Water Versus Carbohydrate–Electrolyte Ingestion Before and During a 15-Km Run in the Heat

Mindy Millard-Stafford, Linda B. Rosskopf, Teresa K. Snow, and Bryan T. Hinson

Twelve highly trained male runners ran 15 km at self-selected pace on a treadmill in warm conditions to demonstrate differences in physiological responses, fluid preferences, and performance when ingesting sports drinks or plain water before and during exercise. One hour prior to the start of running, an equal volume (1,000 ml) of either water or a 6% or an 8% carbohydrate–electrolyte (CE) drink was ingested. Blood glucose was significantly higher 30 min following ingestion of 6% and 8% CE compared to water, significantly lower at 60 min postingestion with both sports drinks than with water, but similar after 7.5 km of the run for all beverages. During the first 13.4 km, oxygen uptake and run times were not different between trials; however, the final 1.6-km performance run was faster with both CE drinks compared to water. Despite a lower preexercise blood glucose, CE consumption prior to and during exercise significantly improved performance in the last 1.6 km of a 15-km run compared to water.

Key Words: sports drinks, exercise and diet, hypoglycemia

Considerable evidence indicates that endurance athletes can benefit from carbohydrate (CHO) ingestion during prolonged exercise lasting ≥2 hr (7–9, 24). Yet relatively few studies (3, 12, 39) have investigated whether moderate duration exercise performance (<1 hr) of high intensity can be improved with CHO ingestion. Since major athletic competitions (e.g., 1992 and 1996 Summer Olympics) are being held in warm, humid environments (36), potential ergogenic effects of optimal fluid replacement become important for events of 30–60 min duration. Although it has been recommended (16) that athletes in events under 1 hr consume 300–500 ml of a 6–10% CHO beverage preevent and 500–1,000 ml of cool water during exercise, there is limited evidence to support this recommendation.

Few data are available on the effects of CHO ingestion during competitive running of moderate duration in the heat. During prolonged running (>2 hr) in the heat, carbohydrate–electrolyte (CE) beverages elicit no adverse physiological effects (30) and can improve endurance performance (24) when administered at regular intervals during exercise. However, it has been documented that relatively

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little fluid (100–300 ml · hr⁻¹) is consumed voluntarily during running (28). This is
in contrast to the fluid intakes of 800–1,000 ml · hr⁻¹ reported during cycling in the
heat (3, 9, 33). This indicates that prevention of dehydration through fluid replace-
ment during run-based exercise presents a much greater challenge than portrayed
in laboratory-based cycling experiments. It also indicates that preevent hydration
practices may be relatively more important during high-intensity running than
cycling.

Although CE sports drinks can enhance endurance performance, water has
also been recommended as a rehydration beverage for athletes competing in the heat
(2). It remains the most readily available fluid in mass participation settings for
athletes. But surprisingly few data exist regarding the effect of sweetened/flavored
beverages on fluid consumption patterns compared to water in highly trained
athletes in the heat (1). Carter and Gisolfi (6) found that cyclists tended to drink more
water than a 7.5% CE beverage during exercise in the heat yet drank significantly
more CE beverage than water during a 3-hr recovery. Beverage palatability is a
significant issue for reasons of both safety and performance, since taste preference
has a strong association with the amount of beverage consumed ad libitum during
exercise (6, 18, 22). Murray (27) stated that beverage characteristics such as
temperature, taste, aroma, mouth feel, and appearance may all affect voluntary fluid
consumption. Maltodextrins purportedly increase mouth feel and substance in a
beverage, while high concentrations of fructose may cause gastrointestinal distress
during exercise (27). Whether subtle differences in sodium content or type of
carbohydrate in a beverage (i.e., maltodextrins, fructose, glucose) influence drinking
patterns and beverage tolerance in adult athletes during exercise in the heat has
not been adequately addressed.

Therefore, the aims of the present investigation were to determine (a) if
ingestion of CE beverages (prior to and during exercise) would affect physiological
responses and improve performance at the end of a 15-km run in warm, humid
conditions and (b) whether two commercially available CE formulations (varying
in sodium content and type of CHO) compared to water would differentially affect
taste preference and ad libitum fluid consumption during exercise.

Methods

Subjects

Twelve highly-trained male runners volunteered to participate in the study. Sub-
jects’ mean physical characteristics are presented in Table 1. Criteria for participa-
tion were training of >65 km · week⁻¹ for the previous 12 weeks with no anticipated
change in run training throughout the study. All subjects signed an informed consent
statement approved by the Institutional Review Board.

