Fluid Replacement after Dehydration: Influence of Beverage Carbonation and Carbohydrate Content

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Abstract

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This investigation evaluated the effects of beverage carbonation and carbohydrate (CHO) content on fluid replacement following exercise/thermal dehydration. On four occasions separated by at least 7 days, eight healthy men cycled at 50% of $\dot{V}O_2$max in a hot environmental chamber (40 °C, 40% relative humidity) until a weight loss of $4.12 \pm 0.22\%$ was attained. In the subsequent four hours, subjects ingested one of four solutions at 15-min intervals. The total volume ingested equalled that lost during dehydration. The solutions were administered in randomized order and varied in their carbonation and carbohydrate (CHO) content: 1. CK: carbonated 10% glucose-fructose solution, 2. NCK: non-carbonated 10% glucose-fructose solution, 3. CNK: carbonated non-caloric solution, and 4. NCNK: non-carbonated non-caloric solution. Plasma volume changes, total plasma protein concentration, plasma osmolality, and the plasma glucose concentration were determined at rest before and after dehydration, and at 30, 90, 150, and 240 min of recovery. Plasma volume changes and the plasma protein concentration were not different (p > 0.05) between treatments. Values for the plasma glucose concentration and the change in plasma osmolality were significantly elevated when CHO beverages were ingested when compared with non-CHO beverage ingestion. Five-min cycling bouts were performed at 70% of $\dot{V}O_2$max before and after dehydration and at 60, 120, 180, and 240 min of rehydration. The respiratory exchange ratio was elevated in both of the CHO treatments when compared with both of the non-CHO treatments at 60, 120, 180 and 240 min of rehydration. Lactate determined from arterialized capillary blood obtained one minute after each cycling bout was not different between treatments at any time point. Heart rates during the standardized cycling bouts remained elevated relative to the pre-dehydration values in all treatments after 240 min of recovery despite ingestion of a volume of fluid equal to that lost. In addition, heart rates were significantly elevated in the CK treatment relative to other treatments at 60 (vs CNK and NCNK), 120 (vs CNK and NCNK), 180 (vs NCNK), and 240 min (vs NCK). Rectal temperatures during the cycling bouts were significantly elevated in the carbohydrate treatments relative to the non-carbohydrate treatments at 120 min (CK vs NCNK, NCK vs NCNK) and 180 minutes (CK vs NCNK and CNK) but remained within the normal range (37.3–37.6 °C). No differences were observed in the % body weight loss or total urine volume after 240 min of recovery. The results suggest that solutions which are carbonated and/or contain 10% CHO are as effective as non-carbonated and non-CHO solutions with regard to fluid replacement over four hours.

Key words

Fluid replacement, rehydration, carbonation

Introduction

Heat tolerance during exercise is highly related to the body's state of hydration (3, 19, 23). In addition, the alterations in physiology which accompany hypohydration reduce exercise capacity (1, 14, 26). Carbohydrate availability, in addition to body water status, is also a primary determinant of exercise performance (2, 4). For the athlete who must train or compete in the hours or days following dehydrating exercise, it is imperative that he rapidly replaces both fluid and carbohydrate.

Although numerous attempts have been made to determine the optimal beverage for maintenance of euhydration and carbohydrate oxidation during exercise (18, 22, 24), little scientific inquiry has been directed at fluid replacement following dehydrating exercise. In one of the few investigations to evaluate different beverages during controlled rehydration (in contrast to ad libitum rehydration), Costill and Sparks (6) reported that plasma volume restoration was greater and body weight recovery was similar when sweat losses were replaced with a 10.6% glucose-electrolyte solution as compared with demineralized water.
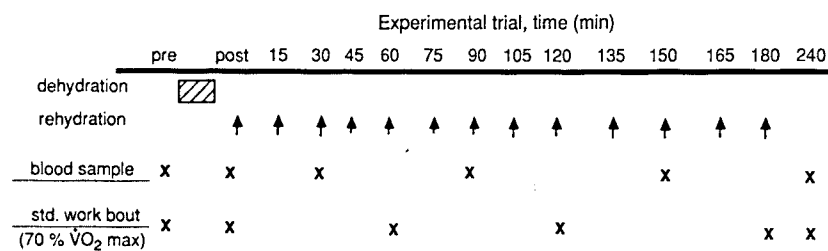
					Experimental trial, time (min)									
	pre	post	15	30	45	60	75	90	105	120	135	150	165	180	240
dehydration	▨														
rehydration			↑	↑	↑	↑	↑	↑	↑	↑	↑		↑	↑	↑	
blood sample	X	X		X				X					X			X
std. work bout (70 % V̇O₂ max)	X	X			X					X					X	X

Fig. 1 Schematic representation of the experimental protocol.

