Gastrointestinal Discomfort During Intermittent High-Intensity Exercise: Effect of Carbohydrate–Electrolyte Beverage

Xiaocai Shi, Mary K. Horn, Kris L. Osterberg, John R. Stofan, Jeffrey J. Zachwieja, Craig A. Horswill, Dennis H. Passe, and Robert Murray

This study investigated whether different beverage carbohydrate concentration and osmolality would provoke gastrointestinal (GI) discomfort during intermittent, high-intensity exercise. Thirty-six adult and adolescent athletes were tested on separate days in a double-blind, randomized trial of 6% and 8% carbohydrate-electrolytes (CHO-E) beverages during four 12-min quarters (Q) of circuit training that included intermittent sprints, lateral hops, shuttle runs, and vertical jumps. GI discomfort and fatigue surveys were completed before the first Q and immediately after each Q. All ratings of GI discomfort were modest throughout the study. The cumulative index for GI discomfort, however, was greater for the 8% CHO-E beverage than for the 6% CHO-E beverage at Q3 and Q4 ($P < 0.05$). Averaging across all 4 quarters, the 8% CHO-E treatment produced significantly higher mean ratings of stomach upset and side ache. In conclusion, higher CHO concentration and osmolality in an ingested beverage provokes stomach upset and side ache.

Key Words: carbohydrate, electrolyte, gastrointestinal discomfort and intermittent exercise

Carbohydrate (CHO) ingestion before and during exercise can delay fatigue (7, 13, 44) and improve exercise performance during cycling (6, 7) and running (43, 44). Recent studies in controlled laboratory settings consistently suggest that carbohydrate supplementation enhances short-term, intermittent, high-intensity exercise performance in cycling, running, and resistance exercise (4, 14, 23, 25), and helps sustain not only sprint velocity, sprint capacity, and jumping ability, but also motor skill performance (8, 24, 42). The benefits of carbohydrate ingestion are also observed in field applications such as ice hockey (2), tennis (41), and soccer (15).

In marathons or triathlons, it is not uncommon to see an increased incidence of gastrointestinal (GI) symptoms associated with food and beverage intake before and during exercise (34). The occurrence of the GI symptoms could be related to

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a reduction of GI blood flow, change of GI motility, altered GI permeability, exercise mode (mechanical vibration), slower gastric emptying, and reduced intestinal absorption (or malabsorption) during exercise (9, 26, 35). Previous studies have indicated that gastric emptying (22, 30) and intestinal fluid absorption (12, 38) are reduced when CHO concentration in test solutions increases from 6% (i.e., 60 g/liter) to 8% or higher. Although gastric emptying (17, 21) and intestinal fluid absorption (5, 11) are not significantly affected during exercise at or below 70% VO\textsubscript{2max}, higher exercise intensity at 75 to 80% VO\textsubscript{2max} might delay gastric emptying (16) and decrease intestinal fluid absorption (19).

It is very common for athletes to replace their sweat losses and obtain exogenous energy by ingesting a carbohydrate-electrolyte (CHO-E) beverage during training and competition. A CHO-E beverage with a carbohydrate concentration high enough to retard gastric emptying and intestinal absorption of fluid could, however, result in an increased risk of GI discomfort during intermittent, high-intensity exercise. To date, little work has been done to determine the prevalence of GI discomfort in intermittent, high-intensity exercise when CHO-E beverages are available to replace sweat-induced body fluid loss. Therefore, an unanswered question is how much carbohydrate can be introduced into a CHO-E beverage before GI discomfort is induced. The purpose of this study was to determine the impact of 2 CHO-E beverages differing in carbohydrate and sodium concentration and osmolality on perceived rating of GI discomfort during intermittent, high-intensity exercise that simulates training and performance in stop-and-go sports.

**Methods**

**Subjects**

Thirty-six subjects participated in the study (25 male, 11 female). Among the subjects, 18 were high school athletes and 18 were competitive runners, cyclists, and triathletes. The study population is described in Table 1. Prior to participating, an explanation of the experiment (without divulging the specific nature of the research) was given to the subjects. All subjects signed informed consent forms that were previously approved by an institutional human subjects review board.

