Gastric Emptying of Fluids During Variable-Intensity Running in the Heat

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This study examined gastric emptying, core temperature, and sprint performance during prolonged intermittent shuttle running in 30 °C when ingesting a carbohydrate-electrolyte solution (CES) or flavored water (FW). Nine male soccer players performed 60 min of shuttle running, ingesting fluid before exercise and every 15 min during exercise. Gastric emptying was measured using a double-sampling aspiration technique, and intestinal temperature was monitored via ingested capsules. There were no differences between trials in the total fluid volume emptied from the stomach during each exercise period ($P = 0.054$). The volume emptied every 15 min was $244 \pm 67$ mL in the CES trial and $273 \pm 66$ mL in the FW trial. Intestinal temperature was higher during exercise in the CES trial ($P = 0.004$), and cumulative sprint time was shorter ($P = 0.037$). Sprint performance was enhanced by the ingestion of a CES, which resulted in elevated core temperatures, and the rate of gastric emptying remained similar between solutions.

**Key Words**: carbohydrate, intestinal temperature, sprinting, exercise performance, sport, nutrition, exercise physiology

During intermittent high-intensity running, ingesting a suitable carbohydrate-electrolyte solution (CES) has been shown to improve exercise capacity (5, 6, 22, 31) and performance (23, 32, 33) under laboratory conditions. When sports involving intermittent exercise are played in a hot environment, the volume of the drink ingested and absorbed is often considered more important than the carbohydrate intake. This is because the fatigue process during exercise in the heat is mainly a consequence of dehydration and hyperthermia rather than a lack of carbohydrate availability (15, 18). The taste and availability of the drink and the subjective belief in the benefits derived from it are central in determining the volume ingested during exercise. Learned drinking behavior will similarly help maximize the volume of fluid that can be consumed. The rate of gastric emptying, however, is a key variable regulating the availability of the drink for use by the body (12, 15).

Several studies examining the efficacy of consuming fluids in the heat have reported the development of significantly elevated core temperatures when participants ingested CES rather than a similar volume of an energy-free placebo solution (7, 16, 19). There are 2 obvious explanations for why a CES drink could promote
an increase in the rate of heat storage in the body. The first is that the exogenous carbohydrate allows subjects to exercise at a slightly higher intensity, resulting in greater heat production and, hence, storage. The second is that the carbohydrate component of the drink slows gastric emptying sufficiently to limit water absorption and thereby compromise thermoregulation (15, 18).

In the study of Morris and coworkers (19), exercise intensity was considered to have been the same in all trials because no statistical differences were detected in heart rate, sprint times, total exercise duration, or ratings of perceived exertion regardless of the drinks ingested. Because there was a trial-order effect in this study, it is possible that differences in exercise intensity promoted by consumption of the CES drink might have been obscured. In the investigations of Millard-Stafford et al. (16) and Fritzsche et al. (7) it is likely that a greater amount of work was performed when the CES was ingested, resulting in a greater rate of heat storage.

Intermittent, high-intensity exercise delays the gastric emptying of fluids compared with an equivalent energy expenditure during constant-load exercise (14) or low-intensity walking (13, 14). Solutions containing 4% or more glucose have also been shown to empty more slowly from the stomach at rest than an equivalent volume of water (30). In addition, the type of transportable carbohydrate in 6% solutions is thought to have little effect on gastric emptying rate (27). It is therefore possible that the carbohydrate drinks used in the studies mentioned previously (7, 16, 19) were emptied from the stomach more slowly than the carbohydrate-free drinks. If this was the case, it was probably hypohydration and hypovolemia that led to the faster rate of rise in core temperature in the CES trials in these studies. In a recent study, however, there were no differences detected in the gastric emptying rates of a 6.4% CES drink and a carbohydrate-free solution during 30 min of high-intensity intermittent shuttle running carried out under relatively cool (15–17 °C) environmental conditions (13). In that study, the exercise intensity of the shuttle running delayed gastric emptying of both the CES and the placebo drink to an equivalent extent compared with that when equivalent volumes of the same solutions were consumed during low-intensity walking. Nonetheless, the influence of a longer period of intermittent exercise and a raised environmental temperature on gastric emptying has yet to be determined.

Therefore, the main purpose of the present study was to investigate whether gastric emptying of a 6.2% CES was slowed compared with a carbohydrate-free drink during 60 min of high-intensity intermittent exercise in the heat. The second purpose was to determine whether the faster rate of rise in core temperature could be caused by higher intensity sprinting on the CES trial and whether this greater heat storage promoted an increased perception of exertion during 60 min of exercise.

