Fluid Replacement During Sustained Activity in the Heat: Nutrient Solution vs. Water

LESLIE LEVINE, M.S., MADELEINE S. ROSE, Ph.D., RALPH P. FRANCESCONI, Ph.D., P. DARRELL NEUFER, M.A., and MICHAEL N. SAWKA, Ph.D.

LEVINE L, ROSE MS, FRANCESCONI RP, NEUFER PD, SAWKA MN. *Fluid replacement during sustained activity in the heat: nutrient solution vs. water.* Aviat. Space Environ. Med. 1991; 62:559–64.

This study examined the thermoregulatory and hydrational status of men during sustained activity in a hot-dry (37°C, 20% rh) environment while they consumed only a nutrient solution (nutrient), or consumed only colored, flavored water (control). Eleven heat acclimated young men attempted 24-h sustained activity experiments. These experiments consisted of alternating 45-min bouts of treadmill walking (410 W, ~30% $\dot{V}O_{2max}$) and rest (including sedentary activity). Data were analyzed through 13 h (after 13 h subjects began to discontinue testing). No significant differences between trials were observed for metabolic rate, fluid intake, skin or rectal temperature, sweating rate, plasma volume (as indicated by hemoglobin concentration) or plasma glucose concentrations. By the 8th h plasma osmolality was higher and by the 11th h plasma free fatty acids were lower during the nutrient trial compared to the control. In separate experiments with nine different men, the gastric emptying rates of the nutrient solution and water were compared during exercise (55% $\dot{V}O_{2max}$) in the heat (35°C, 20% rh). The gastric emptying rates of the nutrient solution and water were similar (~ 20 ml · min^{-1}). These data indicate that during 13 h of sustained activity in a hot environment, the nutrient solution and water provided similar thermoregulatory and hydrational benefits.

FLUID REPLACEMENT is essential for enabling thermoregulation in individuals working for sustained periods in warm environments (22). During some military or industrial situations when individuals are encapsulated in chemical protective clothing in temperate as well as warm environments, relatively high sweating rates are elicited, often resulting in large losses of body fluids and electrolytes (4,12,19). For these individuals fluid intake is sometimes the only means of sustenance available. There are several physiological reasons why inadequate fluid and nutrient intake during sustained activity might reduce performance. First, inadequate fluid replacement causes hypohydration, which impairs thermoregulation and cardiovascular function (14,20, 22,24). Hypohydration reduces the ability of the body to dissipate heat, which leads to elevated core temperature relative to euhydration, and thereby increases the risk of heat injury (8,22). Second, lack of food or nutrient supplement can lead to hypoglycemia, particularly when combined with physical exercise continued over many hours. Hypoglycemia, when accompanied by exercise-induced reductions in muscle glycogen, may result in muscle fatigue as well as impaired central nervous system function (3,9,10). Third, both hypohydration and hypoglycemia can adversely affect electrolyte balance which may also limit performance (9,22).

To avoid the potential problems of dehydration and inadequate nutrient intake, for soldiers encapsulated in protective clothing for sustained periods, a National Research Council (NRC) advisory committee recommended the development and use of a nutrient solution (13). This solution was intended for use in previously well nourished and hydrated individuals, and was not intended to meet all nutritional needs, but would provide a palatable source of fluid, enough carbohydrate (CHO) to prevent hypoglycemia (and ketosis), and electrolytes to replace about half of the sodium lost via sweat. This nutrient solution was designed for use in conditions where no food could be consumed, and where low to moderate intensity activity (~300 W) results in high sweating rates (~500 ml · h^{-1}) for up to 24 h (21).

The purpose of this study was to examine the thermoregulatory and hydrational status of men during sustained activity in a hot environment, while they con-

From the U.S. Army Research Institute of Environmental Medicine, Natick, MA.

This manuscript was received for review in November 1989. The revised manuscript was accepted for publication in December 1990.

Address reprint requests to: Leslie Levine, who is a Research Physiologist, U.S. Army Research Institute of Environmental Medicine, Kansas Street, Natick, MA 01760-5007.

sumed only the nutrient solution or consumed only colored, flavored water. Since the addition of solutes and calories can delay gastric emptying (2), (while addition of glucose has been shown to increase intestinal water absorption (5)), separate experiments were conducted to compare the gastric emptying rates of the nutrient solution and water, during exercise in the heat.