<table>
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<tr>
<th>Table 1 Subject Description</th>
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<tr>
<td>Younger (N = 18)</td>
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<td>Age (y)</td>
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*Note.* Values are mean ± standard error.
Beverage Treatments

A water treatment (equal in volume to the CHO-E beverage treatments) was conducted to help familiarize subjects with the protocol; this familiarization treatment is not included in the data analysis. During the experimental treatments, 2 commercially available CHO-E beverages were compared (Table 2). Although the source of carbohydrate varied between these 2 beverages, both had a total carbohydrate within the range recommended for sports drinks (1). To date, there is no data suggesting that the type of CHO used in these 2 beverages at this given concentration could potentially cause GI distress. Each athlete received 1 beverage per session in a counterbalanced order and ingested predetermined volumes immediately before starting (4.5 mL/kg), between quarters (1.5 mL/kg), and at halftime (4.5 mL/kg). Pilot studies indicated that this volume of fluid would approximate sweat loss.

Exercise Protocol

Subjects arrived for testing in the evening after 2 to 3 h fasting. During the day of each experiment, athletes consumed their own breakfast that was kept consistent from treatment to treatment and were provided the same lunch (850 to 950 calories, 57% CHO, 26% fat and 17% protein) to assure consistency across treatments. On arrival at the laboratory, a urine sample was obtained from the subjects to assess initial hydration (urine specific gravity). After initial body weight was recorded, subjects completed 4 circuits (quarters) each comprised of 3 exercise stations (Figure 1). Exercise at each station lasted 4 min. The stations consisted of (a) treadmill sprinting (1-min sprint/1-min walk × 2), (b) lateral hops (20-s hopping/40-s rest × 4) and (c) shuttle run (30-s sprint plus vertical jump/30-s rest × 4). Subjects were given 30 s to transition from one station to another, a 3-min rest following quarters 1 and 3, and a 5-min rest at the end of quarter 2 (Q2, half time). During rest periods, the subjects first completed a sensory questionnaire and then consumed the assigned beverage in its entirety. Exercise time for each quarter was 12 min and total time of activity for the experiment was 48 min. All subjects were re-weighed following completion of the exercise. Room conditions ranged from 17 to 20 °C WBGT, with relative humidity ranging from 25 to 45%.

Table 2 Composition of Test Beverages

<table>
<thead>
<tr>
<th>Test beverages</th>
<th>Carbohydrate concentrations</th>
<th>Sodium (mEq/L)</th>
<th>Potassium (mEq/L)</th>
<th>Osmolality (mOsm/kg)</th>
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<tr>
<td>Lemon-lime Gatorade® Thirst Quencher®</td>
<td>2% Glucose 4% Sucrose 3.3% Fructose</td>
<td>2.7% Glucose 2% Maltodextrin</td>
<td>18 3 305</td>
<td>5 3 434</td>
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Heart rate (HR) was measured using telemetered, recordable HR monitors (Polar XL, Polar Electro, Kempele, Finland). The average HR was determined as the average HR during the entire protocol, including recovery portions. Pre- and post-exercise nude dry body weights and volume of fluid consumed were used to calculate sweat rates and the extent of dehydration.

Sensory perceptions of GI discomfort were obtained from written surveys before exercise and after each Q. Subjects recorded their subjective perceptions of GI discomfort by drawing a mark on an unstructured line scale that was bracketed by the descriptors “none” and “severe” for the perception being evaluated. The position of the mark was later translated to a 100-point scale (0 = none; 100 = severe) blind to the subject’s knowledge. A GI discomfort cumulative index was calculated by averaging the sum of the ratings for the 7 questions that focused on burping, throat burn, heartburn, stomach bloating, sloshing, stomach upset, and nausea. Ratings of perceived exertion (RPE; Borg) were collected using a 10-point scale following the completion of each event during each of the four Qs.

**Statistical Analysis**

Statistical evaluation of the data was performed using 2-way ANOVA for repeated measures. Duncan post hoc analyses were used to isolate specific differences when significant effects were found from the ANOVA. Significance level was set at $P < 0.05$. Values are presented as means ± standard error. Statistical power for medium effect sizes (0.5 standard deviation) is conservatively estimated to be 0.55.

**Results**

The mean rating for the GI discomfort cumulative index, although modest, gradually increased over time for both beverages, but was significantly greater for the 8%
CHO-E treatment than the 6% CHO-E treatment after Q3 (at 47 min) and Q4 (at 63 min) (Figure 2). Specific ratings for GI discomfort throughout exercise at 0, 13, 29, 47, and 63 min were mild, but significantly more stomach upset was reported for the 8% CHO-E beverage ($P < 0.05$, Figure 3) than for the 6% CHO-E beverage.

Figure 2 — Changes of GI discomfort cumulative index rating over time. A GI discomfort cumulative index was calculated by averaging the sum of the ratings for the 7 questions on burping, throatburn, heartburn, stomach bloating, sloshing, stomach upset, and nausea. *Significantly different from 6% CHO-E at $P < 0.05$. Values are mean ± standard error.