Although optimal fluid and carbohydrate replacement are important to athletes following exercise, other factors such as palatability often dictate the choice of beverage. As a result, carbonated "soft drinks" are often ingested following exercise.

Despite the widespread use of carbonated beverages for rehydration, little scientific inquiry has evaluated this practice. An early investigation conducted by Lolli et al. (16) suggested that the addition of CO_2 to water hastened gastric emptying. However, in another early investigation Hale et al. (10) found no difference in the gastric emptying rates of water or carbonated water when measured at 10-minute intervals after the ingestion of 250 ml. Recently, Zachwieja et al. (27) also found no difference in the gastric emptying rates of water and carbonated water ingested during 20 min of cycle exercise (55% of $\dot{V}O_2$max). Furthermore, Ryan et al. (25) found no differences in the gastric emptying of 6% carbohydrate, 6% carbonated carbohydrate, 10% carbohydrate, or 10% carbonated carbohydrate solutions during 1 h of treadmill running (60−65% of $\dot{V}O_2$max).

Prolonged rehydration with carbonated beverages following relatively large sweat losses has not previously been evaluated. Consequently, the present investigation was an initial attempt to evaluate fluid replacement with carbonated beverages. An additional purpose of this investigation was to determine the effectiveness of rehydration with solutions containing a carbohydrate concentration of 10% and to evaluate possible interactive effects between beverage carbonation and carbohydrate content.

Materials and Methods
Subjects

Eight healthy men (age 28.0 ± 6.0 yrs (mean ± SD), height 177.0 ± 5.0 cm, weight 79.4 kg, $\dot{V}O_2$max 3.96 ± 0.3 l/min, and % body fat 12.8 ± 4.5) participated in this investigation after being informed of the risks and stresses involved and giving their written consent. Prior to initiating this investigation, approval was obtained from the university institutional review board.

Preliminary Testing

One week prior to experimental testing, each subject's maximal oxygen consumption ($\dot{V}O_2$max) was determined. Subjects cycled on a Lode (Groningen, Holland) constant power ergometer at 125, 175, and 225 watts for 5, 3, and 3 minutes. Thereafter, the workload was increased by 25 watts each minute until volitional exhaustion. Expired gases were sampled from a mixing chamber using an Applied Electro-

chemistry S-3A O_2 analyzer (Applied Electrochemistry, Sunnyvale, CA) and a Beckman LB-2 CO_2 analyzer (Fullerton, CA). Inspired gas volumes were quantified using a Parkinson-Cowan gas meter (Instrumentation Associates Inc., New York, NY). Both the gas composition and volume information were processed through an analog-to-digital converter which was interfaced with an Apple II microcomputer for the determination of oxygen consumption ($\dot{V}O_2$) and the respiratory exchange ratio (RER). Workloads corresponding to 50 and 70% of $\dot{V}O_2$max were determined for use during the experimental trials.

Experimental Testing

A schematic representation of the testing sequence is presented in Fig. 1.

Dehydration Procedure

On four occasions separated by at least seven days the subjects reduced their body weight by approximately 4% by cycling at 50% of $\dot{V}O_2$max on a Monark cycle ergometer (Stockholm, Sweden) in a hot environmental chamber (40 °C, 40% relative humidity). Body weight loss and exercise duration were constant for each subject for the four trials. On the evening prior to each testing session, subjects ingested ~ 500 ml of water at 2100 hours to ensure euhydration. Immediately prior to dehydration, the subjects urinated and were weighed on a balance accurate to ± 10 grams. After completion of 60, 90, and 105 minutes of exercise, the subjects recovered for approximately five minutes in a normal (~ 23 °C, ~ 50% relative humidity) environment to dry themselves and be reweighed. Immediately after being weighed the subjects resumed exercise and were weighed periodically until the desired weight loss was attained. Rectal temperatures and heart rate were continually monitored during the dehydration procedure.

Test Solutions

Following dehydration, subjects ingested one of four solutions, assigned in randomized order, during the first three hours of recovery. A total of 13 feedings, each of which corresponded to 7.7% of the weight lost during dehydration, were given at 15-minute intervals. The test solutions varied in their carbohydrate (CHO) and CO_2 content: 1) carbonated 10% glucose-fructose (CK), 2) carbonated non-carbohydrate (CNK), 3) non-carbonated 10% glucose-fructose (NCK), and 4) non-carbonated non-carbohydrate (NCNK). Carbonation represented 2.5% of the volume for CK and CNK. The test solutions were kept in 946 ml bottles at 4 °C prior to and after beverage distribution. After distributing each 15-minute volume, the bottle was sealed tightly to prevent

Table 1 Test solution composition.