METHODS

Subjects. Eleven healthy young men of average size and body composition as follows. (mean $\bar{X}$ ± S.D.) age, 24 ± 5 years; ht, 176.2 ± 5.2 cm; wt, 78.7 ± 12.7 kg; body fat, 15.9 ± 6.5%, maximal oxygen uptake ($\dot{V}O_{2max}$) 4.2 ± 0.5 L • min^{-1}, served as test subjects for the sustained activity experiments. For the gastric emptying experiments, nine healthy young men volunteered as test subjects. Their physical characteristics are as follows: ($\bar{X}$ ± S.D.) age, 19 ± 1 years; ht, 172.7 ± 7.5 cm; wt, 66.9 ± 3.9 kg; and $\dot{V}O_{2max}$ 3.9 ± 0.3 L • min^{-1}. All subjects gave their voluntary and informed consent to participate in these experiments, which received approval by the appropriate Institutional Review Boards. Investigators adhered to Army Regulation 70–25 and United States Army Medical Research and Development Command Regulation 70–25 on Use of Volunteers in Research.

Protocol. The sustained activity experiments were conducted in Natick, MA, during February and March, when the test subjects were not naturally heat-acclimatized. The subjects were heat acclimated prior to the experiment (so that changes in acclimation status during testing would not confound results), by participating in an 8 to 10-d exercise-heat acclimation program. The acclimation program consisted of level treadmill walking (1.56 m • s^{-1}) for two 50-min exercise bouts, each preceded by a 10-min rest, in a hot environment (T_a = 37°C, rh = 50%, wind speed = 0.9 m • s^{-1}). All testing was conducted while subjects wore shorts and comfortable athletic shoes and socks. The subjects were encouraged to drink fluids to maintain euhydration throughout the acclimation program. On alternate days during acclimation, the subjects drank either the control or nutrient solution to become familiar with each. Acclimation was determined to be complete when there were no longer changes in heart rate or rectal temperature between consecutive acclimation days (8 or 10 d for these volunteers).

The test subjects were familiarized with all testing procedures during the acclimation program. Also during this period, body composition was estimated using a hydrostatic weighing technique, and $\dot{V}O_{2max}$ was determined using a progressive intensity, continuous running protocol on a motor driven treadmill (24). For 10 d prior to experimental testing and throughout the study, nude body weights were measured in the morning to establish the baseline body weights that represented euhydration for each subject.

Following the heat-acclimation and familiarization period, the subjects, wearing shorts, comfortable athletic shoes and socks, attempted to complete two 24-h trials 1 week apart, once while consuming only the control solution (CN) and once while consuming only the nutrient solution (NT). (There were two additional acclimation days during the week between the trials to insure maintenance of acclimation status.) For the 24-h trials, the control and nutrient drinks were administered in a counterbalanced order design. The trials were conducted in a hot-dry environment (37°C, 20% rh, 0.9 m • s^{-1} wind speed) and consisted of alternate sessions of 45-min walks on a level treadmill at 1.56 m • s^{-1} and 45-min periods of generally sedentary activity where subjects were weighed, completed cognitive and psychological tests (21), and rested. The subjects remained in the hot environment throughout all testing, exercise, and rest.

The environmental conditions, exercise intensity, and the alternating bouts of exercise and sedentary activity, were selected to elicit the magnitude of thermal and physiological strain (metabolic and sweating rates) for which the nutrient solution was intended. The subjects did not test in protective clothing so that steady-state thermoregulation could be achieved and maintained for up to 24-h. Since the purpose of this study was to compare the thermoregulatory and hydrational effects of the nutrient solution and water under specific conditions of metabolic and thermal strain, wearing protective clothing would have precluded thermal equilibrium, and would have confounded interpretation of the data.

The subjects consumed their normal diets (~2500 kcal • d^{-1}; 45% CHO, 35% fat, 20% protein) for (at least) the 2 d prior to testing. On the test morning, after breakfast (~900 kcal, 65% CHO, 22% fat, 13% protein), the subjects were instrumented for the monitoring of heart rate (HR), rectal temperature (T_{re}), and mean skin temperature ($\bar{T}_{sk}$), and for the sampling of venous blood. A baseline blood sample (15 ml) was drawn after the subjects had stood quietly for 20 min in a comfortable antechamber (20°C). Exercise blood samples (10 ml) were obtained during the 25th min of alternate (i.e., second, fourth, sixth, etc.) exercise bouts, while the subjects walked on the treadmills.