Maximal Treadmill Testing

In the initial testing session, held at least 1 week prior to the 15-km trials, maximal
oxygen uptake (VO₂ max) was assessed from a treadmill test utilizing a continuous,
grade-incremented protocol. Subjects ran at a constant speed (290 m · min⁻¹) with
a 2.5% increase in grade every 2 min until exhaustion. VO₂ and other metabolic
Table 1  Physical Characteristics of the Subjects (N = 12)

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<th>Mean</th>
<th>SD</th>
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<td>Best 10-km time (min)</td>
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</table>

measures were continuously sampled every 30 s using an automated gas collection system (Rayfield REP-200B interface, Waitsfield, VT). The volume of expired air was measured with a Parkinson-Cowan CD-4 dry gas meter (Carl Poe, Inc., Houston, TX). Concentrations of O2 and CO2 in the expired air were assessed with Applied Electrochemistry S-3A (Sunnyvale, CA) and Beckman LB-2 (Schiller Park, IL) gas analyzers, respectively. Subjects also completed a practice run on the treadmill 1 week prior to the test trials to familiarize themselves with the pace they might select in the subsequent trials.

15-Km Run Trials

Following the orientation session, three 15-km runs, separated by at least 1 week, were completed by each subject. Subjects ran at a self-selected pace on a motorized treadmill in an environmentally controlled room. The mean temperature increased slightly from 27.2 °C, 76% RH, to 28.3 °C, 62% RH, at the end of the run. Subjects were cooled with fans throughout the run. Tests were conducted in the fall–winter season when subjects were not heat acclimated. During the entire 15-km run, subjects controlled the treadmill speed and could vary the pace at their own discretion. Since no warm-up was permitted before the 15-km run, subjects selected a moderate run pace for the first 1.6 km (~5 min/km) and then were instructed to run at a “hard training pace” until 13.4 km (~4 min/km). There were rest breaks at 7.5 km (3 min) and 13.4 km (5 min) for blood collection and ad libitum fluid ingestion. Following the break at 13.4 km, an all-out maximal effort was requested during the final 1.6-km portion of the run. Prize money was awarded based on two categories: subjects’ cumulative times for all three 15-km trials, and the cumulative times during the three final 1.6-km runs.

Subjects maintained diet and training records for the 7 days before each test and were asked to replicate these in the week preceding each of the subsequent trials. The mean (±SE) daily CHO intake in the 3 days before each test was not significantly different across trials (401 ± 8, 402 ± 9, and 412 ± 10 g). Training mileage was also not significantly different in the week prior to each test (61.4 ± 8.3, 66.6 ± 5.9, 61.0 ± 6.3 km·week^{-1}). No training was performed in the 24 hr preceding each test.
At 8 a.m., subjects reported to the lab following a 10-hr fast. Sixty minutes prior to the start of running, 1 L of either distilled water, a 6% sucrose/glucose sports drink (Gatorade, The Quaker Oats Company, Chicago, IL), or an 8% fructose–glucose syrup/maltodextrin sports drink (PowerAde, The Coca-Cola Company, Atlanta, GA) was ingested in counterbalanced order. The fructose content of the 8% CE beverage was less than 40% of the total CHO. The 6% and 8% CE beverages contained 20 mEq · L⁻¹ Na⁺, 3 mEq · L⁻¹ K⁺, and 10 mEq · L⁻¹ Na⁺, 3 mEq · L⁻¹ K⁺, respectively. The CE beverages were lemon-lime flavor, and the temperature of all beverages was 10 °C. Subjects were also permitted to ingest the beverages ad libitum during the run, during brief scheduled breaks at 7.5 and 13.4 km, and during a 30-min recovery period. The two CE trials were conducted in a double-blind fashion. Subjects completed a questionnaire containing 5-point Likert scale ratings regarding beverage palatability, taste preference, and gastrointestinal tolerance after the 15 km-run.

**Physiological Measures**

Two blood samples were obtained preexercise (30 and 60 min following fluid ingestion) and during the breaks at 7.5 and 13.4 km during the run. All samples were obtained via venipuncture at an antecubital vein. A consistent body position was used for all venipunctures; subjects remained upright until just prior to providing the blood sample in a seated position. A reflectance spectrophotometer (Kodak Ektachem DT60, Eastman Kodak Co., Rochester, NY) was used to analyze hemoglobin, serum glucose, and electrolytes. Whole blood lactate was measured using a YSI Model 27 analyzer (YSI Inc., Yellow Springs, OH). Hematocrit was obtained using the microhematocrit method. Percentage change in plasma volume was calculated from hematocrit and hemoglobin values (11). Serum insulin was measured using radioimmunoassay (Roche Biomedical Laboratories, Burlington, NC).

