

# Effect of sodium in a rehydration beverage when consumed as a fluid or meal

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**Ray, Melinda L., Mark W. Bryan, Timothy M. Ruden, Shawn M. Baier, Rick L. Sharp, and Douglas S. King.** Effect of sodium in a rehydration beverage when consumed as a fluid or meal. *J. Appl. Physiol.* 85(4): 1329–1336, 1998.—To investigate the impact of fluid composition on rehydration effectiveness, 30 subjects (15 men and 15 women) were studied during 2 h of rehydration after a 2.5% body weight loss. In a randomized crossover design, subjects rehydrated with water (H<sub>2</sub>O), chicken broth (CB: 109.5 mmol/l Na, 25.3 mmol/l K), a carbohydrate-electrolyte drink (CE: 16.0 mmol/l Na, 3.3 mmol/l K), and chicken noodle soup (Soup: 333.8 mmol/l Na, 13.7 mmol/l K). Subjects ingested 175 ml at the start of rehydration and 20 min later; H<sub>2</sub>O was given every 20 min thereafter for a total volume equal to body weight loss during dehydration. At the end of the rehydration period, plasma volume was not significantly different from predehydration values in the CB ( $-1.6 \pm 1.1\%$ ) and Soup ( $-1.4 \pm 0.9\%$ ) trials. In contrast, plasma volume remained significantly ( $P < 0.01$ ) below predehydration values in the H<sub>2</sub>O ( $-5.6 \pm 1.1\%$ ) and CE ( $-4.2 \pm 1.0\%$ ) trials after the rehydration period. Urine volume was greater in the CE ( $310 \pm 30$  ml) than in the CB ( $188 \pm 20$  ml) trial. Urine osmolality was higher in the CB and Soup trials than in the CE trial. Urinary sodium concentration was higher in the Soup and CB trials than in the CE and H<sub>2</sub>O trials. These results provide evidence that the inclusion of sodium in rehydration beverages, as well as consumption of a sodium-containing liquid meal, increases fluid retention and improves plasma volume restoration.

electrolytes; fluid retention; fluid intake

IT WAS OBSERVED BY Adolph and Dill (2) that individuals adapting to desert conditions ingested water (H<sub>2</sub>O) to a greater extent immediately after exercise and during mealtime than at any other time of day. However, fluid ingestion still lagged behind fluid loss during exercise- and heat-induced dehydration; in fact, subjects typically ingested fluids until roughly one-half of their fluid loss had been restored. Failure to adequately replace body fluid losses by ad libitum ingestion, referred to as involuntary dehydration, has subsequently been observed by others (1, 26). Subsequent research has attempted to determine the factors that enhance fluid intake by the athlete and its absorption and subsequent restoration of body weight and plasma volume.

Evidence from the few studies that have examined postexercise rehydration supports the addition of electrolytes, particularly sodium, to a rehydration beverage for promotion of body H<sub>2</sub>O restoration (8, 18, 20, 32). Sodium is the major extracellular ion; thus including sodium in a rehydration beverage influences the restoration of the extracellular (and consequently plasma

volume) fluid space. Costill and Sparks (8) observed a greater plasma volume recovery in subjects consuming a carbohydrate-electrolyte (CE) beverage (22 mmol/l sodium) than in those consuming H<sub>2</sub>O after 4% dehydration. However, neither beverage completely restored plasma volume to predehydration levels after 4 h of rehydration. Body H<sub>2</sub>O restoration may be accelerated when subjects consume beverages containing higher sodium concentrations. For example, Maughan and Leiper (18) observed a positive net fluid balance when subjects consumed beverages containing 52 and 100 mmol/l sodium 5.5 h after a 30-min rehydration period. In contrast, solutions containing less sodium (<26 mmol/l) resulted in a negative fluid balance. Recently, we observed a greater percent recovery of plasma volume when subjects consumed beverages containing 109.5 and 154.5 mmol/l sodium than when they consumed H<sub>2</sub>O or a beverage containing 31.5 mmol/l sodium (unpublished observations).

Previous research indicates that food consumption stimulates fluid intake at rest and during exercise (2, 11, 36). The beverage volume consumed during meals was significantly greater than the beverage volume consumed between meals in resting men: 68% of the total daily fluid intake was consumed at mealtimes (11). Subjects provided H<sub>2</sub>O ad libitum while walking 14.4 km for 6 h in desert conditions increased their H<sub>2</sub>O intake by 50–200% during a 30-min period in which food was available (36).

Few studies have examined the effectiveness of consuming food and fluid simultaneously on body H<sub>2</sub>O restoration after exercise. In one study, subjects were able to restore body weight losses of 4–7% after a 5-h rehydration period in which subjects ingested a 5% CE beverage along with a meal in a volume equal to the volume of fluid lost during exercise (33). Maughan et al. (19) reported a more positive net fluid balance 6 h after subjects consumed a meal and H<sub>2</sub>O after exercise- and thermal-induced dehydration than after subjects received a CE beverage alone. Lower cumulative urine volumes were observed with ingestion of the meal, leading to a greater retention of the ingested fluid.