Just prior to entering the environmental chamber, each subject was given a 500-ml container filled with either the control or the nutrient solution, each initially at 15°C. A refill was provided whenever the container was empty, if the subject wanted a fresh solution, or every 3 h, whichever came first. During the 24-h tests, the subjects were allowed to drink *ad libitum* as long as they remained within 2% of their baseline body weights, otherwise, they were encouraged to drink more (or less) often. They were weighed upon entering the environmental chamber, and again after each 45-min exercise bout. The nutrient solution had an energy value of ~94 kcal • L^{-1} including 24.8 g • L^{-1} CHO, 24 mEq • L^{-1} sodium, and an osmolality of 165 mOsm • kg^{-1}. The control solution was colored-flavored water without carbohydrates or electrolytes. Table I outlines the complete formula for each solution.

Measurements. The electrocardiogram was obtained with chest electrodes (CM5 placement), the signal was radiotelemetered to an oscilloscope-cardiotachometer unit (Hewlett-Packard). During the $\dot{V}O_{2max}$ tests, an automated system (Sensormedics Horizon MMC) was used to collect and analyze expired gas samples to determine O_2 uptake. During the 24-h trials in the envi-

TABLE I. FORMULA FOR THE TEST DRINKS.

	Nutrient Solution (g/L^{-1} water)	Control Solution (g/L^{-1} water)
Malti Dextrin—42	10.396	—
Fructose	14.437	—
Aspartame	0.106	—
Sodium Chloride (Na, 0.52 g/L) (Cl, 0.80 g/L)	1.325	—
Citric Acid	2.650	—
Tricalcium Phosphate	0.389	—
Sodium Benzoate	0.212	—
LL Flavor Fries & Fries 88481	0.064	0.064
LL Flavor Fries & Fries 88484	0.042	0.042
LL Flavor Fries & Fries 80523	0.053	0.053
FDC Yellow 5	0.002	0.002
Lime Shade McCormick C00266	0.004	0.004
Total g/L	29.680	0.165
Total kcal/L	93.7	—
Total CHO (g/L)	24.8 (2.48%)	—
Total Sodium (mEq/L)	24.1 (24 mM)	—
Osmolality (mosm/kg)	165	<5

ronmental chamber, 2-min samples of expired respiratory gases were collected in 150-L Douglas bags 25 min into alternating (i.e., first, third, fifth, etc.) exercise bouts. The gas volumes were measured with a Tissot gasometer, and the O_2 and CO_2 concentrations were measured with an electrochemical O_2 analyzer (Applied Electrochemistry S-3A) and an infrared CO_2 analyzer (Beckman LB-2), respectively. Metabolic rate and respiratory exchange ratio (RER; $\bar{V}CO_2 \cdot \bar{V}O_2^{-1}$) were calculated from these measurements. Endurance time was measured from the beginning of the first exercise bout (shortly after the subjects entered the hot environmental chamber), to the time the subject exited the chamber.

Rectal temperatures were measured with a thermistor probe (Yellow Springs Instruments, Yellow Springs, OH) inserted ~ 10 cm beyond the anal sphincter. Skin temperatures were measured with thermocouples secured to the skin (taped so that tape was not placed on or in direct contact with the thermocouple) at three points on the body (chest, calf, and forearm), from which mean weighted skin temperatures were calculated (1). Total body sweating rates were calculated from weights taken before and after each trial, and after each 45-min exercise bout (K-120 Sauter precision electronic balance, accuracy ±10 g), and adjusted for fluid intake and urine output.

Free flowing venous blood samples were collected from an indwelling flexible Teflon catheter placed within a superficial forearm vein. Patency was maintained with heparinized saline. Triplicate measures were made of all variables, using standard laboratory techniques for hemoglobin (Hemoglobinometer, Coulter Electronics Inc., Hialeah, FL), plasma glucose and free fatty acids (analyzed by Smith Kline Laboratories, Cambridge, MA), and plasma osmolality (freezing point depression, Osmette A, Precision Systems, Inc., Natick, MA).