	CK	CNK	NCK	NCNK
Carbohydrate (g/100 ml)	10.0	0.0	10.0	0.0
Glucose (g/100 ml)	3.8	0.0	3.8	0.0
Fructose (g/100 ml)	5.7	0.0	5.7	0.0
Other (g/100 ml)	0.5	0.0	0.5	0.0
Sodium (mmol/l)	10.9	7.2	10.9	7.2
Potassium (mmol/l)	4.3	5.0	4.3	5.0
Osmolality (mOsm/kg)	648	57	627	36
pH	3.2	3.3	+3.2	3.3

a loss of carbonation. The pertinent characteristics of these beverages are presented in Table **1**.

Resting Measurement

Prior to and immediately after dehydration, the subjects were seated for 15 minutes prior to any data collection. A venous blood sample (5 ml) was then obtained from a superficial forearm vein. Similar blood samples were obtained at 30, 90, 150, and 240 minutes of rehydration. Following data collection at 240 minutes, the subjects urinated and were weighed. Urine volume and body weight were then determined.

Standardized Cycling Bout

Following the resting measurements before (Pre), immediately after dehydration (Post), and at 60, 120, 180, and 240 minutes, the subjects performed a 5-minute cycling bout at 70% of $\dot{V}O_2$max. Expired gases were obtained during the last minute of each bout using the Douglas bag method. $\dot{V}O_2$, RER were determined (as described in the preliminary testing section). Heart rates and rectal temperatures were obtained at 15-second intervals during the last two minutes of exercise, while a rating of gastrointestinal comfort (1 = Very comfortable, 2 = Comfortable, 3 = Moderately uncomfortable, 4 = Very uncomfortable) was obtained with 15 seconds remaining in each bout (Table **3**). In addition, immediately after the standardized bout a 30 ul arterialized-capillary blood sample was obtained from the subject's earlobe (15).

Blood Analysis

All resting venous blood samples were obtained with a 21 gauge needle and heparinized syringe. Hemoglobin concentration (cyanmethhemoglobin method) and hematocrit (microcentrifuge method) were determined for the calculation of plasma volume changes (7). The remaining blood was centrifuged at 1000 g for 12 minutes. The supernatant was removed and frozen at − 80 °C until analysis. Prior to analysis each sample was centrifuged at 2000 g for 10 minutes and the supernatant used for subsequent biochemical determinations. Plasma protein concentration was determined using the Biuret method (5); an enzymatic method (17) was used for determination of glucose concentration. Plasma osmolality was quantified using freezing point depression (Advanced Instruments Inc., Needham Heights, Mass). Blood samples obtained from the earlobe were immediately pipetted into 100 ul of 8% perchloric acid, shaken vigorously, and frozen at − 20 °C prior to being analyzed for lactic acid (17).

Statistical Analysis

Total urine volume and body weight loss data were analyzed using a one-way analysis of variance (ANOVA). All other data were analyzed using a two-way ANOVA for repeated measures. When a significant F-ratio was observed, a Tukey post-hoc test was performed to determine the location of the differences. Differences between means were evaluated at the 0.05 level of significance. All data are presented as mean ± SE.

Results

On the average, the subjects reduced their body weight by 4.12 (± 0.02) % during the dehydration procedure. Total exercise time to achieve this weight reduction was 128 ± 3 minutes.