On the basis of these studies, it is clear that inclusion of sodium in high concentrations in a rehydration beverage is essential in promoting body fluid restoration after heat- and exercise-induced dehydration. In addition, the limited data available on postexercise rehydration with a meal indicate that food consumption may significantly enhance body weight and fluid balance restoration. Solid food is not always available or appealing to the athlete after exercise; consuming a high-sodium beverage and meal simultaneously in the

form of soup would provide the athlete with fluid and electrolytes while minimizing gastric fullness and hunger. Because it is not often practical for athletes to frequently consume large volumes of fluid after exercise, we sought to determine whether consuming a small volume of fluid at the onset of rehydration followed by H<sub>2</sub>O promoted effective body H<sub>2</sub>O restoration. Therefore, the purpose of this investigation was to examine the effectiveness of rehydration with four different beverages: H<sub>2</sub>O, a commonly used CE beverage (CE), and chicken broth (CB) and chicken noodle soup (Soup) containing high concentrations of sodium.

## METHODS

**Subjects.** Thirty subjects (15 men and 15 women) were recruited to participate in the study. They were physically active college-age individuals who typically exercised 3–4 days/wk. Informed consent was obtained from the subjects in accordance with the guidelines established by the Human Subjects Review Board of Iowa State University. Laboratory measurements were made on four randomly assigned days, separated by  $\geq 1$  wk. Physical characteristics of the subjects are presented in Table 1.

**Dehydration.** On each of four visits to the laboratory, subjects underwent a combination of thermal- and exercise-induced dehydration and then a 2-h rehydration period with one of four different beverages in a randomized crossover design. Subjects reported to the laboratory at 7:00 AM after an overnight fast and  $\geq 16$  h after exercise. Subjects voided, and a body weight was obtained. A resting blood sample (5 ml) was obtained by venipuncture without stasis for the determination of Hb, hematocrit, osmolality, and plasma sodium and potassium concentrations. A probe was inserted to a depth of 8 cm beyond the anal sphincter for the measurement of rectal body temperature. Subjects then performed 20 min of light exercise on a cycle ergometer (50–100 W) at 20°C, followed by 10 min of sauna exposure at 65°C. Subjects repeated the alternating periods of exercise and sauna exposure until 2–3% of the initial body weight was lost. During the dehydration period, which lasted for 90–120 min, rectal temperature and heart rate were monitored every 30 min. All urine was collected and pooled for the determination of total urine volume, specific gravity, osmolality, and sodium and potassium concentrations.

**Rehydration.** After the dehydration period, subjects underwent a 30-min transition period to allow the body fluid compartments to stabilize (25). During this time, subjects changed into dry clothes, and a Teflon catheter was inserted into a forearm vein. The catheter was kept patent with infusion of 1–3 ml of 0.9% sodium chloride every 20 min during the rehydration period. After the 30-min transition period, subjects began a 2-h rehydration period in a thermoneutral environment (20°C). Subjects were in a seated position throughout the rehydration period. On each day, subjects rehydrated with H<sub>2</sub>O, CB, CE, or Soup (Table 2). H<sub>2</sub>O was kept at 22°C, and CE was kept at 4°C. CB and Soup were

Table 2. Beverage characteristics

	H <sub>2</sub> O	CB	CE	Soup
Osmolality, mosmol/kgH <sub>2</sub> O	24.5	306.5	359.3	270.5
[Na <sup>+</sup> ], mmol/l	0.0	109.5	16.0	333.8
[K <sup>+</sup> ], mmol/l	0.0	25.3	3.3	13.7
[Ca <sup>2+</sup> ], mmol/l	0.0	1.8	3.7	5.7
Total CHO, g/l	0.0	0.8	64.7	93.0
Simple sugars, g/l	0.0	0.2	51.3	3.0
Total fat, g/l	0.0	1.2	0.0	14.0
Total protein, g/l	0.0	16.5	0.0	30.0

Osmolality for Soup was determined on liquid fraction. Electrolyte and nutrient concentrations for Soup were determined after homogenization. CB, chicken broth; CE, carbohydrate-electrolyte beverage; Soup, chicken noodle soup; [Na<sup>+</sup>], [K<sup>+</sup>], and [Ca<sup>2+</sup>]: Na<sup>+</sup>, K<sup>+</sup>, and Ca<sup>2+</sup> concentration; CHO, carbohydrate.

heated to 120°F before ingestion. Subjects ingested 175 ml (6 ounces) of the respective beverage at the beginning of the rehydration period and 175 ml 20 min later. For the remainder of the rehydration period, subjects ingested an equal volume of H<sub>2</sub>O at 20-min intervals. The total volume ingested by each subject throughout the 2-h rehydration period was equal to the volume of H<sub>2</sub>O lost (decrease in body weight) during dehydration.