In a separate experiment, the gastric emptying rate of the nutrient solution was compared to that of water in heat-acclimated subjects during exercise in a hot environment (35°C, 20% rh). After an overnight fast, the subjects were intubated, via the nasal passage, with a #14 French, Levine gastric tube. Each subject ingested 200–300 ml of water to facilitate intubation and to aid in the removal of the fasting gastric residue, following a 10-min warm-up run on the treadmill (2.69 $m \cdot s^{-1}$ 0% grade). After the warm-up exercise, stomach contents were aspirated with a 50-ml syringe. The subjects then ingested 400 ml of water on one day, or the same volume of the nutrient solution on a separate day, immediately followed by 15-min of treadmill exercise (2.69 $m \cdot s^{-1}$, 0% grade, ~55% $\dot{V}O_{2max}$). Each drink was labeled with a non-absorbable marker, phenol red, to allow for quantification of gastric secretions (25). Immediately postexercise, gastric contents were aspirated, and within 10 min, a second 400-ml of test drink was ingested. The entire ingestion-exercise-aspiration procedure was performed three times during each experiment. A detailed description of the experimental procedures has been previously reported (14,15).

Statistical treatment: All experimental data were evaluated using a repeated measures analysis of variance, with Tukey's *post hoc* procedure used to locate significant differences ($p < 0.05$). Due to subject attrition over the course of the 24-h tests, statistical analyses were performed on data through 13 h only, and complete data through 13 h was obtained on only 10 subjects during the control trial, ($n = 10$ for the control, while $n = 11$ for the nutrient trial). Examination of the incomplete data sets after the initial 13 h showed no data trends that had not been previously established. Data are reported as the mean ± S.D.

RESULTS

During the exercise bouts the mean metabolic rate was 404 ± 27 W during CN, and 416 ± 27 W during NT. These values were not significantly different, and represented ~ 30% of maximal aerobic power for these subjects. Respiratory exchange ratios (RER) were lower ($p < 0.01$) during CN from the third exercise bout on (3.5 h), and during both trials decreased ($p < 0.05$) over time. The 13-h RER were 0.75 ± 0.03 for CN, and 0.83 ± 0.05 for NT. There were no significant differences in HR between trials, with gradual increases ($p < 0.05$) over the course of 13 h, averaging 100 $b \cdot min^{-1}$ during CN, and 104 $b \cdot min^{-1}$ during NT.

Fig. 1 illustrates the mean fluid balance determined from the difference between fluid ingested and that lost via urine and sweat. Average fluid ingested per hour was not significantly different between CN (600 ± 135 $ml \cdot h^{-1}$) and NT (723 ± 226 $ml \cdot h^{-1}$). Sweating rates (CN, 518 ± 219 $g \cdot h^{-1}$; NT 547 ± 199 $g \cdot h^{-1}$), urine output (CN, 143 ± 112 $ml \cdot h^{-1}$; NT, 240 ± 173 $ml \cdot h^{-1}$), and body weight loss (CN, −1.7 ± 1.2 kg (−2% body wt); NT, −1.2 ± 0.8 kg (−1.6% body wt) were also not significantly different between trials. For fluid ingestion and urine output, hour by hour volumes were also similar for CN and NT and neither increased nor decreased over time in either trial. When net fluid

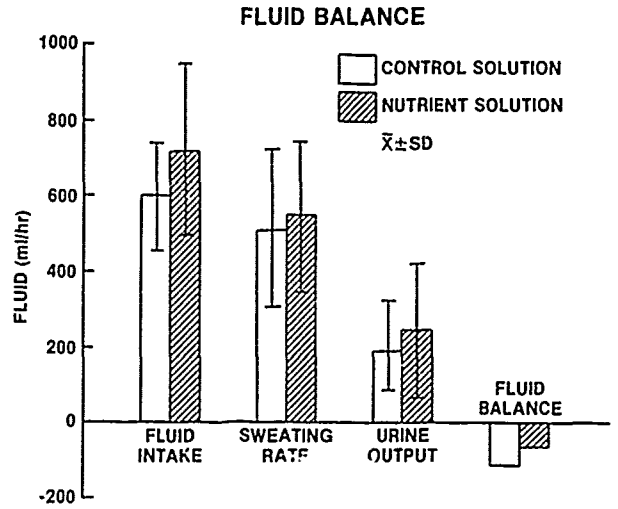

Fig. 1. The subjects' fluid balance during the initial 13 h of the Control and Nutrient Solution experiments.

balance was calculated from these variables, fluid loss averaged ~110 ml • h^{-1} during CN and ~65 ml • h^{-1} during NT.