Resting measurements

The change in plasma volume (Fig. **2a**) was similar in the four experimental treatments immediately after
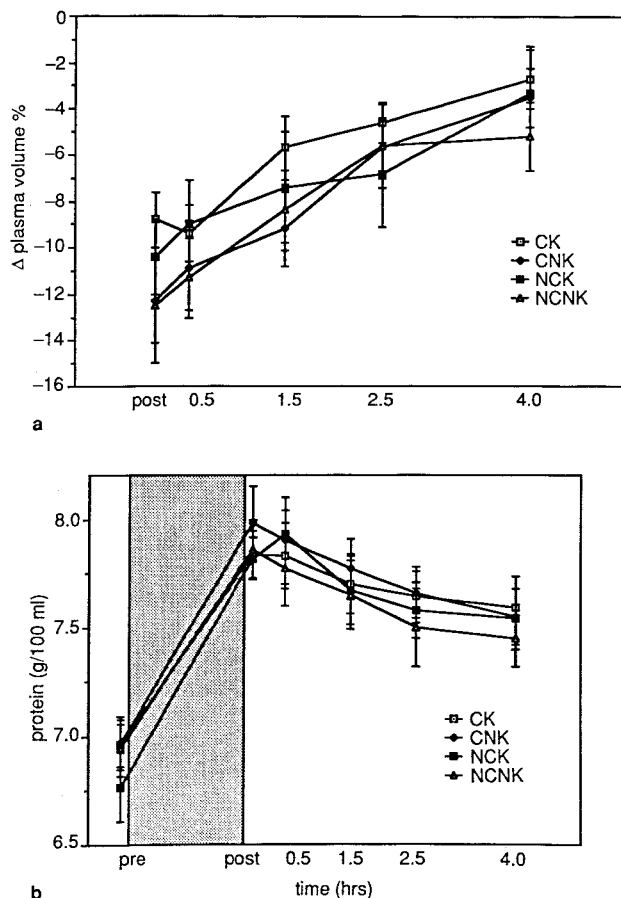
Fig. 2 **a)** Plasma volume changes (%) during four hours of rehydration. All values are expressed as mean ± SE. **b)** Total plasma protein (g/100 ml) before and immediately after dehydration and during four hours of rehydration. The shaded area denotes the dehydration period. No significant differences were observed between treatments for plasma volume changes or total plasma protein. A significant elevation in total plasma protein from the value obtained before exercise was observed in all treatments and remained after 240 min of recovery.
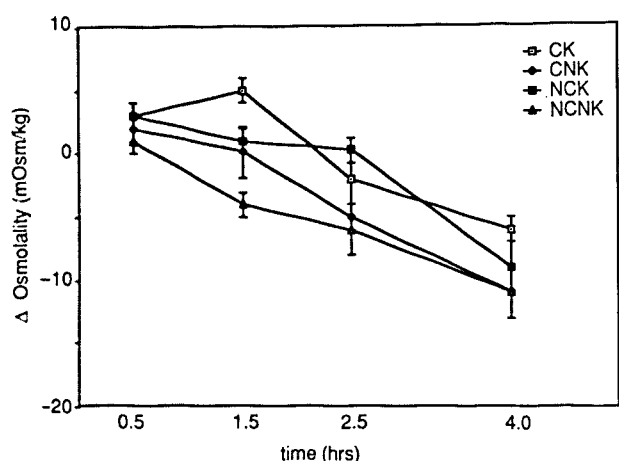
Fig. 3 The change in plasma osmolality, calculated from the value obtained immediately after dehydration. Differences between treatments were observed at 1.5 h (CK vs NCNK and CNK, NCK vs NCNK), 2.5 h (CK vs NCNK, NCK vs NCNK and CNK), and 4.0 h (CK vs NCNK and CNK).

Fig. 4 Plasma glucose before and immediately after dehydration and during four hours of rehydration. Significantly higher values were observed at 30, 90, 150, and 240 min of recovery for CK and NCK when compared with CNK and NCNK.

dehydration and no differences were observed between treatments at any time. Following 240 minutes of recovery the mean plasma volume changes were $-2.7\ (\pm 1.3)$, $-3.5\ (\pm 1.3)$, $-3.3\ (\pm 2.0)$, and $-5.2\ (\pm 1.5)$ % for CK, CNK, NCK, and NCNK, respectively. Accordingly, total plasma protein concentration (Fig. 2b) was significantly elevated in all treatments following dehydration and remained elevated following 240 minutes of recovery. In addition, no differences were observed between treatments.

When the subjects were on the CHO treatments, the values for the change in plasma osmolality (calculated from each preceeding time point, e. g. the 0.5 h value was obtained by subtracting the post dehydration osmolality value from the 0.5 h value, Fig. 3). were significantly higher than for the non-CHO treatments at 1.5 h (CK vs CNK and NCNK; NCK vs NCNK), 2.5 h (CK vs NCNK; NCK vs NCNK and CNK), and 4.0 h (CK vs CNK and NCNK) of rehydration.

As expected, the ingestion of the carbohydrate-containing beverages (CK and NCK) resulted in significantly higher plasma glucose levels at 30, 90, 150, and 240 minutes as compared to those elicited by ingestion of the non-carbohydrate beverages (CNK and NCNK) (Fig. 4).

