R91-33

MILITARY MEDICINE, 156, 9:494, 1991

Acceptability and Effect of Carbohydrate-Electrolyte Solutions on Electrolyte Homeostasis during Field Training

*LTC Madeleine S. Rose, AMSC**
*Patricia C. Szlyk, BA PhD**
*Ralph P. Francesconi, MS PhD**
Laurie S. Lester, PhD†
COL Robert Whang, MC USAR‡

Two lemon-lime flavored 2.5% carbohydrate-electrolyte solutions (CE1 supplemented with Na^+, K^+, and Mg^+; and CE2 supplemented with NA^+) were compared to plain water (water) and lemon-lime flavored water placebo (placebo) to evaluate their acceptability and consumption during 8 days of field training in hot weather. Acceptability ratings and consumption of CE2 and the flavored water placebo were similar and greater, respectively, than those for CE1. Average Na^+ and K^+ intakes, and serum electrolytes levels, were not affected during the 8-day trial. If food intake is adequate, consumption of carbohydrate-electrolyte solutions is apparently unnecessary to maintain electrolyte homeostasis.

Introduction

When unacclimatized soldiers must perform heavy work in a hot environment, extensive dehydration and heat casualties may reduce the effectiveness of a military unit. Loss of more than 2% body weight from sweat can affect both performance and recovery from physical activity.[1-3] Moreover, significant loss of water with accompanying losses in sodium (Na^+) and potassium (K^+) may predispose an individual to heat cramps, exhaustion, or stroke.[2,4-6]

It has been hypothesized that consumption of a carbohydrate-electrolyte solution to replace fluid, energy, and electrolyte losses might reduce fatigue and heat injury. Alternatively, if the carbohydrate beverages are too concentrated, then gastric emptying may be compromised, rehydration delayed,[7-10] and slowed fluid absorption could contribute to dehydration.

While the carbohydrate delivered from a 5% carbohydrate-electrolyte solution may be inadequate to meet the total energy requirements of heavy exercise,[7] the benefits of continued ingestion of a carbohydrate-electrolyte solution (vs. water) during work are: stabilization of blood glucose levels,[11,12] increased intestinal water absorption,[13] and increased consumption due to increased palatability of flavored water.[14]

Researchers do not agree on the requirement for electrolyte replacement during work in the heat, particularly if dietary consumption is adequate.[3,6,15] Current doctrine recommends that salt be added to the food (maximum intake of 10–15 g salt/day) for individuals working in the heat.[4,6,16-18] It should be noted that most of the earlier studies evaluating salt requirements were of short duration (<24 hours),[3,6] did not assess period of acclimatization,[4,15] or were acute observations of desert dwellers.[16]

This study was designed to determine the acceptability of two 2.5% carbohydrate-electrolyte solutions and examine the effects of their long-term (8 days) consumption on fluid intake and on circulating and urinary electrolytes in soldiers consuming an adequate diet during hot weather field training.

Methods

The composition of the two lemon-lime flavored 2.5% carbohydrate-electrolyte solutions (CE1 and CE2) and the overall physical characteristics of the subjects are described elsewhere.[19] Briefly, CE1 (supplemented with Na^+, K^+, and Mg^{++}), CE2 (supplemented with Na^+), plain water (water), and a lemon-lime flavored water placebo (placebo) were evaluated for acceptability. Each subject was given one of the four test beverages (CE1, CE2, water, or placebo) to consume ad libitum as the primary source of drinking fluid, and in addition, each was allowed to consume supplemental water and other liquids (e.g., milk, soda, etc.), especially at meal times.

Soldiers were given fluid intake cards in the a.m. and p.m. to record the number of canteens of primary test beverage and all other beverages consumed between meals. Fluid intake during the two hot meals (breakfast and dinner) was recorded by data collectors. Food intake data were also collected at the A-ration breakfast and dinner meals using a modified visual estimation method.[20] Subjects recorded lunch (Meal Ready to Eat) and snack food intake on the fluid intake card. A 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely)[21] was printed on this fluid intake card and used to rate daily the acceptability of the test beverages during the warmest portion of the day. Acceptability data from an end-of-study questionnaire were collected to obtain general impressions of the test beverages.

Urine was collected twice a day (a.m. and p.m.) and analyzed for sodium (Na^+) and potassium (K^+) concentration. Blood was collected within 2 hours following arrival at Fort Hood and on the eve of day 8. The serum samples were frozen and later analyzed for electrolytes using flame photometry (Radiometer Copenhagen FLM3).