Fig. 2 presents the subjects' T_{re} and $\overline{T}_{sk}$ responses during the two trials. For T_{re}, no significant differences were found between trials, but in each trial there was an increase ($p < 0.05$) over time. By the completion of 13 h, T_{re} was 37.8 ± 0.22°C for CN, and 38.0 ± 0.22°C for NT. The $\overline{T}_{sk}$ followed the same pattern as T_{re} generally increasing ($p < 0.05$) over time, but not different between trials. At the completion of 13 h the $\overline{T}_{sk}$ was 35.1 ± 0.66°C during CN and 35.4 ± 0.56°C during NT.

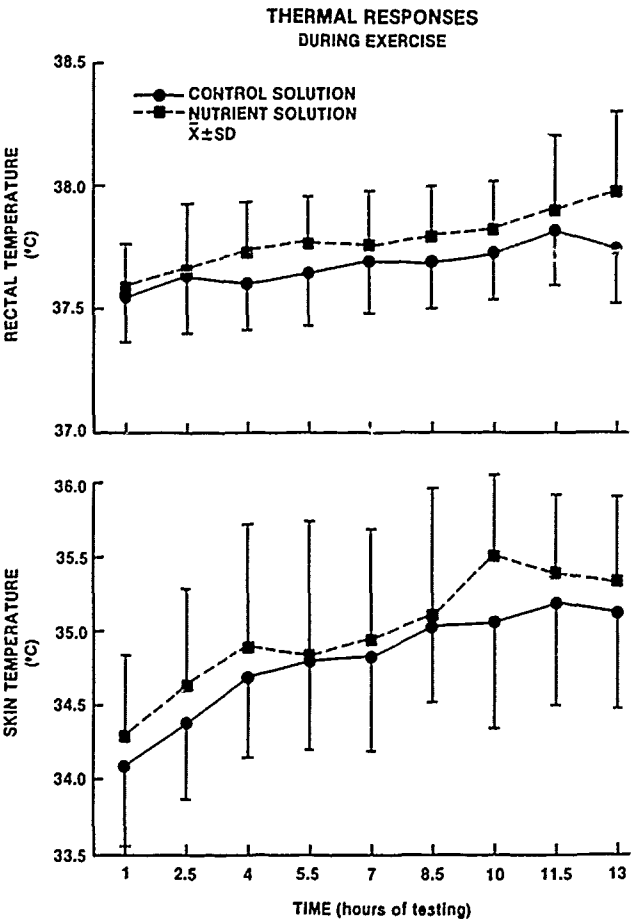

Fig. 2. Rectal temperature and mean skin temperature responses during the 45th min of each exercise bout for the Control and Nutrient Solution experiments.

Table II presents data obtained from the venous blood samples. Plasma osmolality was significantly higher during NT compared to CN at the 8-h and 11-h measurements, while hemoglobin and glucose values were not different between trials through 13 h of testing. However, a trend toward higher glucose levels during NT became more pronounced when incomplete data after 13 h were examined. Plasma free fatty acids were lower, ($p < 0.01$) during NT compared to CN by the 11-h measurement.

During the 24-h experiments the mean endurance times were not different ($p > 0.05$), 16 ± 3 h for CN and 17 ± 4 h for NT. Only two subjects were able to complete 24 h, and both times this occurred during NT. All subjects who withdrew from a trial before 24-h, did so at their own request, for the following reasons: foot and leg soreness (5 cases), blisters (5 cases), chafing (4 cases), overall fatigue (4 cases), lightheadedness and nausea (1 case), and heat rash (1 case). These reasons for discontinuing were nearly equally divided between trials. None of the subjects were removed from testing because of cardiovascular or thermal strain (HR ≥ 180 b • min^{-1} for 5 consecutive min, or T_{re} ≥ 39.5°C, two previously established safety criteria).

Table III presents the gastric emptying characteristics of water and the nutrient solution during exercise in the heat. The gastric emptying rate was similar for the two fluids. The mean gastric emptying rate for each solution was ~20 ml • min^{-1} which indicates that 75% of the original drink was emptied from the stomach within 15 min.