The quantity of urine produced during the rehydration procedure was not different between experimental treatments (397 (± 49), 463 (± 54), 428 (± 49), and 480 (± 73) ml for CK, CNK, NCK, and NCNK, respectively) (Table 2). Additionally, the net body weight deficit measured as the pre-dehydration body weight – the post rehydration body weight (in absolute and relative terms) was not different between the four experimental treatments (Table 2).
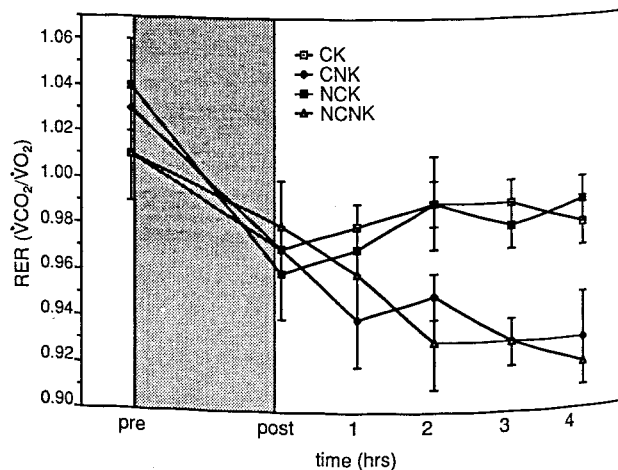
Standardized Cycling Bout

The RER was significantly reduced in all treatments except NCNK as a result of the exercise undertaken in the dehydration protocol as indicated by comparison of the Pre and Post dehydration values (Fig. 5). As expected, carbohydrate ingestion resulted in significantly higher RER values
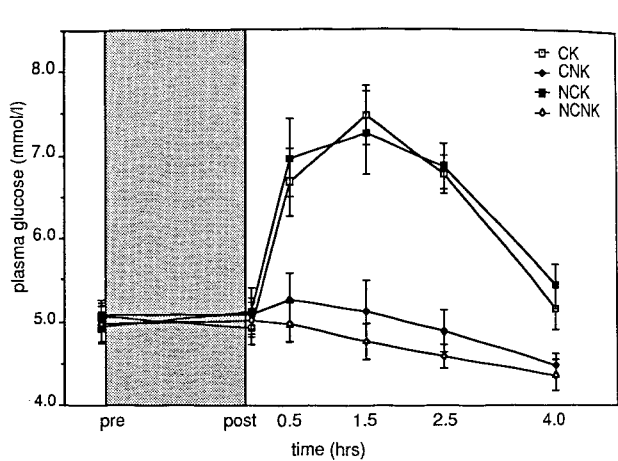
Table 2 Urine volume (ml) and body weight deficit (kg) (%) during rehydration. Body weight deficit (kg) was calculated by subtracting the pre dehydration body weight from the post rehydration body weight. The % body weight deficit was calculated by dividing the body weight deficit (kg) by the pre dehydration body weight. No significant ($p < 0.05$) differences between treatments were observed. All values are mean $\pm$ SE.

Trial	Urine Volume (ml)	Body Wt. deficit (kg)	Body Wt. deficit (%)
CK	397 (49)	-1.12 (0.09)	-0.95 (0.12)
CNK	463 (54)	-1.40 (0.09)	-1.22 (0.19)
NCK	428 (49)	-1.15 (0.09)	-0.97 (0.15)
NCNK	480 (73)	-1.28 (0.08)	-1.24 (0.80)

Fig. 5 The respiratory exchange ratio ($\dot{V}CO_2/\dot{V}O_2$) during the standardized cycling bout before and immediately after dehydration and during four hours of rehydration. Differences were observed at 60 (CK vs CNK), 120 (CK and NCK vs both CNK and NCNK), 180 (CK and NCK vs both CNK and NCNK), and 240 min (CK and NCK vs both CNK and NCNK).

Table 3 Standardized cycling bout lactic acid concentration (mmol/l) before (Pre) and immediately after dehydration (Post), and during four hours of rehydration (60, 120, 180, 240 min). No significant (p < 0.05) differences were observed between treatments.

Trial	Pre	Post	Time (min) 60	120	180	240
CK	7.03 ±0.49	5.55* ±0.45	6.16 ±0.46	5.94 ±0.37	5.96 ±0.40	5.25* ±0.45
CNK	7.47 ±0.87	5.93* ±0.67	5.49* ±0.64	4.92* ±0.64	4.81* ±0.50	4.89* ±0.54
NCK	7.30 ±0.69	5.55* ±0.65	5.93* ±0.46	6.15 ±0.58	5.73* ±0.31	5.34* ±0.55
NCNK	7.06 ±0.62	5.84* ±0.55	5.71* ±0.49	5.11* ±0.50	4.38* ±0.38	4.35* ±0.48

*Significantly different from Pre. All values are mean±SE.

compared to the ingestion of the artificially sweetened beverages at 60 (CK vs CNK), 120 (CK and NCK vs both CNK and NCNK), 180 (CK and NCK vs both CNK and NCNK), and 240 minutes (CK and NCK vs both CNK and NCNK).