The Statistical Package for the Social Sciences was used to analyze the data. The Newman-Keuls and Tukey post-hoc com-

*Heat Research and Military Nutrition Divisions, U.S. Army Research Institute of Environmental Medicine, Natick, MA† Science and Advanced Technology Directorate, Natick RD&EC, Natick, MA‡ 44th Evacuation Hospital, 807th Medical Brigade, Oklahoma City, OK.

The views of the authors do not purport to reflect the positions of the Department of the Army or the Department of Defense. Human subjects participated in this study 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.

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

TABLE I

HEDONIC RATINGS OF BEVERAGES

Test Beverage	Hedonic Rating: Daily	Hedonic Rating: End-of-Study Questionnaire	Test Beverage Intake (L/d)
CE1	5.1[a]	5.1[a]	2.1 ± 0.2[a]
Water	6.5[c]	6.1[a,b]	2.4 ± 0.2[b]
Placebo	6.6[b,c]	6.6[a,b]	3.0 + 0.2[b]
CE2	6.7[b]	6.9[b]	2.6 ± 0.2[a,b]

Based on 9-point rating scale where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely.
Means with unlike superscripts differ, $p < 0.05$.

parisons were done when significant differences ($p<0.05$) were found. Means ± SE are reported.

Results

Table I shows the mean hedonic ratings for each beverage from the daily and end-of-study evaluations. As anticipated, the ratings were slightly variable in terms of day-to-day quantitative ratings, but the relative order of the ratings was analogous. Both evaluations indicated that CE2 was the most preferred and CE1 the least, and the difference between these two carbohydrate-electrolytes beverages was significant ($p<0.05$). Although subjects drank about 500 ml/day more of CE2 (Table I) than CE1, this difference was not significant. The consumption of either water or placebo was significantly higher than that of CE1, with no significant differences between water and the placebo for hedonic rating or consumption. However, it is important to note that the ratio of test beverage to plain water consumed was 4.4 for the CE1 group, 11.4 for placebo, and 2.6 for CE2.

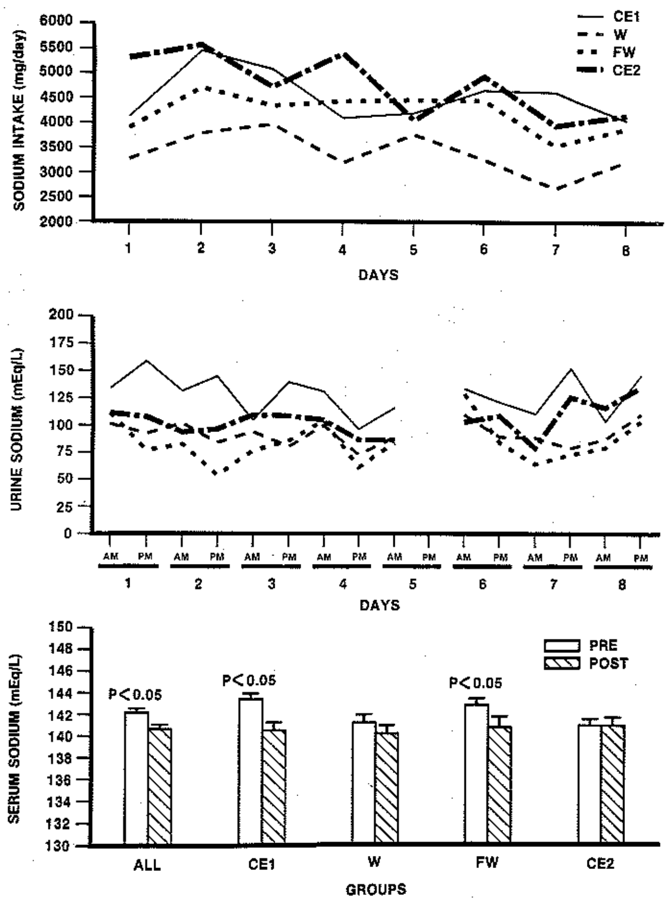

Fig. 1. Sodium changes in dietary intake, urinary excretion, and serum values for each of four test beverage groups before, during, and/or after 8 days of work in the heat. CE1 and CE2 are carbohydrate-electrolyte solutions, W is plain water, and FW is the flavored water placebo.