DISCUSSION

The present study examined the thermoregulatory and hydrational effects of a nutrient solution during sustained, moderate intensity activity. This duration and intensity are different from conditions of athletic competition where previous investigators have examined whether the ingestion of carbohydrate-electrolyte beverages can enhance athletic performance, have generally employed high intensity (65–80% $\dot{V}O_{2max}$) exercise of relatively short (<3 h) duration, and have reported equivocal results (3,9). The nutrient solution tested in this study was intended for use in conditions where moderate intensity exercise and moderately high sweating rates could persist for up to 24 h (13). The present investigation was directed toward several military and industrial applications and was successful in meeting the test criteria, as subjects engaged in sustained activity, including exercise at an intensity of 410 W, alternating with rest, which resulted in sweating rates of 530 ml • h^{-1}.

Fluid balance was similar for both experimental conditions, as the subjects dehydrated by nearly 2% of their

TABLE II. HEMATOLOGICAL VALUES FROM VENOUS BLOOD SAMPLES FOR THE CONTROL AND NUTRIENT SOLUTION (NS), $\bar{X}$ (S.D.).

	Sample Time (h)				
	Pre	2	5	8	11
Osmolality (mosm/kg)					
Control	291 (3)	288 (5)	286 (5)	285 (8)	285 (6)
Nutrient	293 (5)	290 (3)	*289 (4)	*290 (4)	*290 (3)
Hemoglobin (g/L)					
Control	160 (10)	146 (7)	148 (9)	146 (9)	148 (9)
Nutrient	156 (4)	145 (6)	144 (6)	142 (8)	145 (7)
Glucose (mmol/L)					
Control	5.9 (1.2)	—	5.2 (0.4)	—	4.9 (0.3)
Nutrient	6.0 (1.2)	—	5.5 (0.5)	—	5.2 (0.4)
Free Fatty Acids (mmol/L)					
Control	0.3 (0.1)	—	0.6 (0.2)	—	1.3 (0.3)
Nutrient	0.2 (0.1)	—	0.4 (0.2)	—	**0.7 (0.2)

* $p < 0.05$; ** $p < 0.01$ (Nutrient compared to Control).

TABLE III. CHARACTERISTICS OF GASTRIC EMPTYING, $\bar{X}$ (S.D.).

	Original Drink, 400 ml emptied (ml)	Emptying Rate (ml/min)
Bout 1		
Control Solution	271 (20)	18 (1)
Nutrient Solution	308 (18)	21 (1)
Bout 2		
Control Solution	325 (18)	22 (1)
Nutrient Solution	295 (17)	20 (1)
Bout 3		
Control Solution	319 (20)	21 (1)
Nutrient Solution	299 (19)	20 (1)

body weight. With this small reduction in body water, the subjects could be classified as being marginally euhydrated or slightly hypohydrated (6). Hypohydration results in increased body heat storage and reduced exercise endurance in comparison to euhydration (14,20,22,24,26). The increased heat storage during hypohydration is attributed to a decreased sweating rate (evaporative heat loss) and decreased cutaneous blood flow (dry heat loss). The physiological mechanisms believed to be responsible for the decreased heat loss are reduced blood volume and plasma hyperosmolality (22–24,26). Since hemoglobin values were nearly identical during both experimental conditions, there was probably no difference in blood volume. Therefore, both experimental conditions resulted in a similar hydrational status for the subjects, as indicated by the indices of body weight and blood volume.

Plasma osmolality was higher by 3–5 mosmol • kg^{-1} during NT than CN. Although the nutrient solution is hypotonic, it contains 24 mEq • L^{-1} of sodium. Apparently some of the additional solutes were not cleared by the kidneys during the exercise-heat exposure, and were retained in the extracellular fluid. Interestingly, T_{ic} and $\bar{T}_{sk}$ were consistently (but not significantly) higher throughout NT compared to CN. Numerous investigators have reported an association between plasma hyperosmolality and elevated core temperature as well as reduced heat loss during exercise-heat stress (16,17,23, 24,26). Also, several studies have demonstrated that the ingestion of hypertonic fluid, despite the maintenance of euhydration, is associated with elevated core temperature in the heat (7,16,17). In this study, the higher osmolalities may have been responsible for the tendency toward higher T_{re} noted during the NT.