**Methods**

**Experimental Design**

Subjects performed 60 min of the Loughborough intermittent shuttle test (LIST) (21) in an environmental temperature of 30 °C (30.4 ± 0.1 °C, 31.8% ± 0.6% relative humidity) on 2 separate visits to the laboratory 7 days apart. The test involved performing 4 bouts of the LIST, each lasting approximately 15 min and with periods of exercise separated by about 5 min of rest. During the rest periods subjects were
seated while gastric aspiration took place, and this was immediately followed by ingestion of the required bolus of fluid. Subjects consumed either a 6.2% CES containing maltodextrin and glucose syrup (osmolality 292 ± 5 mOsmol/kg, estimated Na\(^+\) 24 mmol/L and K\(^+\) 0.62 mmol/L; Lucozade Sport, GlaxoSmithKline, Brentford, UK) or flavored water (FW), consisting of a commercially available low-sugar orange drink (Robinsons Ltd, Chelmsford, UK) and an artificial sweetener (Sweetex, Crooks Laboratories, Basingstoke, UK). The FW had an osmolality of 47 ± 4 mOsmol/kg and an electrolyte content of Na\(^+\) 5 mmol/L and K\(^+\) 0.06 mmol/L. Both the CES and the FW were formulated in single batches, and the drinks were administered in a double-blind fashion with the treatment order randomized.

Participants

Nine male soccer players were selected on the basis of their VO\(_{2\text{max}}\), training status, and ability to be successfully intubated with an orogastric aspiration tube. Their median age and mean mass, height, and estimated VO\(_{2\text{max}}\) were 22 (18–31) y, 80.8 ± 8.5 kg, 1.80 ± 0.08 m, and 55.5 ± 4.2 mL·kg\(^{-1}\)·min\(^{-1}\), respectively. An effect-size analysis indicated that the sample size had 87% power to detect meaningful differences in gastric emptying based on findings of a previous study (14). At the time of the investigation subjects were unaccustomed to exercise in warm weather. All subjects were fully informed of the demands and possible risks associated with participation in this study and their right to withdraw their involvement at any time. Each subject signed a consent form before taking part in this study, which had the approval of the local ethics-advisory committee.

Preliminary Measurements

All potential subjects were screened in order to determine who could be successfully intubated with the orogastric tube both at rest and after a 15-min period of the exercise protocol. Maximal oxygen uptake was estimated using a progressive multistage shuttle-running test (25). Subjects performed between 30 and 45 min of the LIST protocol to familiarize themselves with the activity pattern and physical demands of the protocol.

Main Trials

In the 2 days preceding each main trial subjects were asked to consume the same diet and not to drink alcohol. Over the 24 h before each trial subjects refrained from strenuous physical activity and ingesting caffeine. Subjects fasted for at least 10 h before each trial, and at 11 PM on the day before each trial they ingested 500 mL of water and swallowed a disposable temperature-sensor capsule (CorTemp, HQinc, Palmetto, FL, USA). We have previously shown these devices to be a valid and reliable means of determining core temperature during the LIST protocol (8). Participants were asked to ingest another 500 mL of water at 6 AM on the day of each trial before arriving at the laboratory at 8 AM. This dietary routine was implemented in an attempt to replicate the intestinal transit time and hence standardize the position of the temperature sensor in the intestinal tract during each trial. Before use, individual temperature sensors were calibrated (8). After the subjects voided, nude body mass (BM) was recorded to the nearest 50 g (Avery, Birmingham, UK)
and 4 skin thermistors (409B, YSI, Ohio, USA) were attached to subjects on the chest, upper arm, thigh, and calf at the locations outlined by Mitchell and Wyndham (17). Cables were secured with medical tape (Transpore, 3M, Loughborough, UK), and the sites of attachment were marked for the subsequent trial by the removal of body hair. Skin thermistors were connected to a lightweight (25-g), portable data logger (ML2002, Mini-Mitter Inc, Oregon, USA) that was tightly secured to the torso in a neoprene waist pouch.