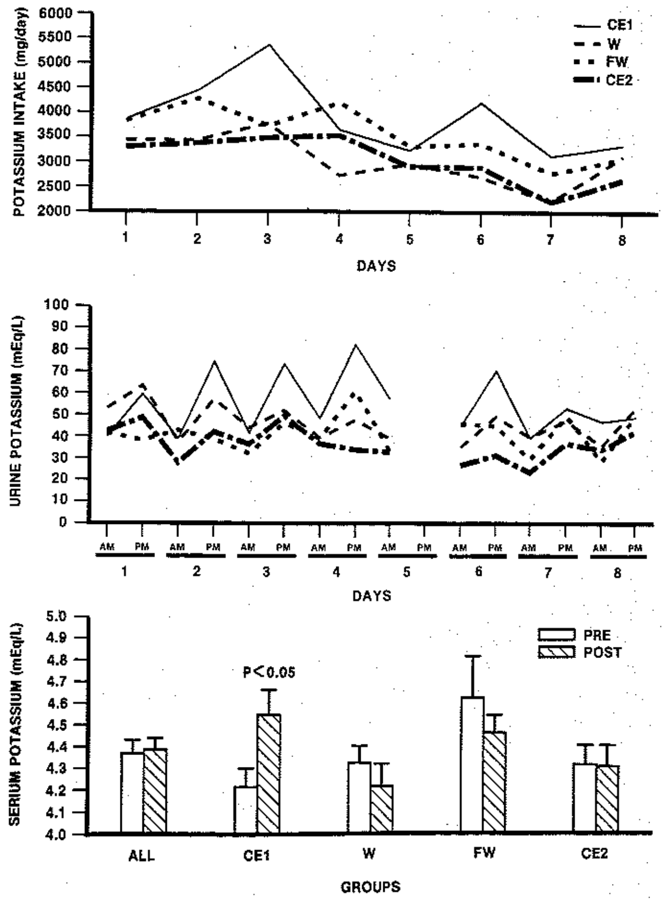

Fig. 2. Potassium changes in dietary intake, urinary excretion, and serum values for each of four test beverage groups before, during, and/or after 8 days of work in the heat. Abbreviations are identical to those in Figure 1.

The mean Na^+ intake for all participants was 4,227 ± 91 mg/day or 10.6 g of salt (Fig. 1). The mean Na^+ intake of the water group (3,393 ± 147 mg/day) was significantly lower than that of all other groups, including the group drinking the unsupplemented placebo (4,217 ± 150 mg/day). The pattern of urinary Na^+ excretion closely followed Na^+ intake. The serum Na^+ values decreased significantly pre- to post-FTX for the CE1 and placebo groups, but these remained well within the range for physiological normality.

The dietary intake (mean 3.4 ± 0.07 g/day), urinary excretion, and serum levels of K^+ are shown in Figure 2. The only difference in K^+ intake among groups was the significantly higher intake in the CE1 group (3.9 ± 1.8 g/day). The CE1 group drank the K^+-supplemented beverage from the morning through late afternoon period, and this was reflected in the elevated urinary K^+ levels in the p.m. samples. The significant increase in serum K^+ in the CE1 group was in contrast to no significant alterations in any of the other groups.

Discussion

The formulation of the carbohydrate-electrolyte solutions appeared to affect acceptability ratings. The hedonic ratings for CE2, which were significantly higher than for CE1, suggested that subjects preferred CE2 over CE1. Additional data suggested that the perceived saltiness of CE1 most likely reduced its acceptability and contributed to its lower consumption.[22] Subjects assigned to the CE1 group recommended reducing the salt content of the CE1 solution.[22] Sweetness was significantly different among CE1, CE2, and the flavored water placebo, and consequently opinions on the amount of sweetness were mixed.

Hedonic ratings of test beverages were positively correlated with consumption data. For example, CE1 was generally the least preferable and also the least consumed of all three of the flavored test beverages. Likewise, both acceptability ratings and consumption of CE2 and the flavored water placebo were remarkably similar.

Since subjects were allowed to supplement the assigned test beverage with water or other fluids and recorded the type and quantity, we were able to compare the consumption of the three test beverages to that of plain water for each group. These results indicated that soldiers preferred each of the colored, flavored test beverages over plain water (flavored water placebo/water = 11.4; CE1/water = 4.4; CE2/water = 2.6).

An active person may lose 8–12 liters of sweat per day[17,18] containing 10–15 g of salt. Thus, the mean salt intake during the present study (10.6 g salt/day) was apparently adequate to replace normal losses in sweat, and supplementation with electrolyte solutions was probably unnecessary. Additionally, when Na^+ intake is decreased, renal conservation mechanisms result in reduced Na^+ excretion. Since subjects who were not receiving an Na^+-supplemented beverage continued to excrete Na^+ at normal levels, dietary intake was apparently adequate in all groups for the work and environmental conditions of the present study. While the intake and urinary excretion of Na^+ was highest in the CE1 group, there also occurred a statistically significant reduction in serum Na^+ in this group. However, this slight reduction was apparently not physiologically significant since levels remained clinically normal.