The availability of an ingested fluid is dependent upon the rates of gastric emptying and intestinal absorption. The caloric content of the ingested fluid is believed to be a primary factor impeding the rate of gastric emptying, while addition of citric acid can also reduce the gastric emptying rate (2,11). The nutrient solution contained 2.5% carbohydrate and 0.26% citric acid, so in theory it could have reduced the gastric emptying rate compared to water. In the present study, the gastric emptying rate for both solutions was approximately 20 ml • min^{-1}. These values are similar to those previously reported for the gastric emptying rate of water during exercise-heat stress (2,11,14,15,18). In a comprehensive review (2), Costill reported that for resting subjects, water and a 2.5% glucose solution had similar gastric emptying rates, while 5% and 10% glucose solutions progressively decreased the gastric emptying rate. However, he has suggested that up to 8% CHO in an ingested solution would not inhibit the gastric emptying rate during moderate exercise (2).

Ingestion of the nutrient solution resulted in a greater reliance upon CHO utilization as indicated by elevated RER during exercise. A greater dependence on ingested CHO as a substrate was substantiated by somewhat elevated plasma glucose and lower plasma free fatty acid concentrations during NT. Ivy (9) has found that if CHO supplementation can prevent a marked decline in plasma glucose levels, then exercise endurance can be improved. Carbohydrate supplementation can improve either moderate (45% $\dot{V}O_{2max}$) or high (>70% $\dot{V}O_{2max}$) intensity exercise where muscular exhaustion would normally occur within 3–4 h (3,9). In the present investigation, the subjects were able to maintain normal blood glucose concentrations during CN as well as NT, and did not experience muscular exhaustion during either trial. The relative exercise intensity required for this study (30% $\dot{V}O_{2max}$) may have been too low, and the actual endurance times too short (16–17 h) for CHO supplementation to provide a significant benefit to our

subjects who were well nourished prior to the initiation of the experiment.

The only two subjects who completed 24 h of testing were drinking the nutrient solution, and did so during the first of their two experimental trials. None of the test subjects who were assigned the nutrient solution for their second trial were able to complete 24 h. While none of the subjects reached the safety criteria for HR or T_{re}, and so were not removed from testing but stopped at their own request, their foot and leg problems, lightheadedness, or overall fatigue can be described as extreme. These test subjects were highly motivated, but could not reasonably continue testing at the time they requested to stop. Since physiological explanations for any nutrient solution advantage are not readily apparent based on examination of our data, there may have been other reasons for the two completed 24-h nutrient trials. One week between trials may not have been long enough for thorough healing of sore feet and legs, blisters and chafing. Perhaps because of the demanding nature of the study, the subjects may not have been as motivated for the second trial. Additionally, the subjects preferred the nutrient solution, and may have been more motivated to continue in that trial (21). Since most of the subjects' endurance times were limited by foot problems and other reasons probably unrelated to either drink, their effect on endurance *per se* was not tested.

In summary, for men engaged in sustained (through 13 h) physical activity in a hot environment, the thermoregulatory strain, hydrational status, and gastric emptying rates were similar whether they were drinking water or the nutrient solution. These data indicate that no thermoregulatory or hydrational advantages (or disadvantages) are provided by the nutrient solution when it is compared to water during the conditions tested in this study.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the effort of the volunteers for their participation, and Ms. Patricia DeMusis for preparing the manuscript. The views, opinions and findings in this report are those of the authors and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other official documentation.