Respiratory exchange ratio (RER) and VO₂ were measured at 3.2, 6.4, 9.6, and 12.8 km of the treadmill run. Expired air was collected for 1 min using a Daniels valve and the Douglas bag method. The CHO oxidation rate was calculated from VO₂ and RER, assuming a nonprotein R. Heart rate (HR) was obtained every 1.6 km by telemetry using a Polar HR monitor (Polar CIC, Inc., Port Washington, NY) worn on the chest. Perceived exertion (RPE) was rated every 1.6 km using the traditional Borg scale (4).

Nude dry body weight was recorded prior to running (following drink ingestion) and 5 min following the run. Sweat rate was calculated based on net change in body weight with corrections for fluids ingested, urine output, and respiratory losses (25).

**Statistical Analyses**

An analysis of variance with repeated measures was used to determine differences among the drink trials. Contrast comparisons were used to determine which means were significantly different. An alpha level of .05 was used to indicate statistical significance. All values reported are means (±SE).
Results

Blood glucose and insulin data are presented in Figures 1 and 2, respectively. Blood glucose was significantly higher 30 min following ingestion and significantly lower at 60 min just prior to the onset of the 15-km run with both the 6% and 8% CE beverages compared to water. However, after 7.5 km of the run, blood glucose concentration was similar for all trials. Preexercise insulin levels were also significantly higher 30 and 60 min following ingestion of the CE beverages compared to water but were not significantly different after 7.5 km of running.

Additional hematological data are presented in Table 2. There were no significant differences in serum potassium, but sodium values were significantly lower for water 60 min following fluid ingestion and at 7.5 km of the run. Chloride concentration was also higher for the 8% CE beverage during the run. Blood lactate concentration was higher at 30 and 60 min postingestion with the 6% and 8% CE drinks compared to water but was not significantly different during the run. Percentage change in plasma volume was not different between the 6% CE and 8% CE beverages and water (1 ± 2.6%, -0.7 ± 2.9%, -0.2 ± 2.5%, respectively) at 13.4 km of the run compared to the value obtained 30 min following fluid ingestion.

No significant differences were observed in HR, RPE, or RER between the three trials (Table 3). The percentage of HRmax increased from 88 to 95% over the 15 km for all trials. The percentage of VO2max utilized during the first 13.4 km was not significantly different between the trials (Table 3). During the first 13.4 km of the run, the CHO oxidation rates were not significantly different between the 8% CE

![Graph showing glucose levels](image)

**Figure 1** — Mean (±SE) blood glucose levels before and during 15-km treadmill run in the heat. First and second data points represent 30 min and 60 min following fluid ingestion (preexercise). Fourth data point represents 13.4 km of the run. *Significant difference (p < .05) between beverage treatments. Error bars do not appear where SE is less than 0.5 mmol.
Figure 2 — Mean (±SE) serum insulin levels before and during 15-km treadmill run in the heat. First and second data points represent 30 min and 60 min following fluid ingestion (preexercise). Fourth data point represents 13.4 km of the run. *Significant difference (p < .05) between beverage treatments. Error bars do not appear where SE is less than 1.5 μU/ml.

beverage (3.12 ± 0.2 g · min⁻¹), the 6% CE beverage (3.06 ± 0.3 g · min⁻¹), and water (2.91 ± 0.2 g · min⁻¹).

The time to complete the first 13.4 km was not different between trials of the 6% CE beverage (55.4 ± 1.4 min), the 8% CE beverage (55.4 ± 1.3 min), and water (55.9 ± 1.1 min). However, the 1.6-km performance run was significantly faster with the 8% and 6% CE drinks by 17 and 14 s, respectively, compared to water (Figure 3). This represents about a 5% improvement in high-intensity performance (run speed of 17.5 km · hr⁻¹) at the end of a 15-km run. Eleven out of 12 runners completed the performance run faster with the 8% CE beverage compared to water, and 8 of 12 runners were faster with the 6% CE beverage compared to water. When run times were analyzed according to the test order, no significant difference was found.

The ad libitum fluid intake during the run was not significantly different between the 6% CE beverage (282 ± 55 ml), the 8% CE beverage (298 ± 56 ml), or water (301 ± 52 ml). The amount of fluid consumed during running was quite variable, ranging from 10 to 760 ml. The volume of fluid ingested during the 30-min recovery period was also not significantly different between the 6% CE beverage (440 ± 86 ml), the 8% CE beverage (282 ± 37 ml), and water (303 ± 59 ml). The percentage of body weight lost during the run was similar for the 6% and 8% CE beverages and water (−2.2 ± 0.2, −2.4 ± 0.2, −2.3 ± 0.2%, respectively). Mean sweat rates were also not different between the 6% and 8% CE beverages and water (1,855 ± 112, 1,932 ± 107, and 1,853 ± 96 ml · hr⁻¹, respectively).

