJ \cdot d^{-1}$ and during HW of 24.4 $MJ \cdot d^{-1}$.

In contrast, there is one study that reported much higher energy expenditure values for conditions similar to HW (Aakvaag et al. 1978). Cadets from the Norwegian Military Academy had a mean expenditure of 45.9 $MJ \cdot d^{-1}$ while undergoing 107 h of continuous operations. These values were determined from heart rate measurements. This method may have overestimated energy expenditure since factors such as fatigue, environmental temperature, time of day and previous activity, can influence the relation between heart rate and energy expenditure (Acheson et al. 1980).

Coupled with the energy surplus, there was an average weight gain of 2.7 kg during HW. However, assuming that a kg of fat is equivalent to 32.2 MJ, the observed energy surplus equates to a calculated weight gain of only 0.24 kg. Because energy expenditure was underestimated and the observed weight gain was greater than the calculated gain, it is likely that other factors contributed to the weight gain. One explanation is an increase in body water. Salt consumption increased during HW as compared to pre-HW, and it is well known that an increase in dietary sodium results in a positive sodium balance over 3 to 5 days (Maxwell and Kleeman 1980). After a new steady state is achieved, the increase in total body solute leads to water retention in an effort to maintain serum osmolality. Body weight increases due to the expansion of extracellular fluid volume (ECF). In this study, an abrupt increase in total body sodium is supported by the dietary data and the significant increase in Na (*U*) after HW as compared to pre-HW. Further, a significant positive correlation between the change in body weight and Na (*U*) from pre- to post HW was noted. The supposition that the gain in body weight is due to an increase in ECF is strengthened further by the significant decrease in hct with no significant change in hb. Because the change in calculated PV explained only 12% of the variability in the change in body weight, it is likely that a proportionally greater increase in interstitial water occurred. Although ECF was not measured, most trainees exhibited edema of the extremities, thereby indicating ECF expansion.

In addition to dietary sodium, sleep deprivation can increase PV (Plyley et al. 1987) and the trainees slept only 5 h throughout HW. Moreover, repeated episodes of dehydration with rehydration can increase PV above resting values (Costill et al. 1975). The activity and fluid replacement behaviors of the trainees during HW exhibited such a pattern. Thus, several factors may have contributed to the increase in PV.

The vitamin and mineral intakes of the trainees were also evaluated in this study and were found to exceed the RDA, both before and during HW. The RDA are recommendations for intakes that should meet the needs of most healthy persons under usual environmental conditions. Whether stressors, such as cold, exercise, and sleep deprivation, increase vitamin and mineral requirements is presently unknown. If the requirements are higher under such conditions, then the RDA may not be appropriate for the trainees. However, the short duration of HW and adequate dietary intakes prior to HW makes it unlikely that deficiencies occurred.

In conclusion, the results of this study indicate that conditioned men were able to increase energy consumption to meet energy demands. Further, their food selections provided amounts of vitamins and minerals that exceeded the RDA. However, increased sodium intakes during this period increased fluid requirements and body weight, and probably contributed to edema formation.

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