Figure 3 — Changes in the stomach upset rating over time. *Significantly different from 6% CHO-E at $P < 0.05$. Values are mean ± standard error.
Gastrointestinal Discomfort and Carbohydrate Concentration after 47 min of exercise. This trend continued to the 63-min time point, although this was not statistically significant at that time. During exercise, the mean rating of stomach upset and side ache for all 4 Qs was significantly higher for the 8% CHO-E treatment than for the 6% CHO-E treatment ($P < 0.05$, Figure 4).

Mean heart rate ranged from 97 to 169 beats/min (b/min) for 6% CHO-E and 107 to 176 b/min for 8% CHO-E. Mean HR was significantly higher in Q4 (138 ± 19) vs. Q1 (128 ± 19), but no statistically significant differences were found between treatments. The average HR was 147 b/min and represented 76% of HR$_{peak}$ (determined by age-predicted maximum heart rate and responses on graded exercise tests). There was also no effect of treatment on HR recovery during each Q rest period. Mean HR recovery during the rest periods was 17, 18, 18, and 23 b/min for Q1 to Q4, respectively. In general, RPE increased 1 to 2 points from Q1 to Q4, but the values were not different between treatments. Independent of time (Q), average RPE values were 7, 7, and 6 for treadmill, lateral hops, and shuttle/jump events, respectively. The stability of the HR and RPE data demonstrates that exercise intensity did not differ between treatments.

Urine specific gravities before exercise for 6% and 8% CHO-E treatments were 1.014 ± 0.002 and 1.013 ± 0.002, respectively. Mean fluid loss between treatments was similar. Sweat rates were 1.03 ± 0.3 and 1.04 ± 0.3 liters/h for the 6% CHO-E and 8% CHO-E treatments, respectively. Change in body weight resulting from sweat loss was 0.26 ± 0.04 kg for the 6% CHO-E beverage and 0.28 ± 0.04 kg

Figure 4 — Average ratings in side ache and stomach upset ratings for 4 quarters. *Significantly different from 8% CHO-E treatment. $P < 0.05$. Values are mean ± standard error.
for the 8% CHO-E beverage ($P > 0.05$). Percent dehydration did not differ between treatments and was $0.34 \pm 0.05\%$ for the 6% CHO-E treatment and $0.38 \pm 0.05\%$ for the 8% CHO-E treatment. Dehydration in both treatments was nearly prevented by the volumes ingested before and during exercise (mean consumed volume was $0.85 \pm 0.14$ liters). The average percent fluid replaced for the 6% CHO-E treatment was $80.6 \pm 14.0\%$ and $78.8 \pm 14.4\%$ for 8% CHO-E treatment ($P > 0.05$).

**Discussion**

This study investigated the effect of ingesting 2 different CHO-E beverages on GI symptoms during intermittent, high-intensity exercise. Our major findings are that perceived GI discomfort, although relatively slight, increased during intermittent, high-intensity exercise and that greater GI discomfort was associated with an increase in beverage CHO content and osmolality.

GI symptoms, such as abdominal bloating, eructation, flatulence, stomach ache, nausea, vomiting, heartburn, side ache, intestinal cramps, and diarrhea have often been reported by athletes during races and practices. These symptoms can be caused by many factors such as food and fluid intake, decrease in splanchnic blood flow, hypertonicity of ingested fluid, CHO malabsorption, slow gastric emptying and intestinal absorption, dehydration, hyperthermia, exercise mode (mechanical vibration), exercise duration, and exercise intensity (18, 27, 33, 35, 36). In the present study, exercise intensity, exercise duration, hydration level, ingested volume of fluid, ingestion time, environmental temperature, and relative humidity were standardized for all experiments. Thus, differences in the GI perceptual responses are the result of differences in beverage composition.

It has been reported that the rates of gastric emptying and intestinal absorption are not significantly affected by beverage CHO concentration at 6% or below compared to water (12, 22). These findings suggest that ingestion of water and a CHO beverage with low CHO concentration (up to 6%) might not have a significant impact on GI discomfort. A further increase of CHO concentration above 6% is known to slow the rate of gastric emptying (22) and intestinal fluid absorption (12), and might increase GI discomfort. Sodium is the major electrolyte in the beverages tested and it differed nearly four-fold between the 6% and 8% formulas (18 vs. 5 mEq). With the overriding effect of CHO content, it is unlikely that increasing the beverage sodium content significantly affects gastric emptying (22) and intestinal absorption (10) of fluid. To date, there are no data to show that beverage electrolyte concentration in this range induces GI discomfort. Therefore, in this study, CHO concentration and hypertonicity of the beverage are likely to be the main contributors to GI discomfort.