No significant differences were observed in the Likert ratings for stomach upset, bloating, or cramping during the run. There was also no significant
Table 2  Hematological Parameters (mmol · L⁻¹) 30 and 60 Min Following the 1 L Fluid Ingestion and During the 15-Km Run

<table>
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<th>60 min post</th>
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<td>SE</td>
<td>M</td>
<td>SE</td>
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</table>

⁺Water significantly different (p < .05) than 6% CE, 8% CE. 8% CE significantly different (p < .05) than water. 8% CE significantly different (p < .05) than 6% CE, water.

A difference in the 5-point rating of "taste" for the 6% CE beverage (3.4 ± 0.3), the 8% CE beverage (3.8 ± 0.4), or water (3.4 ± 0.3). However, subjects tended to rate water higher (3.6 ± 0.4) on the 5-point scale as the fluid replacement beverage they typically preferred to use during training and competition (p < .06) compared to the 6% CE beverage (2.4 ± 0.4) and the 8% CE beverage (2.6 ± 0.3).

Discussion

There are conflicting findings in the literature regarding the ergogenic effects of CHO when fed in the hour prior to exercise (8, 10, 14, 17, 18, 35, 39). One finding of the present study is that 1.6-km run performance was improved after 13.4 km of running when 1 L of a CE beverage (providing 60 or 80 g CHO) was ingested 60 min before exercise followed by ad libitum ingestion during exercise as compared to a water-only trial. A similar magnitude of performance improvement (6%) was recently observed during 1 hr of intense cycling in the heat when trained cyclists consumed 79 g of CHO during exercise (3). Our results are also consistent with the results of other prolonged cycling studies (17, 35) which indicated that 1–2 g of CHO
Table 3  Physiological Responses During the First 13 Km of the Run

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</table>

Figure 3 — Mean (±SE) run time during final 1.6-km performance run. *Water trial was significantly slower ($p < .05$) than the two CE trials.
per kilogram body weight ingested 1 hr prior to exercise enhanced performance in thermonutral conditions.

Few studies (15, 21, 29) have examined the effect of preexercise CE ingestion on run performance, and none were conducted in the heat. In untrained runners, Ventura et al. (39) reported that 75 g of glucose ingested 30 min before exercise in thermonutral conditions increased time to fatigue by 10% during short-duration (10 min), high-intensity (82% VO2max) running compared to either placebo or fructose.

The underlying mechanism responsible for the improved performance with CE ingestion in our trained runners is not clear. In events lasting more than 90 min, CHO might provide an exogenous source for increased CHO oxidation and blood glucose maintenance. But hypoglycemia was not a limit to performance in this 1-hr run event. In a similar study, Below et al. (3) found that when subjects consumed CHO during exercise, improvements in 1-hr cycling performance were not associated with increased blood glucose levels or carbohydrate oxidation. These investigators were also uncertain as to the underlying mechanism.

Maintenance of muscle glycogen levels may play a role. Tsintzas et al. (38) reported that CHO feedings during exercise resulted in a 42% sparing of muscle glycogen during 1 hr of running at 70% VO2max. The typical daily CHO intake in our runners was only moderate (6 g per kilogram of body weight, <60% of total calories). This may have been inadequate for these highly trained runners, since a CHO intake of 8 g/kg did not prevent depletion of muscle glycogen stores during intense run training (20). Moreover, since muscle glycogen utilization has been observed to be greater in the heat (13), the CE treatments may have had an ergogenic effect since the athletes had borderline CHO intakes and were not heat acclimatized.

Another potential explanation may be that electrolytes and/or citrate found in the sports drink may enhance buffering capacity. When subjects ingested similar amounts of sodium citrate/citric acid as in the present study (<3 g), Powers et al. (32) found lower hydrogen ion concentrations with a CE and electrolyte placebo compared to a nonelectrolyte placebo following a 30-min ride to exhaustion at 85% VO2max. However, despite shifts in blood acid-base balance, other authors (31, 37) have observed no enhancement in run performance when subjects ingested a dosage of sodium citrate (≥0.3 g/kg body weight) well above the levels in our subjects (<0.1 g/kg body weight). Thus, the buffering capacity of sports drinks remains to be clarified.