**Beverage composition.** Analysis of beverage composition was performed in triplicate. Because of the large quantity of solids in Soup, it was homogenized before analyses of electrolyte and nutrient content. Sodium, potassium, and calcium were measured using an inductively coupled plasma-emission spectrometer (Leeman Plasma-Spec, Leeman Labs, Lowell, MA), as previously described (34). Total fat was measured using a chloroform-methanol extraction-based gravimetric method (2a). Total protein was measured using a micro-Kjeldahl-based method (2a) with an automated system (Technicon Auto Analyzer II, OI Analytical, Wilsonville, OR). Total carbohydrate was calculated using the 4-4-9 rule, based on the fat, protein, solids, and ash contents of the samples. The solids and ash contents were measured using gravimetric weight loss. Solids were measured by weight loss after the sample was heated in a vacuum oven, and ash was measured by weight loss after the sample was heated in a furnace (2a). Total sugars were measured using an automated system (Alpkem 305A photometer, OI Analytical) to colorimetrically measure the total reducing sugars present (3). Osmolalities of the fluids and of the liquid fraction of Soup were determined using a vapor pressure osmometer (model 5500, Wescor, Logan, UT). Osmolality for Soup was determined on the liquid fraction after it was strained.

The total amount of sodium ingested was 40.7 mmol (CB), 6.4 mmol (CE), and 118.4 mmol (Soup). The total amount of potassium ingested was 9.47 mmol (CB), 1.27 mmol (CE), and 4.86 mmol (Soup). Total carbohydrate ingested was 0.28 g (CB), 22.96 g (CE), and 33.0 g (Soup). Soup contained the highest sodium and total carbohydrate concentration among the beverages. CB also contained a significant sodium concentration and had the highest potassium concentration among the beverages. CB and Soup were isotonic, whereas CE was hypertonic, containing a high total carbohydrate content and the lowest electrolyte concentrations among the beverages. Somewhat surprisingly, H<sub>2</sub>O had a measurable osmolality, with no detectable sodium or potassium. Some of the osmolality is likely in the form of calcium and magnesium, which typically amounts to ~5 mosmol/kgH<sub>2</sub>O (Water Treatment Plant, Ames, IA). In addition, this treated H<sub>2</sub>O typically contains a small amount of sodium (~1 mmol/l), which would not be detectable with flame photometry. The other sources of

Table 1. Subject characteristics

	Age, yr	Weight, kg	Height, cm	BMI, kg/m <sup>2</sup>
Men	25 ± 1	82.8 ± 3.2*	179.9 ± 2.3*	25.5 ± 0.6
Women	23 ± 1	61.1 ± 1.3	160.6 ± 2.0	23.8 ± 0.7
Total	24 ± 1	72.0 ± 2.7	170.2 ± 2.3	24.7 ± 0.5

Values are means ± SE for 15 men and 15 women. BMI, body mass index. \*Significantly greater than women ( $P < 0.05$ ).

the osmolality of H<sub>2</sub>O are unknown. However, it is unlikely that this small osmolality in H<sub>2</sub>O created significant osmotic effects. Blood samples, blood pressure, rectal temperature, and body weight were obtained at the beginning of the rehydration period and every 20 min thereafter. Blood samples were taken after the fluid in the dead space of the catheter was discarded and were then immediately transferred into tubes containing lithium heparin for later analysis. On completion of the rehydration period, subjects voided, and a final body weight was obtained. Urine was collected and measured for total volume, specific gravity, osmolality, and sodium and potassium concentrations.

**Percent rehydration.** The percentage of body weight lost during dehydration that was regained during rehydration was used as an index of whole body rehydration (14). The percent rehydration represented the amount of ingested fluid that was retained after the rehydration period. Percent rehydration was determined using body weight and was calculated as follows

$$\% \text{ rehydration} = \frac{[BW_{DH} - (BW_{Pre} - BW_{RH})](\text{kg})}{\text{fluid intake (kg)}} \times 100$$

where  $BW_{Pre}$  is initial body weight,  $BW_{DH}$  is body weight lost during exercise, and  $BW_{RH}$  is body weight after rehydration.

**Biochemical analysis.** Hb concentration was determined in triplicate using the cyanmethemoglobin technique, and hematocrit was determined in triplicate after microcentrifugation. Hematocrit measurements were corrected for plasma trapped within the packed red blood cells (0.96) and also for venous-to-total body hematocrit ratio (0.91) (5). Percent changes in plasma volume from preexercise values were calculated using hematocrit and Hb concentrations according to Dill and Costill (10)

$$\begin{aligned} BV_A &= BV_B(Hb_B/Hb_A) & \Delta BV (\%) &= 100(BV_A - BV_B)/BV_B \\ CV_A &= BV_B(Hct_A) & \Delta CV (\%) &= 100(CV_A - CV_B)/CV_B \\ PV_A &= BV_A - CV_A & \Delta PV (\%) &= 100(PV_A - PV_B)/PV_B \end{aligned}$$

where BV is blood volume, Hb is Hb concentration, CV is red cell volume, Hct is hematocrit, and PV is plasma volume before (B) and after (A) dehydration;  $BV_B = 100$ .