The subjects then entered the gymnasium to perform the shuttle-running test. Temperature in the gymnasium was maintained at 30.4 ± 0.1 °C by means of 4 electrical fan heaters (DE65 Andrew Sykes Ltd, Nottingham, UK) and an indirect gas-fired heater (IG75 Andrew Sykes Ltd, Nottingham, UK). Although the relative humidity in the gymnasium was not controlled, it remained essentially similar (31.8% ± 0.6%) between trials and throughout each testing period.

Each subject then sat down and swallowed the gastric-aspiration tube (French Levine, 14 gauge, Vygon Ltd, France), positioning the tip in his stomach. The length of tube that each subject was required to swallow was established during the familiarization stage, and it was sited so that the stomach could be effectively emptied. A 50-mL catheter-tipped syringe (Becton Dickinson, Drogheda, Ireland) was attached to the tube and used to empty the fasting gastric contents of the stomach. The stomach was then washed with 100 mL of distilled water, and a recovery test was carried out to ensure that the aspiration tube was correctly positioned (11). Subjects then rapidly ingested (121 ± 38 s) one of the test drinks in a volume calculated according to body mass (6.5 mL/kg body mass). The temperature of all drinks was approximately 4 °C. Test drinks contained 23 ± 3 mg/L of phenol red (water-soluble; BDH, Poole, UK). The stomach contents were thoroughly mixed by repeated aspiration and reinjection of the contents using the 50-mL syringe. A 2.5-mL aliquot of gastric contents was collected. The gastric tube was then removed and subjects began exercising.

After each 15-min period of exercise subjects sat down and reinserted the gastric tube. The stomach contents were mixed as before, and a 2.5-mL aliquot of gastric contents was collected. Phenol red (1 mL) at a concentration of 1000 mg/L was injected into the stomach, and the contents were mixed again before a second 2.5-mL sample was collected. The gastric tube was then removed, and subjects rapidly ingested (188 ± 88 s) a volume of cold test drink equivalent to 3.5 mL/kg body mass containing 23 ± 3 mL/L of phenol red, after which they began exercising. After the final 15-min period of exercise, the gastric contents were mixed once more and a 2.5-mL aliquot collected. Then 1 mL of phenol red at a concentration of 1000 mg/L was injected into the stomach, and the contents mixed again before a second 2.5-mL sample was collected. Distilled water (100 mL) was injected into the stomach and mixed with the gastric contents, and the total fluid volume of the stomach was emptied as completely as possible by aspiration. This volume, minus the 100 mL of distilled water, was recorded and used to compare whether the total gastric volume at the end of each trial was similar to that calculated by the method of Beckers et al. (2) and from the dilution of the phenol-red concentration of the stomach contents by the 100 mL of distilled-water wash.

Because phenol-red dye is poorly absorbed by the stomach, the difference in concentration of the dye in the original test drink and the collected samples can be used to calculate the total volume in the stomach and the volume of test drink
remaining in the stomach at specific time points (26). The difference between the total gastric volume and the test-drink volume is the volume of secretions and swallowed saliva that have entered the stomach lumen over that time period.

During exercise, heart rate was measured continuously using short-range telemetry (Polar Electro Fitness Technology, Finland). Core temperature was measured approximately every 80 s during the walking phase of the exercise protocol using an ambulatory data recorder (CT2000, HQinc, Palmetto, FL, USA). During the walking phase, 15-point scales were used to record perceived exertion, thermal comfort (very cold to heat unbearable), gut fullness (not full to extremely full), and thirst (no thirst to extremely thirsty). At the end of exercise, after the final measurement of gastric content, subjects towel dried and nude body mass was measured. Percentage body-mass loss was determined from changes in body mass, and sweat volume was calculated by accounting for ingested and infused fluid while correcting for urine output.

Atmospheric dry- and wet-bulb temperatures, along with black-globe radiant temperature and percentage relative humidity, were continually monitored electronically at 5 points along the running track with temperature probes (Grant temperature probes, Grant Instruments Ltd, Cambridge, UK) and manually using a whirling hygrometer (Brannan Thermometers Ltd, Cumberland, UK). During the sprinting phases of each exercise period, time taken to sprint the first 15 m of the track was measured using infrared photoelectric cells (RS Components Ltd, Switzerland) interfaced with a computer.

Chemical Analysis

The phenol-red concentrations of test solutions and aspirated samples were measured spectrophotometrically at a wavelength of 560 nm after dilution 1:10 with NaOH-NaHCO₃ buffer (250:500 mmol/L, pH 9.7). The carbohydrate contents of drinks and aspirates were determined using a glucose-oxidase method (GOD perid, Roche-Boehringer, East Sussex, UK) after acid hydrolysis of the sample. Osmolality was determined by freezing-point depression (Gonotec Osmometer 034, Clanden Scientific, Hants, UK).