REFERENCES

1. Burton AL. Human calorimetry II. The average temperature of the tissues of the body. J. Nutr. 1935, 9.261–80.
2. Costill DL. Gastric emptying of fluids during exercise. In. Gisolfi GV, Lamb DR, eds. Perspectives in exercise science and sports medicine. vol 3. fluid homeostasis during exercise. Carmel, IN: Benchmark Press, 1990:97–121.
3. Coyle EF, Coggan AR. Timing of carbohydrate supplementation during prolonged strenuous exercise. In: Berkow S, ed. Fluid replacement and heat stress. Washington, DC: National Academy of Sciences, 1990:VIII1–19.
4. Draper ES, Lombardi JJ. Combined arms in a nuclear/chemical environment: force development testing and experimentation. Summary Evaluation Report Phase I. Ft. McClellan, AL: U S Army Chemical School, 1986.
5. Gisolfi CV, Summers RW, Schedl HP. Intestinal absorption of fluids during rest and exercise. In. Gisolfi GV, Lamb DR, eds. Perspectives in exercise science and sports medicine: vol 3. fluid homeostasis during exercise. Carmel, IN. Benchmark Press. 1990:129–75.
6. Greenleaf JE. Hyperthermia and exercise. In: Robershaw D, ed. Environmental physiology III. Baltimore: University Park Press, Vol. 20. 1979:157–208.
7. Harrison MH, Edwards RJ, Fennessy PA. Intravascular volume and tonicity as factors in the regulation of body temperature. J Appl. Physiol. 1978; 44:69–75.
8. Hubbard RW, Armstrong LE. The heat illnesses: biochemical, ultrastructural and fluid-electrolyte considerations. In. Pandolf KB, Sawka MN, Gonzalez RR, eds. Human performance physiology and environmental medicine at terrestrial extremes Indianapolis: Benchmark Press, 1988:305–59.
9. Ivy JL. Carbohydrate supplements during and immediately post exercise. In: Berkow S, ed. Fluid replacement and heat stress. Washington, DC. National Academy of Sciences, 1990.V1–22.
10. Kety SS. The general metabolism of the brain in vivo. In. Richter D, ed. Metabolism of the nervous system. New York. Pergammon Press. 1957:221–37.
11. Murray R. The effects of consuming carbohydrate-electrolyte beverages on gastric emptying and fluid absorption during and following exercise. Sports Med. 1987, 4.322–51.
12. Muza SR, Pimental NA, Cosimini HM, Sawka MN Portable, ambient air microclimate cooling in simulated desert and tropic conditions. Aviat. Space Environ. Med. 1988; 59:553–8.
13. National Research Council. Conclusions and recommendations from a workshop (June 3–4, 1982), held to determine nutritional requirements of military personnel in protective clothing. Washington, DC. Committee on Nutritional Requirements in Protective Clothing. Food and Nutrition Board, Commission on Life Sciences, National Research Council, 1982.
14. Neufer PD, Young AJ, Sawka MN. Gastric emptying during exercise. effects of acute heat stress, acclimation, and hypohydration. Eur. J. Appl. Physiol. 1989; 58:433–9.
15. Neufer PD, Young AJ, Sawka MN. Gastric emptying during walking and running: effects of varied exercise intensity. Eur. J. Appl. Physiol. 1989; 58:440–5.
16. Nielsen B. Effects of changes in plasma volume and osmolality on thermoregulation during exercise. Acta Physiol. Scand. 1974, 90:725–30.
17. Nielsen B, Hansen G, Jorgensen SO, Nielsen E. Thermoregulation in exercising man during dehydration and hyperhydration with water and saline. Int. J. Biometeor. 1971, 15(2–4). 195–200.
18. Owen MD, Kregel KC, Wall PT, Gisolfi CV. Effects of ingesting carbohydrate beverages during exercise in the heat. Med. Sci. Sports Exerc. 1986; 18:568–75.
19. Pimental NA, Cosimini HM, Sawka MN, Wenger CB. Effectiveness of an air-cooled vest using selected air temperature and humidity combinations. Aviat. Space Environ. Med. 1987; 58:119–24.
20. Pitts GC, Johnson RE, Consolazio FC. Work in the heat as affected by intake of water, salt and glucose. Am. J. Physiol. 1944; 142(2):253–9.
21. Rose MS, Francesconi RP, Levine L, *et al.* Effects of a NBC Nutrient solution on physiological and psychological status during sustained activity in the heat. Natick, MA: United States Army Research Institute of Environmental Medicine, July 1987; Tech. Rpt. No. T25-87.
22. Sawka MN, Pandolf KB. Effects of body water loss on exercise performance and physiological functions. In. Gisolfi CV, Lamb DR, eds. Perspectives in exercise science and sports medicine: Vol 3. fluid homeostasis during exercise. Indianapolis: Benchmark Press, 1990:1–38.
23. Sawka MN, Gonzalez RR, Young AJ, Dennis RC, Valeri CR, Pandolf KB. Control of thermoregulatory sweating during exercise in the heat. Am. J. Physiol. 1989; 257:R311–6.
24. Sawka MN, Young AJ, Francesconi RP, Muza SR, Pandolf KB. Thermoregulatory and blood responses during exercise at graded hypohydration levels. J. Appl. Physiol. 1985, 59.1394–401.
25. Schedl HR. Use of polyethylene glycol and phenol red as unabsorbed indicators for intestinal absorption studies in man. Gut 1966; 7:159–63.
26. Senay LC. Temperature regulation and hypohydration. a singular view. J. Appl. Physiol. 1979; 47:1–7.