All plasma volume changes were calculated with reference to the predehydration values obtained for the H<sub>2</sub>O trial. Blood samples were then centrifuged, and the plasma was separated and stored at -20°C for later analysis of plasma electrolytes and osmolality. Plasma and urine osmolality were determined in duplicate using a vapor pressure osmometer (model 5520, Wescor). Plasma and urine electrolytes were measured in duplicate using a digital flame analyzer (model 2655-00, Cole-Parmer, Chicago, IL).

**Dietary and exercise control.** Subjects maintained a dietary record for 3 days before the initial trial. Subjects were required to duplicate this diet for 3 days before each of the last three trials. In addition, subjects were instructed to drink an additional 1 liter of H<sub>2</sub>O on the day before all four trials to ensure euhydration. Diet composition was analyzed for the day before each trial using a computer program (FoodComp, Iowa State University). There were no significant differences in energy and electrolyte intake among trials. Subjects also recorded all physical activity performed for 3 days before the initial trial and reproduced this activity pattern for the 3 days before the following trials.

**Statistics.** Values are means  $\pm$  SE. The blood measurements, blood pressure, and rectal temperature during rehydration were subjected to an initial two-way repeated-measures ANOVA; this was followed by Newman-Keuls post hoc tests where appropriate. All other data were analyzed using one-

way ANOVA. Differences among treatments were accepted as being significant when  $P < 0.05$  was obtained.

## RESULTS

The mean weight loss due to combined exercise and sauna exposure was  $1.8 \pm 0.1$  kg, corresponding to a percent body weight loss of  $2.5 \pm 0.1\%$ . There were no significant differences in body weight before and after exercise and after rehydration or in percent change in body weight after dehydration with respect to trial. During the rehydration period the subjects drank an average of  $370 \pm 13$  ml of H<sub>2</sub>O every 20 min between 40 and 120 min of the rehydration period for a total volume of  $1,836 \pm 53$  ml; there were no significant differences in drink volume with respect to trial. Because of the significantly greater body weight in men than in women, percent weight loss ( $2.6 \pm 0.1$  vs.  $2.4 \pm 0.1\%$ ) and total drink volume ( $2,185 \pm 68$  vs.  $1,487 \pm 50$  ml) were greater ( $P < 0.05$ ) in the men than in the women. There were no significant differences in percent recovery in body weight and plasma volume or in any of the urinary measurements between men and women. Therefore, the data for men and women were combined. No gastrointestinal distress was reported by any subject during the rehydration period.

**Percent rehydration.** The body weight after the 2-h rehydration period was not different from the baseline value in any of the trials (Table 3). There were no significant differences in the percentage of body weight loss that was regained at the end of the 2-h period (percent rehydration:  $75.9 \pm 3.2$ ,  $76.0 \pm 1.8$ ,  $74.9 \pm 2.9$ , and  $78.2 \pm 2.9\%$  in H<sub>2</sub>O, CB, CE, and Soup trials, respectively).

There were no significant differences in rectal temperature due to trial during the rehydration period. In addition, there were no significant differences in systolic or diastolic blood pressure during the rehydration period between trials.

**Plasma volume.** After combined intermittent exercise and sauna exposure, plasma volume decreased similarly in each trial. When the data from all trials are combined, plasma volume decreased  $7.0 \pm 0.7\%$  as a consequence of dehydration. At the end of the rehydration period, plasma volume (Fig. 1) was not significantly different from predehydration values in CB ( $-1.6 \pm 1.1\%$ ) and Soup ( $-1.4 \pm 0.9\%$ ) trials. In contrast, plasma volume remained significantly ( $P < 0.01$ ) below predehydration values in H<sub>2</sub>O ( $-5.6 \pm 1.1\%$ ) and CE ( $-4.2 \pm 1.0\%$ ) trials after the rehydration period.

Table 3. *Body weight before and after dehydration and after rehydration period*

	H <sub>2</sub> O	CB	CE	Soup
Baseline	72.0 $\pm$ 2.7	72.3 $\pm$ 2.7	72.0 $\pm$ 2.7	72.2 $\pm$ 2.7
Dehydrated	70.2 $\pm$ 2.6	70.3 $\pm$ 2.6	70.2 $\pm$ 2.6	70.5 $\pm$ 2.6
Rehydrated	71.6 $\pm$ 2.7	71.8 $\pm$ 2.7	71.6 $\pm$ 2.7	71.8 $\pm$ 2.7

Values are means  $\pm$  SE in kg for 15 men and 15 women. There were no significant differences in body weight due to trial ( $P > 0.05$ ).