Statistical Analysis

All data were initially tested for distribution and homogeneity of variance. An independent 2-way analysis of variance (ANOVA) with repeated measures was used to determine whether there were any differences between fluid conditions and time over the 60 min of exercise. For significant $F$ ratios, a Holm–Bonferroni stepwise method was used to determine the location of the variance (1). Pearson’s product–moment test (2-tailed) was used to test for statistical correlation between study variables. Except for the total time spent sprinting, all data were found to be normally distributed and are presented as means ± standard deviations. The data for total time spent sprinting were analyzed using a Wilcoxon matched-pairs test, and these data are presented as medians and ranges. Weighted mean skin temperature ($T_s$) and total-body heat content (TBHC) were calculated using the method described by Ramanathan (24) and Bittel (3). Changes in body mass during exercise and the heat debt imposed by test drinks (20) were considered when
calculating TBHC. Inferential statistics are based on a population of 9, except for $T_{sk}$ and TBHC, which were calculated from a sample of 5. Significance was accepted at the 5% level, except for the $t$-tests, to which the appropriate Holm–Bonferroni adjustment was applied.

### Results

The total volume of fluid in the stomach after ingestion of the initial bolus of the drink was similar ($P = 0.66$) in the CES (555 ± 59 mL) and FW (542 ± 62 mL) trials. The same volume of test drink (525 ± 55 mL) was ingested immediately before the start of the first bout of exercise. Therefore, it is clear that the gastric volume remaining in the stomach after the initial aspiration of the fasting contents and washing procedure was relatively small and similar in both trials.

There was a tendency for more fluid to be retained in the stomach in the CES trial than in the FW placebo trial (Figure 1), but no significant differences were detected ($P = 0.054$). The total fluid volume in the stomach was less ($P = 0.045$) before the start of the initial exercise block (555 ± 59 mL) in the CES trial than at the start of the last exercise block (769 ± 216 mL) but similar to that at the start of the other 2 exercise blocks (652 ± 156 mL and 636 ± 141 mL, respectively). In the FW trial, the total gastric volume was similar at the start of the 4 exercise blocks (599 ± 156 mL, $P = 0.28$).

The total volumes of fluid emptied every 15 min were similar in the CES trial (224 ± 195 mL, $P = 0.24$). In the FW trial, the total fluid volumes emptied during the first (232 ± 146 mL), second (363 ± 139 mL), and fourth (311 ± 129 mL) exercise

![Figure 1 — Total fluid volume (mean ± standard deviation) in the stomach during each 15-min shuttle-run exercise block under the carbohydrate-electrolyte-solution (CES) and flavored-water (FW) conditions.](image-url)
blocks were essentially the same \((P = 0.17)\), but less volume was emptied during the third \((150 \pm 104 \text{ mL, } P = 0.032)\) exercise block. No differences were detected in the total fluid volumes emptied during each exercise block between trials \((P = 0.42)\), nor in the cumulative total fluid volume emptied between trials \((P = 0.39)\).

The total gastric-fluid volume measured at the end of the last exercise bout in the CES trial was similar \((P = 0.90)\) whether estimated using the formula of Beckers et al. \((2)\) or from dilution of the phenol-red dye by the 100 mL of distilled-water wash or by aspiration of the stomach contents (Table 1). Similarly, the final total gastric volume measurement was similar \((P = 0.98)\) on the FW trial as estimated by the 3 methods (Table 1).

The volume of test drink retained in the stomach was comparable between the 2 trials \((P = 0.20)\). The drink volume in the stomach was similar at the start of all exercise blocks in the CES trial \((595 \pm 147 \text{ mL, } P = 0.10)\) and FW trial \((565 \pm 143 \text{ mL, } P = 0.46)\), and no differences were apparent between trials \((P = 0.38)\). The volume of test drink emptied over each 15-min period of exercise in the CES trial was also not different (Figure 2; \(P = 0.23\)). This amounted to an average of 15.6 \(\pm 10.7\) g of carbohydrate delivered to the duodenum during each exercise block. In the FW trial, the test-drink volumes emptied during the first, second, and fourth exercise blocks were the same \((P = 0.22)\), but less volume was emptied during the third (Figure 2; \(P = 0.032\)) exercise block. No differences were detected in the test-drink volumes emptied during each exercise block between trials \((P = 0.41)\), nor in the cumulative fluid volume emptied between trials over the entire LIST \((P = 0.51)\).