The combination of exercise and thermal dehydration resulted in a significant reduction in lactate accumulation following the standardized cycling bout performed immediately after dehydration (Post) in all treatments except NCNK (Table 3). No differences were observed when the four treatments were compared.

The dehydration procedure resulted in a significant elevation in exercise heart rate in all treatments which was maintained at 240 minutes (Fig. 6). In addition, heart rates were significantly elevated in the CK treatment relative to other treatments at 60 (vs CNK and NCNK), 120 (vs CNK and NCNK), 180 (vs NCNK), and 240 minutes (vs NCK).

Rectal temperatures during the standardized cycling bout were significantly higher for the carbohydrate treatments relative to the non-carbohydrate treatments at 120 (CK vs NCNK, NCK vs NCNK) and 180 minutes (CK vs NCNK and CNK) (Fig. 7).

Ratings of gastrointestinal comfort were similar at all time points regardless of the beverage consumed during rehydration (Table 4).

Discussion

This investigation was conducted to determine the influence of beverage carbonation and carbohydrate content on the ability to recover fluid losses and normal physiologic function following dehydration. The data from this investigation suggest: 1) Carbonated beverages were as effective as non-carbonated beverages in permitting rapid fluid replacement and recovery following dehydration, 2) rehydration was similar when 10% CHO or non-CHO solutions were ingested.
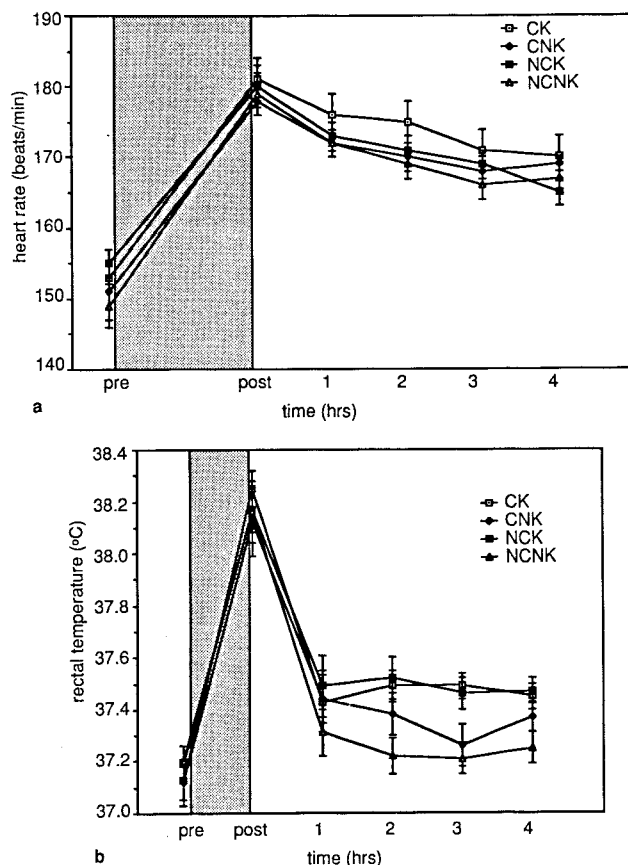
Fig. 6 a) Heart rate (beats/min) during the standardized cycling bout before and immediately after dehydration and during four hours of rehydration. Heart rates were significantly elevated in all treatments after dehydration and remained significantly elevated at 240 min of recovery. Heart rates were significantly elevated on treatment CK relative to other treatments at 60 (vs CNK and NCNK), 120 (vs CNK and NCNK), 180 (vs NCK), and 240 min (vs NCK). **b)** Rectal temperature (°C) during the standardized cycling bout before and immediately after dehydration and during four hours of rehydration. Rectal temperatures were significantly greater on the CHO treatments relative to the non-CHO treatments at 120 (CK vs NCNK, NCK vs NCNK) and 180 min (CK vs NCNK and CNK).

Table 4 Perception of gastrointestinal comfort during the standardized cycling bouts in four hours of rehydration (60, 120, 180, 240 min). No significant (p < 0.05) differences were observed between treatments. No significant differences between groups or over time were observed. All values are mean±SE.