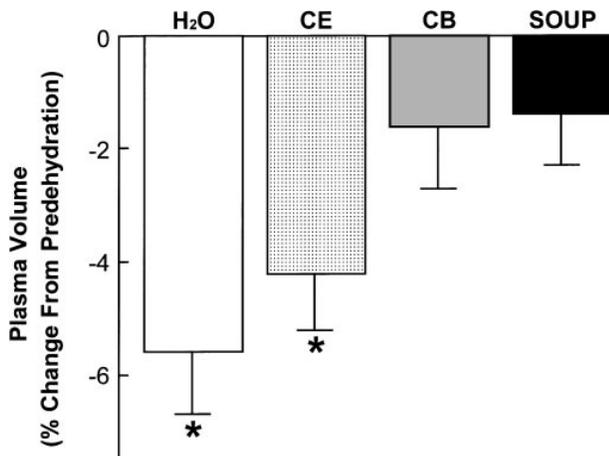


Fig. 1. Percent changes in plasma volume from predehydration values. H<sub>2</sub>O, water; CE, carbohydrate-electrolyte drink; CB, chicken broth; Soup, chicken noodle soup. Values are means  $\pm$  SE;  $n = 30$  subjects. \*Significantly lower than respective predehydration values ( $P < 0.05$ ).

**Urine volume, specific gravity, osmolality, and electrolytes.** Urine volume measured during and at the end of the rehydration period was significantly greater in the CE than in the CB trial (Table 4;  $P = 0.02$ ). There were no significant differences in urine specific gravity with respect to trial. Urine osmolality was significantly higher in the CB and Soup trials than in the CE trial ( $P = 0.01$ ). Urinary sodium concentration was significantly higher in the CB and Soup trials than in the CE and H<sub>2</sub>O trials ( $P = 0.0004$ ). Despite the greater urinary sodium concentrations with CB and Soup, more sodium was retained with ingestion of these beverages than with CE and H<sub>2</sub>O (Table 5;  $P < 0.05$ ). In fact, urinary sodium output exceeded sodium intake in the CE and H<sub>2</sub>O trials. Although the total urinary excretion of potassium did not differ between trials, the urinary potassium concentration was significantly higher with CB than with the other three beverages (Table 4;  $P = 0.007$ ).

**Plasma osmolality.** Before dehydration, plasma osmolality averaged  $274.9 \pm 0.6$  mosmol/kgH<sub>2</sub>O (Fig. 2). Exposure to heat and prolonged exercise resulted in a mean increase in plasma osmolality to  $281.6 \pm 0.6$  mosmol/kgH<sub>2</sub>O. Plasma osmolality in the CB and CE trials was significantly greater than in the H<sub>2</sub>O trial (significant main effect,  $P = 0.04$ ).

**Plasma electrolytes.** The mean plasma sodium concentration (Fig. 3) increased from  $137.0 \pm 0.2$  to  $140.3 \pm 0.2$  mmol/l after dehydration. There were no significant

differences in plasma sodium concentration due to trial. The plasma potassium concentration (Fig. 4) increased from  $3.92 \pm 0.04$  to  $4.01 \pm 0.03$  mmol/l after dehydration. The plasma potassium concentration in the Soup trial was significantly lower than in the CB trial at 20–120 min, the H<sub>2</sub>O trial at 40–80 and 120 min, and the CE trial at 40 min ( $P < 0.05$ ). In addition, the plasma potassium concentration was higher in the CB trial than in the CE trial at 60 and 80 min of rehydration.

## DISCUSSION

Consuming CB or Soup after heat- and exercise-induced dehydration resulted in a significant recovery in plasma volume and reduced urine volumes compared with H<sub>2</sub>O. In contrast, ingestion of a commonly used CE beverage did not restore plasma volume more effectively than did ingestion of H<sub>2</sub>O and resulted in a greater urine production than the other beverages. These results are interesting, since subjects ingested only 350 ml (12 ounces) of each beverage during the first 20 min of the rehydration period.

Previous studies have shown that the extent to which body fluid balance is restored varies with the composition of a rehydration beverage. Electrolyte concentrations are higher with CB (109.5 mmol/l Na, 25.3 mmol/l K) and Soup (333.8 mmol/l Na, 13.7 mmol/l K) than with many sports drinks used for rehydration after exercise, including the CE beverage used in this study (16 mmol/l Na, 3.3 mmol/l K). Soup contained the highest carbohydrate concentration, followed by CE and CB, whereas CE was the most concentrated beverage; CB and Soup were relatively isotonic. Consequently, analysis of the effect of consumption of these beverages on rehydration is somewhat complex because of the variation in electrolyte and carbohydrate concentration, as well as osmolality, among these beverages. This complexity is exacerbated by the difficulty in assessing the osmotic effects of Soup because of its large solid fraction. Although the osmolality of this beverage as consumed was the lowest among the three test beverages, it is likely that this beverage displays significantly higher osmolality within the gastrointestinal tract. In fact, complete hydrolysis of the carbohydrate in this beverage would increase the osmolality of this solution to  $\sim 870$  mosmol/kgH<sub>2</sub>O. However, because some of the osmolytes are absorbed as the contents pass through the gastrointestinal tract, it is impossible to predict precisely the effective osmolality in the intestine.