A small but significantly \((P = 0.001)\) greater volume of secretions was present in the stomach throughout the CES trial \((71 \pm 22 \text{ mL/15 min})\) than in the FW trial \((41 \pm 23 \text{ mL/15 min})\).

The interval between starting to drink the initial bolus of test drink and commencing the first exercise block was similar \((P = 0.94)\) in the CES \((362 \pm 164 \text{ s})\) and FW \((355 \pm 218 \text{ s})\) trials, and this period was the same as that subsequently taken between exercise blocks in the CES \((277 \pm 53 \text{ s, } P = 0.17)\) and FW trials \((330 \pm 81 \text{ s, } P = 0.96)\). The interval between finishing one block of exercise and the start

### Table 1  Comparison of Total Volume Remaining in the Stomach at the End of Each Trial Measured by the Dye-Dilution Method of Beckers et al. \((2)\), the Dilution of the Dye by the Wash Volume of Distilled Water, and Direct Aspiration

<table>
<thead>
<tr>
<th>Method</th>
<th>Carbohydrate-electrolyte solution</th>
<th>Flavored water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated gastric volume, Beckers et al. ((2)), mL</td>
<td>470 ± 131</td>
<td>371 ± 220</td>
</tr>
<tr>
<td>Calculated gastric volume (dilution by water wash volume), mL</td>
<td>476 ± 140</td>
<td>357 ± 210</td>
</tr>
<tr>
<td>Aspirated gastric volume (minus the washout volume), mL</td>
<td>447 ± 136</td>
<td>354 ± 201</td>
</tr>
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</table>
Gastric Emptying During Interval Running in 30 °C

of the next was similar throughout the CES ($P = 0.98$) and FW trials ($P = 0.96$), but the times were slightly shorter in the CES than in the FW trials ($P = 0.002$). The time interval between the end of the fourth exercise block and the completion of the gastric-emptying measurement at the end of the experiment was similar ($P = 0.94$) in the CES (220 ± 128 s) and FW trials (225 ± 122 s). The time taken to ingest the test drinks was similar throughout the CES trial (112 ± 41 s, $P = 0.41$) and FW trial (123 ± 40 s, $P = 0.69$), with no significant difference between trials ($P = 0.24$).

Deep body temperature, as determined by the ingested temperature-sensor capsule, was higher ($P = 0.004$) during the hour of exercise in the CES than in the FW trial (Figure 3). Mean core temperatures were similar before starting the CES (37.2 ± 0.2 °C) and FW trials (37.0 ± 0.2 °C), and at the end of the 60 min of exercise they were 39.6 ± 0.6 °C and 39.2 ± 0.6 °C, respectively. $T_{sk}$ was similar in the CES (33.9 ± 0.42 °C) and FW (33.66 ± 0.39 °C) trials. There was a trend for $T_{sk}$ to increase over time in both fluid conditions ($P = 0.075$). The change over time was not significantly different between trials, but subjects appeared to exhibit a higher $T_{sk}$ during the last block of the CES when compared with the FW trial. Postexercise $T_{sk}$ was 35.42 °C (± 1.96) and 34.98 °C (± 0.92) in the CES and FW trials, respectively. Mean TBHC showed a marked increase during the protocol ($P = 0.031$), but there were no differences detected at rest or as a change over time during exercise between fluid conditions. At the end of exercise, TBHC was 10.37 MJ (± 0.55) in the CES trial and 10.24 MJ (± 0.73) in the FW trial, a gain of 654 KJ and 541 KJ in the CES and FW trials, respectively.

Figure 2 — Volume (mean ± standard deviation) of ingested drink emptied from the stomach during each 15-min shuttle-run exercise block when ingesting the carbohydrate-electrolyte-solution (CES) and flavored-water (FW) test drinks.
Although no difference could be detected between trials in mean sprint times for each exercise block \((P = 0.48)\), subjects cumulatively sprinted more slowly in the FW trial (median, range: 103.6 s, 97.4–111.6) than in the CES trial (102.4, 94.9–108.8; \(P = 0.037\)). This is an overall difference between trials of 1.2 s (± 0.4). Heart rates were similar between the 2 trials (Figure 4) but increased significantly over the 60 min of exercise.