Trial	Time (min) 60	120	180	240
CK	1.7 ±0.2	1.8 ±0.3	2.0 ±0.2	1.4 ±0.2
CNK	1.5 ±0.3	1.3 ±0.2	1.6 ±0.2	1.6 ±0.2
NCK	1.4 ±0.2	1.6 ±0.2	1.9 ±0.2	1.6 ±0.2
NCNK	2.2 ±0.3	1.9 ±0.2	2.0 ±0.3	1.6 ±0.3

Rehydration evaluated from body weight and plasma volume restoration as well as the total plasma protein concentration (Fig. 2) was similar but incomplete in the four experimental treatments. The inability to fully replace fluid losses occurred despite ingestion of a volume of fluid equal to that lost during dehydration. Utilizing a protocol very similar to the one employed in the present investigation, Costill and Sparks (6) also reported that rehydration was incomplete despite the ingestion of a quantity of fluid equal to that lost during dehydration. This body fluid deficit following the rehydration procedure in this investigation has many possible explanations. First, following the dehydration procedure the subjects' rectal temperature was 38.3 °C, which likely maintained some degree of sweat production into the rehydration period. Moreover, during recovery the subjects performed a standardized cycling bout every hour which resulted in noticeable sweat production. Other sources of fluid loss include urine production ~ 450 ml and losses known to occur from respiratory sources.

A major finding of this investigation was that fluid replacement was similar in the carbonated and non-carbonated treatments. Although gastric emptying and intestinal absorption data were not obtained, the similar plasma volume and total plasma protein values at all time points suggest that beverage carbonation did not measurably alter the availability of ingested fluid. Lolli et al. (16) reported that carbonation enhanced the gastric emptying of water. However, other investigators (10, 25, 27) have reported no differences in gastric emptying between carbonated beverages and non-carbonated beverages of similar composition. The results from the present investigation support previous findings of similar fluid replacement with carbonated and non-carbonated solutions and extend those findings to the situation of prolonged fluid replacement following dehydration, when factors such as fluid retention become important.

Recent evidence suggests that the ingestion of solutions with a relatively high carbohydrate concentration (7.5−10%) during exercise will not impair fluid replacement relative to water or a water placebo, as determined from plasma volume changes and gastric emptying (18, 22). Few attempts, however, have been made to determine whether these findings also apply to controlled rehydration following large sweat losses. The data obtained from the present investigation as well as the earlier work of Costill and Sparks (6) suggest that 10% carbohydrate solutions and non-carbohydrate solutions are equally as effective in replacing body water deficits. Thus, in addition to providing a substantial amount of carbohydrate, it appears that a high rate of fluid replacement can be attained at rest even when the carbohydrate concentration is as high as 10%.

The ingestion of carbohydrate during rapid rehydration would be advantageous, as the rate of muscle glycogen resynthesis is reportedly 3 times faster if carbohydrate is ingested immediately after exercise as opposed to delaying feeding by 2 hours (12). Furthermore, in this investigation subjects ingested ~ 250 ml of the 10% carbohydrate beverage (in CK and NCK) every 15 minutes, a rate of carbohydrate administration of ~ 1.4 g CHO·kg body weight^{-1}·hour^{-1} for three hours. Ivy and co-workers (13) have reported that the ingestion of carbohydrate at a rate of 1.5 g·kg body

weight^{-1}·hour^{-1} elicited rates of muscle glycogen resynthesis of 5.8 and 4.5 mmol·kg wet weight muscle during the first and second two-hour periods of recovery from exhaustive exercise. Thus, the uncompromised fluid replacement and high rate of CHO delivery with 10% CHO solutions is of practical importance for the athlete who must train or compete in the hours or days following exercise-induced dehydration.

During prolonged exercise the RER and the carbohydrate oxidation rate decline and this is thought to be a probable cause of fatigue (4). The ingestion of carbohydrate during exercise maintains the RER and carbohydrate oxidation at a higher level and delays fatigue (4). The ~ two hours of cycling in the heat in this investigation most likely reduced muscle and liver glycogen levels to a large degree. However, following dehydration ~ 325 g of carbohydrate were ingested in the CK and NCK treatments while only ~ 8 g were ingested in the CK and NCK treatments. The fact that the RER was higher after the two CHO treatments when compared with the non-CHO treatments suggests that the carbohydrate was available for oxidation soon after ingestion.