The combination of the K^+ content of the CE1 beverage and dietary intake in this group led to a statistically significant elevation in mean serum K^+ during this training exercise. With sufficient food intake, the K^+-supplemented beverage probably was unnecessary. For example, the total K^+ intake of the placebo and CE1 groups was similar despite the fact that the CE1 group was drinking a K^+-supplemented solution; both groups completed the test with no significant effects on mean serum K^+ levels.

In conclusion, drinking carbohydrate-electrolyte solutions did not elicit physiologically significant alterations in serum electrolytes. Circulating Na^+ and K^+ levels of all groups remained in the normal clinical range during the 8-day interval. Thus, while the results of this study established the safety of ingesting these beverages under moderate work in the heat, we found no evidence that providing a carbohydrate-electrolyte solution provides nutritional or hydrational benefit to individuals under these conditions. Our data indicate that if food intake is adequate, consumption of water or non-nutritive flavored beverages is sufficient to maintain electrolyte and fluid homeostasis. The effectiveness of carbohydrate-electrolyte solutions under severe heat stress conditions cannot be determined from this study and awaits future field studies.

References

1. Gosselin RE: Rates of sweating in the desert, in Physiology of Man in the Desert, Edited by Adolph EF, New York, Interscience Press, 1947
2. Strydom NB, Wyndham CH, van Graan CH, et al: The influence of water restriction on the performance of men during a prolonged march. S Afr Med J 40:539–544, 1966
3. Ladell WSS: The effects of water and salt intake upon the performance of men working in hot and humid environments. J Physiol 127:11–46, 1955
4. Taylor HL, Henschel A, Michelsen O, et al: The effect of the sodium chloride intake on the work performance of man during exposure to dry heat and experimental heat exhaustion. Am J Physiol 140:439–451, 1943
5. Wyndham CH: Heat stroke and hyperthermia in marathon runners, in The Marathon: Physiological, Medical, Epidemiological, and Psychological Studies. Edited by Milvy P, New York, New York Academy of Sciences, 1977
6. Pitts GC, Johnson RE, Consolazio FC: Work in the heat as affected by intake of water, salt and glucose. Am J Physiol 142:253–259, 1944
7. Foster C, Costill DL, Fink WJ: Gastric-emptying characteristics of glucose and glucose polymer solutions. Res Q Exer Sport 51:299–305, 1980
8. Neufer PD, Costill DL, Fink WJ, et al: Effects of exercise and carbohydrate composition on gastric emptying. Med Sci Sports Exer 18:658–662, 1986
9. Costill DL, Saltin B: Factors limiting gastric emptying during rest and exercise. J Appl Physiol 37:679–683, 1974
10. Coyle EF, Costill DL, Fink WJ, et al: Gastric emptying rates for selected athletic drinks. Res Q 49:119–124, 1978
11. Costill DL, Bennett A, Branam G, et al: Glucose ingestion at rest and during prolonged exercise. J Appl Physiol 34:764–769, 1973
12. Brooke JD, Davis GJ, Green LF: The effects of normal and glucose syrup work diets on the performance of racing cyclists. J Sports Med 15:257–265, 1975
13. Hughes S: Acute secretory diarrhoeas. Drugs 26:80–90, 1983
14. Szlyk PC, Hubbard RW, Matthew WT, et al: Mechanisms of voluntary dehydration among troops in the field. Milit Med 152:405–407, 1987
15. Leithead CS, Leithead LA, Lee FF: Salt deficiency heat exhaustion. Ann Trop Med Parasitol 52:456–467, 1958
16. Sohar E, Adar R: Sodium requirements in Israel under conditions of work in hot climate. UNESCO/India Symp Environ Physiol Psychol Lucknow, Dec 7–12 1962, pp 55–62
17. Lee DHK: Terrestrial animals in dry heat: man in the desert, in Handbook of Physiology. Edited by Dill DB, Adolph EF, Wilber CG, Washington, American Physiology Society, 1964.
18. Dill DB, Jones BF, Edwards HT, et al: Salt economy in extreme dry heat. J Biol Chem 100:755–767, 1933
19. Rose MS, Szlyk PC, Francesconi RP, et al: Carbohydrate-electrolyte solutions during field training: an Overview. Milit Med 156:305–308, 1991.
20. Rose MS, Buchbinder JC, Dugan TB, et al: Determination of nutrient intakes by a modified visual estimation method and computerized nutritional analysis for dietary assessments. Natick, MA, USARIEM Technical Report T6-88, September 1987
21. Peryam DR, Girardot NF: Advanced taste test method. Food Engineering 24:58–61, 1952
22. Rose MS, Szlyk PC, Francesconi RP, et al: Effectiveness and acceptability of nutrient solutions in enhancing fluid intake in the heat. Natick, MA, USARIEM Technical Report T10-89, March 1989