A limitation when interpreting the performance data is the lack of a true control trial. Due to the scheduling restrictions among these highly trained runners, it was not feasible to add a fourth 15-km trial. Since beverage palatability and tolerance were important dependent variables, the addition of artificial sweeteners and flavoring was purposely not included in the water trial. From a practical view, water remains the most widely available and consumed beverage in prerase settings and thus provides a meaningful comparison. Cumulative times for all three trials were used in determining substantial financial bonuses in order to elicit similar motivation for all trial conditions. In addition, subjects tended to rate water higher than CE drinks as their preferred fluid replacement beverage during training and competition.

The comparison of water to the two CE beverages revealed differences in the glycemic response. We observed, as have others, that the hypoglycemia related to
preexercise CHO feedings is ameliorated when the exercise is of sufficient duration (18, 34) and intensity (26). However, Foster et al. (14) found that glucose consumed 30 min prior to cycling exercise (80% \( \text{VO}_{\text{max}} \)) lowered blood glucose concentration (3.5 mmol) and diminished the time to fatigue. Since we did not sample until 7.5 km into the run, it is conceivable that blood glucose concentration remained lower during the first 25–30 min of the CE trials.

Serum sodium and chloride concentrations were lower with the ingestion of plain water versus a CE beverage although still within normal ranges. Therefore, these differences (<3 mmol · L\(^{-1}\)) appear to not be physiologically significant, especially since the risk of hyponatremia is low in exercise under 1 hr duration.

The taste preference data, along with the ad libitum fluid intake during exercise, did not indicate significant differences in beverage palatability. This is in contrast to previous investigations that indicated increased preference for sweetened/flavored beverages compared to water during intermittent walking (19) and recovery periods following exercise (6). However, Carter and Gisolfi (6) observed that cyclists tended to drink more water than CE during exercise. Meyer et al. (22) demonstrated that grape and orange flavors were preferred over water and apple flavors by children who became dehydrated during cycling in the heat. The interpretation of these findings is unclear, however, since the four drinks also differed in electrolyte and CHO content. In a subsequent study, Meyer et al. (23) found no difference in children’s drinking behaviors when either water or one of three different 6% CHO beverages (containing 0, 8.8, or 18.5 mmol · L\(^{-1}\) of \( \text{Na}^+ \)) was ingested during 30 min recovery from cycling in the heat.

Our findings are consistent with the latter study, since the higher \( \text{Na}^+ \) content of the 6% CE beverage (20 mmol · L\(^{-1}\)) did not appear to increase ad libitum fluid consumption compared to beverages with 0 (water) or 10 mmol · L\(^{-1}\) of \( \text{Na}^+ \) (8% CE). Moreover, the added sweetness and mouth feel provided in the 8% CE beverage (due to maltodextrins) did not increase drink desirability during either exercise or recovery. As exercise progressed, some subjects claimed the CE beverages became either too sweet or too salty, which might be attributed to altered sensory perceptions. The tendency for our subjects to prefer water as a fluid replacement beverage during training and competition was somewhat unexpected. Whether this is due to factors other than taste (such as the added expense of sports drinks) is not known.

Our data suggest that preexercise ingestion (plus ad libitum ingestion during competition) of a sports drink can benefit high-level athletes competing in events of ≤1 hr duration in the heat, especially where a final sprint or kick can be critical to performance outcomes. The recent ACSM position stand (1) recommended 500 ml consumed 2 hr prior to competition as a means of increasing hydration status. This is particularly advantageous for moderate duration running events (<15 km) where drinking tends to be minimal. Brouns et al. (5) found fluid intakes of only 100–300 ml · hr\(^{-1}\) during the run phase of a triathlon when subjects were encouraged to drink as much as possible. In the present study, subjects consumed fluid primarily during the short breaks, with little ingested while running. Our data support the recommendation (16) that in athletic events of less than 1 hr duration, preevent CHO ingestion can be advantageous. However, the volume of fluid suggested during exercise (500 to 1,000 ml) is probably unreasonable in run-based activities unless there are adequate rest periods.
In conclusion, ingestion of two different CE beverages 1 hr prior to exercise elicted a lower preexercise blood glucose concentration compared to water, but this did not persist over the course of a 15-km run. Athletes did not consume more water ad libitum compared to sports drinks during or following the 15-km run, even though they tended to rate water higher as their preferred fluid replacement beverage in training/competition. Furthermore, when compared to ingestion of water, ingestion of CE beverages both before and during exercise significantly improved performance at the end of a 15-km run in a warm, humid environment.

References


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