The elevated heart rate observed during the standardized cycling bout at 240 minutes in all treatments contrasts with the results of Costill and Sparks (6), who reported a normalization of exercise heart rate after 120 minutes of recovery with a glucose-electrolyte solution and after 180 minutes when water was ingested. The difference between the results of Costill and Sparks and those obtained in this study is probably related to the dehydration protocol used. In contrast to the thermal and exercise dehydration used in the present investigation, Costill and Sparks induced dehydration by thermal means only. Nielsen et al. (21), as in the present investigation, also utilized thermal and exercise dehydration and reported that heart rate during exercise remained about 11 beats/min higher (averaged for all the groups) than the pre-dehydration level despite two hours of rehydration that resulted in an expansion of plasma volume above the pre-dehydration level.

The maintenance of an elevated exercise heart rate after rehydration and recovery in all treatments in this investigation and in that of Nielsen et al. (21), when compared with the investigation of Costill and Sparks (6), is probably not related to greater plasma volume reduction and reduced cardiac stroke volume resulting from exercise/thermal dehydration as opposed to thermal only dehydration. After rehydration and recovery in the present investigation the plasma volume deficit averaged across the four treatments was about 3.5%; in Costill's and Sparks' investigation (6) the average plasma volume deficit for the two fluid replacement trials was about 5.5%. Furthermore, despite a plasma volume increase of 14% above the pre-dehydration level for the most effective rehydration solution, Nielsen et al. (21) reported that the submaximal exercise heart rate was about 8 beats/min above the pre-dehydration value.

A more likely cause of the elevated heart rate during exercise despite the ingestion of a volume of fluid equal to that lost is reduced muscle glycogen stores caused by the exercise/thermal dehydration when compared with thermal dehydration. Heigenhauser et al. (9) reported that glycogen depletion resulted in an elevated heart rate during stand-

ardized submaximal exercise when compared to that attained with normal glycogen stores.

During the standardized cycling bout, heart rates were elevated in treatment CK relative to other treatments at 60 (vs CNK and NCNK), 120 (vs CNK and NCNK), 180 (vs NCNK) and 240 minutes (vs NCK). Although this elevation in heart rate would be expected to be the result of a reduced plasma volume and cardiac stroke volume, this is probably not the case as there were no differences in plasma volume or total plasma protein concentration between treatments. A more plausible explanation is that the dehydration procedure appeared to result in greater physiologic stress in the CK treatment than in the other treatments as the resting heart rate immediately following dehydration (before any solution was ingested) tended (p = 0.09) to be elevated (113, 108, 109, 106, bpm for CK, CNK, NCK, and NCNK, respectively).

The elevation in rectal temperature in the carbohydrate treatments (CK and NCK) relative to the non-carbohydrate treatments (CNK and NCNK) during the standardized cycling bouts, although statistically significant, is not likely to be of practical significance as the values remained within the "normal" range (37.3−37.6) (9). However, this finding may be related to the thermic effect of calorie ingestion as subjects in the carbohydrate treatments ingested ∼ 1300 kcals while those in the non-carbohydrate treatments ingested ∼ 35 kcals. An alternative or additional explanation for the elevated rectal temperatures in the CHO treatments, when compared to the non-CHO treatments, is that the much higher osmolality of the CHO beverages resulted in a higher plasma osmolality during rehydration. This possibility is supported by the fact that the reduction in plasma osmolality was significantly less when the CHO solutions were ingested when compared with ingestion of the non-CHO solutions (Fig. 3). Elevations in plasma osmolality result in a delay in cutaneous vasodilation (8) and a reduction in sweat rate (20), the net result of which is to increase heat storage.

The finding that lactate accumulation was not different between treatments suggests that lactate production and/or removal were not measurably affected by the ingestion of beverages containing CO_2.

The tendency for athletes to refrain from the ingestion of carbonated beverages is often based on the belief that these beverages may result in gastric distress. The similar ratings of gastrointestinal comfort for the four test solutions suggest that when the beverage carbonation content is 2.5% of volume or less this belief is unfounded. Our finding of a similar level of gastric distress between carbonated and non-carbonated solutions is supported by the findings of others (25, 27) who administered solutions with a similar level of carbonation. It is possible that gastric distress could become more evident with a higher level of carbonation, however, this possibility has yet to be examined.

In light of the similar rehydration and physiologic responses resulting from the ingestion of carbonated and non-carbonated beverages in this investigation and the investigations of others (10, 25, 27), it appears that taste preference rather than physiologic concerns should dictate whether car-

bonated beverages are utilized for fluid replacement. Furthermore, the similar fluid replacement and greater carbohydrate delivery, when comparing the carbohydrate and non-carbohydrate treatments, suggest that over the course of four hours, post-exercise fluid and carbohydrate replacement can be achieved simultaneously when the beverage carbohydrate concentration is 10%.

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