Table 4. Urinary measurements during rehydration

	H <sub>2</sub> O	CB	CE	Soup
Volume, ml	232.3 $\pm$ 31.2	188.2 $\pm$ 19.6	309.9 $\pm$ 30.2*	231.3 $\pm$ 28.6
Specific gravity	1.016 $\pm$ 0.001	1.026 $\pm$ 0.004	1.020 $\pm$ 0.005	1.019 $\pm$ 0.001
Osmolality, mosmol/kgH <sub>2</sub> O	491.2 $\pm$ 48.9	609.7 $\pm$ 39.4†	401.8 $\pm$ 51.0	567.6 $\pm$ 51.2†
[Na <sup>+</sup> ], mmol/l	60.9 $\pm$ 6.6	87.2 $\pm$ 6.7‡	48.0 $\pm$ 7.0	90.2 $\pm$ 10.7‡
[K <sup>+</sup> ], mmol/l	65.4 $\pm$ 6.7	88.9 $\pm$ 6.3§	51.4 $\pm$ 6.0	68.0 $\pm$ 6.2

Values are means  $\pm$  SE for 30 subjects. \*Significantly higher than CB ( $P < 0.05$ ); †significantly higher than CE ( $P < 0.05$ ); ‡significantly higher than CE and H<sub>2</sub>O ( $P < 0.05$ ); §significantly higher than H<sub>2</sub>O, Soup, and CE ( $P < 0.05$ ).

**Table 5. Intake and total urinary output of sodium and potassium**

	H <sub>2</sub> O	CB	CE	Soup
<b>Intake</b>				
Sodium	0.0*	40.7*	6.4*	118.4*
Potassium	0.0*	8.9*	1.2*	4.9*
<b>Output</b>				
Sodium	16.2 ± 4.0	16.5 ± 2.2	14.8 ± 3.2	19.7 ± 3.2
Potassium	15.2 ± 2.9	16.5 ± 2.0	15.8 ± 3.2	16.4 ± 3.1

Values are means ± SE in mmol for 30 subjects. \*Significantly different from each other,  $P < 0.05$ .

The addition of sodium to a rehydration beverage significantly increases fluid retention in the extracellular space, leading to a greater plasma volume restoration than is observed after ingestion of H<sub>2</sub>O and dilute electrolyte solutions (8, 14, 26; unpublished observations). Recently, we observed significantly higher recovery of plasma volume and lower urine volumes after ingestion of beverages containing 109.5 and 159.5 mmol/l sodium than after ingestion of a beverage containing 31.5 mmol/l sodium or H<sub>2</sub>O (unpublished observations). In the present study the higher sodium concentration in CB and Soup was associated with a significantly higher plasma volume recovery and lower urine volumes than was ingestion of H<sub>2</sub>O. On the other hand, Gisolfi et al. (13) recently observed no differences in plasma volume expansion after infusion of 6% glucose solutions containing 0, 25, or 50 mmol/l sodium into the duodenojejunum and concluded that addition of sodium to fluid rehydration beverages may not be of importance in fluid absorption. One explanation for the differences between the study of Gisolfi et al. and the present study may be the higher sodium concentrations used in the beverages in the present study.

In the present study, consuming CE resulted in a similar plasma volume recovery and larger urine volume than did ingestion of H<sub>2</sub>O. These findings do not agree with those of previous studies demonstrating

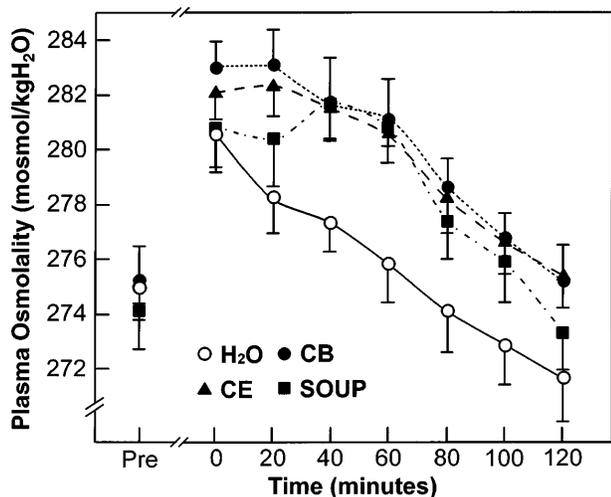


Fig. 2. Plasma osmolality during 2 h of rehydration. Values are means ± SE;  $n = 30$  subjects. Pre, prehydration. CB and CE significantly higher than H<sub>2</sub>O (significant main effect,  $P = 0.04$ ).

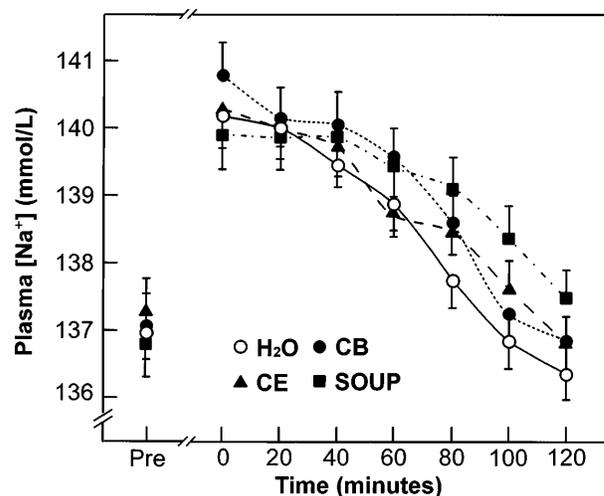


Fig. 3. Plasma sodium concentrations ( $[Na^+]$ ) during 2 h of rehydration. Values are means ± SE;  $n = 30$  subjects.

greater plasma volume recovery and reduced urine volumes with ingestion of beverages similar in composition to CE than with ingestion of H<sub>2</sub>O (8, 14). The reason for the differences between these studies and the present study is unclear, particularly given the similarity in methodology used in these studies. However, the relatively large number of subjects used in the present study reduces the possibility that the high urine volumes observed in CE can be attributed to experimental error.