The data indicate that the mean cumulative GI discomfort rating tended to increase over exercise time with a significant difference between the 6% CHO-E and 8% CHO-E beverages at Q3 (47 min) and Q4 (63 min). Rating of stomach upset was significantly higher at Q3 (47 min) for the 8% CHO-E beverage compared to the 6% CHO-E beverage. Mean rating of stomach upset and side ache averaged over all 4 quarters was significantly higher for the 8% treatment. These absolute ratings might be on the low end of the scale, but the relative difference between treatments was significant and could still be meaningful. In this study, the slow increases in GI discomfort over time for both treatments are not surprising because
the subjects were unaccustomed to ingesting relatively large volumes of fluid and because of the repetitive, high-intensity nature of the exercise. The higher ratings for 8% CHO-E were likely caused by its higher CHO concentration and osmolality, which are known to slow gastric emptying (22) and intestinal fluid absorption (12) and thereby slowing the exit of fluid from the GI tract. Previous studies have indicated that drinking a hypertonic beverage leads to increased GI discomfort (18, 36) and that CHO malabsorption is significantly related to GI symptoms during exercise (27). This leads to the logical speculation that there is a threshold for CHO concentration and osmolality above which the risk of GI discomfort increases.

Why and how do hypertonicity and CHO concentration exert their effects on GI discomfort? There are several possibilities. First, a slower gastric emptying rate associated with high CHO concentration (high energy density) (22) and increased gastric secretion (39) result in a large gastric residual volume that contributes to GI discomfort. Second, a slower rate of CHO absorption in the small intestine resulting from the hypertonicity induced by higher CHO concentration could initiate feedback inhibition of gastric motility and gastric emptying (3, 32). Third, intestinal fluid absorption is significantly reduced at rest (12) and during exercise (38) when CHO concentration in a beverage increases beyond 6%. Slowed fluid absorption is another possible factor for GI discomfort. Finally, hypertonic fluid emptied from the stomach will increase intestinal secretions (20), and thereby increase GI symptoms during high-intensity exercise.

The most reasonable explanation for the side ache produced during exercise in this study is the higher beverage CHO concentration and osmolality associated with the 8% beverage. Side ache is sometimes experienced by athletes during exercise. Often referred to as a “stitch,” it might be caused by tugging of the viscera on peritoneal ligaments or by ischemia caused by a decrease of blood flow to the diaphragm. Plunkett and Hopkins (31) suggested that the production of stitch was related to fluid absorption, and that isotonic beverages produced less stitch symptoms than a beverage with higher CHO concentration and osmolality. Consistent with this notion is the finding in the present study that ingestion of a hypertonic beverage with higher CHO concentration (8%; 434 mOsm/kg) produced a significantly greater symptom of side ache during intermittent, high-intensity exercise compared to the ingestion of an isotonic 6% CHO beverage. Higher CHO concentration and osmolality in an ingested beverage reduces intestinal fluid absorption (38), slowing the removal of fluid from the intestine, and possibly producing side ache by inducing tugging on peritoneal ligaments.

Gastrointestinal discomfort often occurs in endurance exercise, such as long distance running, cycling, and triathlons. Peters et al. (28) found that long-distance running has a higher incidence of lower GI symptoms, while cycling is associated with both upper and lower GI symptoms. Running produces a higher incidence of GI symptoms compared to swimming and cycling in a triathlon (40). Two studies (29, 37) investigated GI symptoms during long-distance walking and indicated that GI symptoms occurred less frequently and were less severe compared with more intense exercise. To our knowledge, no studies have been published on GI discomfort during intermittent, high-intensity exercise. Results of a field study (16) demonstrated that gastric emptying was slowed during intermittent, high-intensity exercise (75% VO_2max) compared with rest or moderate, steady-state exercise. High exercise intensity also decreased intestinal fluid absorption (19). In the present
study, the average exercise intensity was at 76% HR_{peak}, which was similar to the exercise intensity in a study that showed slower gastric emptying with intermittent high-intensity exercise (16). Although it is not certain that stop-and-go sports, with frequent running and jumping, impact GI discomfort resulting from mechanical jarring (35), our data show that GI symptoms can occur with intermittent, high-intensity exercise and are provoked by the ingestion of a beverage with a high CHO concentration.

In conclusion, the ingestion of fluid prevents dehydration during intermittent, high-intensity exercise. A combination of elevated beverage CHO content, osmolality, and high-intensity exercise appear to promote GI discomfort.

References