The production of larger volumes of dilute urine produced in CE than in H<sub>2</sub>O trials is puzzling in light of the higher plasma osmolality in CE. One possibility is that the temperature at which CE was administered (4°C) influenced the rate at which fluid emptied from the stomach, because some have reported that colder beverages empty faster than warmer beverages (7). In contrast, others have observed no effect of beverage temperature on gastric emptying (21) or a slowing of gastric emptying with cold drinks (35). Therefore, it is

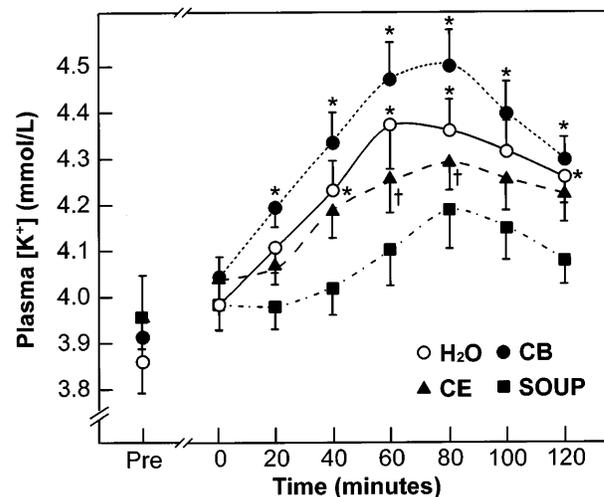


Fig. 4. Plasma potassium concentration ( $[K^+]$ ) during 2 h of rehydration. Values are means ± SE;  $n = 30$  subjects. \*Significantly higher than Soup ( $P < 0.05$ ). †Significantly lower than CB ( $P < 0.05$ ).

unlikely that the temperature of CE affected gastric emptying. An additional possibility may be a direct effect of beverage temperature on arginine vasopressin secretion. Plasma arginine vasopressin concentrations have been reported to be reduced in dehydrated men eating ice chips, despite no change in plasma osmolality and sodium concentrations (31). Thus there may be cold-sensitive oropharyngeal receptors that inhibit arginine vasopressin secretion. An inhibition of vasopressin may account in part for the greater urine volume observed in the subjects consuming CE than in those consuming H<sub>2</sub>O, although further investigation is needed to clarify the effects of beverage temperature on gastric emptying and urine production.

The high sodium intake in the CB and Soup trials may have stimulated fluid control mechanisms, which reduced urine output and thereby increased plasma volume. Fluid-regulating hormones, including renin, ANG II, aldosterone, and arginine vasopressin, are released in response to heat exposure (16), exercise (6, 30), and increases in plasma osmolality (37), promoting the absorption of H<sub>2</sub>O and active uptake of solutes by the kidney. Previous studies have shown that rehydrating with H<sub>2</sub>O or a dilute electrolyte solution results in a drop in plasma osmolality and plasma sodium concentrations, as well as renin, ANG II, and aldosterone concentrations (8, 14, 27, 32, 37). In the present study, plasma osmolality was lower in the subjects consuming H<sub>2</sub>O than in those consuming CB and CE. The lower plasma osmolality in the H<sub>2</sub>O trial may have prevented the maintenance of the fluid-regulating hormones, leading to excess fluid filtration and renal solute reabsorption. A reduction in the concentration of fluid-regulating hormones would explain the higher urine volumes in the H<sub>2</sub>O than in the CB trial and lower urine osmolality and electrolyte concentrations in the H<sub>2</sub>O trial than in the CB and Soup trials. The protein in the Soup may also have contributed to the high urine osmolality by increasing nitrogen output in the urine. However, this is unlikely, since a similar urine osmolality was seen in CB, which contained minimal protein.

The significantly higher plasma potassium concentration in CB is likely due to the increase in extracellular potassium concentration brought about by dehydration and maintained by ingesting CB, the beverage containing the highest potassium concentration. The urinary potassium concentration was significantly higher in CB than in the other beverages. Nielsen et al. (24) observed similar elevations in plasma potassium concentration and urinary potassium excretion after consumption of a beverage containing high concentrations of potassium compared with beverages containing glucose and sodium. Thus the higher plasma potassium concentration may have promoted potassium excretion by the kidneys in the attempt to restore extracellular potassium concentrations.

The explanation for the elevated plasma potassium concentrations throughout the rehydration period in all beverages is unclear, particularly since subjects ingested only 350 ml of each beverage at the beginning of the rehydration period. Others have shown no signifi-

cant differences in plasma potassium concentrations after ingestion of a meal or beverages containing various concentrations of potassium (19, 20). The significantly lower plasma potassium concentrations observed in Soup than in the other beverages are also somewhat surprising, given the greater amount of potassium in Soup than in CE and H<sub>2</sub>O. However, a significant portion of the potassium in Soup is likely contained within the chicken pieces; thus the time required for digestion and absorption may have resulted in the lower plasma potassium concentrations.

Previous investigators have suggested that ingestion of beverages high in potassium concentration may delay rates of plasma volume recovery because of restoration of the intracellular fluid compartment at the expense of extracellular fluid (23, 24). However, Maughan et al. (20) observed no differences in plasma volume recovery 6 h after rehydration with four beverages containing glucose, sodium, potassium, and a combination of glucose, sodium, and potassium. Recently, we observed a lower plasma volume recovery after ingestion of a low-sodium beverage containing high concentrations of potassium (75.8 mmol/l) than after ingestion of beverages containing lower potassium and higher sodium concentrations (unpublished observations). In the present study, consuming CB resulted in a significantly greater plasma volume recovery than consuming H<sub>2</sub>O, despite the fact that CB contained the highest potassium concentration (25.3 mmol/l). However, the potassium concentration in CB is not as high as that of the high-potassium beverage used in the previous study. Taken together, these studies suggest that consuming high concentrations of potassium may not impair rehydration, provided the sodium concentration of the beverage is adequate.

The few studies that have examined the effects of food ingestion on postexercise rehydration report a greater restoration of body weight and plasma volume when a meal and beverage are consumed than when only a beverage is consumed (19, 33), presumably because of the greater intake of electrolytes as well as protein and carbohydrate with the meal. One might expect that consuming Soup, which contained higher concentrations of sodium, protein, and carbohydrate than did the other beverages, would result in a lower urine volume and greater body weight restoration than was observed because of the impact of these nutrients on fluid absorption. It has previously been reported that sodium enhances intestinal H<sub>2</sub>O absorption and promotes greater fluid retention in the extracellular space (12, 26). In addition, specific amino acids such as glycine and alanine also promote net fluid absorption by the small intestine (15). Finally, the addition of glucose to a rehydration beverage has been shown to stimulate sodium and H<sub>2</sub>O absorption in the small intestine (12). In contrast, fat ingestion has a well-known effect of retarding gastric emptying, which would reduce rehydration effectiveness. The improved rehydration with Soup, which included a small amount (4.9 g) of fat, suggests that any effect of fat in reducing

the effectiveness of Soup was obviated by the presence of sodium, carbohydrate, and protein in this beverage.

Whether the enhanced fluid absorption in the small intestine observed with protein and carbohydrate results in an improved whole body H<sub>2</sub>O restoration remains unclear. The consumption of CE, which contained a high carbohydrate concentration, did not result in a significant plasma volume recovery, whereas similar plasma volume recovery was observed with Soup, which contained significant carbohydrate, and CB, which contained minimal carbohydrate. It is possible that the lack of body H<sub>2</sub>O restoration is related to the high osmolality of CE relative to the other beverages. It has previously been shown that fluids with high osmotic concentrations slow gastric emptying (4, 9). On the other hand, others have found that relatively hypertonic CE solutions do not impair rehydration compared with H<sub>2</sub>O (8, 17). Furthermore, the more effective rehydration observed after consumption of Soup, despite the expected hypertonic nature of this beverage in the intestine, also suggests that any negative consequences of ingesting a beverage with a high osmolality may be offset by the inclusion of adequate amounts of sodium. On the basis of these studies, it is difficult to conclude whether the high osmolality or a combination of the high osmolality and low electrolyte concentration of CE impaired rehydration. Inclusion of carbohydrate in a rehydration beverage may be desirable in terms of providing energy during the recovery from exercise. It does appear, however, that greater attention should be paid to sodium than to carbohydrate when formulating a beverage to be used primarily for rehydration purposes. In this study, consuming isotonic beverages containing high sodium concentrations and high or low carbohydrate concentrations was more effective in restoring body H<sub>2</sub>O losses than consuming H<sub>2</sub>O or a relatively hypertonic beverage high in carbohydrate and low in sodium concentration.

In conclusion, greater plasma volume recovery and lower urine volumes were observed in subjects ingesting CB and Soup, containing high concentrations of sodium, than in those consuming H<sub>2</sub>O and CE. These differences were seen, despite the ingestion of only 350 ml of each beverage at the onset of rehydration. Thus the composition of a fluid consumed immediately after heat- and exercise-induced dehydration has an important impact on body fluid restoration and should be considered if rapid rehydration is a goal. Although consuming a meal such as Soup has the advantage of providing fluid and electrolytes while minimizing hunger commonly experienced after exercise, additional research is needed to formulate a rehydration beverage containing the optimal combination of electrolytes, carbohydrates, and possibly protein to maximize body H<sub>2</sub>O restoration.

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