No significant differences were detected between fluid conditions in any of the subjective experiences measured during the protocol. Rating of perceived exertion (4) increased over time during both trials \((P < 0.01)\), and in the last period of exercise it was equivalent to a rating of 14.6 ± 2.6 and 16.6 ± 2.0 in the CES and FW trials, respectively. Thermal discomfort increased over time in both trials \((P = 0.01)\), as did thirst drive \((P < 0.01)\). At the end of exercise these ratings were equivalent to the descriptors “extremely hot” and “thirsty.” Participants reported increased feelings of gastric fullness during the first block of exercise compared with the remaining 3 blocks of exercise \((P = 0.03)\), feeling “fairly full” at the end of exercise.

The osmolality of the urine collected before starting the trials was similar \((P = 0.536)\) before exercise in the CES (790 ± 480 mOsmol/kg) and FW trials (790 ± 610 mOsmol/kg). At the end of the 60 min of exercise, urine osmolality was 480 ± 260 mOsmol/kg in the CES trial and 610 ± 190 mOsmol/kg in the FW trial. The volume of fluid lost as sweat during the protocol was 2.1 ± 0.5 L and 1.4 ± 0.7 L in the CES and FW trials, respectively. These fluid losses were significantly different between trials \((P = 0.01)\), and the overall percentage of body mass lost

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**Figure 3** — Intestinal temperature (mean ± standard deviation; °C) during the shuttle-run protocol under the carbohydrate-electrolyte-solution (CES) and flavored-water (FW) conditions. Main effect \((P < 0.05)\) CES versus FW.
was 1.5% ± 0.7% in the CES and 0.9% ± 0.7% in the FW trial \( (P = 0.09) \), assuming that all fluid that emptied into the small intestine was absorbed.

Environmental temperature (30.4 ± 0.1 °C) and relative humidity (31.8% ± 0.6%) remained constant, and no differences were detected between trials in these parameters.

**Discussion**

The main finding of this study was that the volume of fluid emptied from the stomach during intermittent shuttle running was not different between a 6.2% CES and FW. Ingestion of the CES resulted in a higher core temperature and improved cumulative 15-m-sprint performance compared with FW during 60 min of the LIST performed in an environmental temperature of 30 °C.

Deep body temperature was significantly higher during the CES trial, which is in agreement with previous investigations that have studied outdoor running (16) and laboratory-based protocols that include sprinting exercise (7, 19). Participants also lost more fluid as sweat when ingesting a CES, suggesting that they were under greater thermal stress than when drinking equivalent amounts of water.

The purpose of the present study was to ascertain whether this additional heat storage was a result of either the separate or the synergistic effect of dehydration, caused by delayed gastric emptying as a consequence of the energy content of the sports drink, an increase in metabolic heat production occurring as a result of working at a higher exercise intensity supported by the additional carbohydrate in the CES.
The total volume of fluid, which includes test drink, saliva, and gastric secretions, emptied into the intestine during each of the 15-min blocks of the exercise protocol in the present study was similar in the CES and FW trials. There was, however, a trend for a slightly larger total volume of fluid to be retained in the stomach when subjects ingested the CES ($P = 0.054$). Previous investigations have shown that solutions with carbohydrate concentrations of 6% or more empty more slowly than energy-free drinks ingested at rest (15, 30) or during low-intensity exercise (13). On the other hand, the total fluid volume emptied after ingestion of either a CES or a carbohydrate-free placebo drink was similar during 30 min of the LIST protocol carried out in temperate conditions (13). In the present study, the difference in the total volume emptied between trials amounted to an average of approximately 100 mL of fluid over the 60 min of exercise. There was no difference in the volume of test drinks emptied over this period, but the volume of secretions present in the stomach was slightly higher in the CES trial than in the FW trial. This approximated an additional 120 mL of secretions’ being produced during the whole of the CES trial compared with that in the FW trial, which in all probability accounts for the tendency for a larger gastric-fluid volume in the CES trial. There was notably less fluid emptied during the third block of exercise; this appears to be a consistent finding during both trials, for which currently there appears to be no reliable explanation.

The trend toward a reduction in the rate of gastric emptying during the CES trial in the present study could have resulted in decreased availability of water and, hence, reduced water uptake. It is possible that ingesting the carbohydrate beverage resulted in a small but marked decrease in water replacement compared with the FW drink. If this did occur, dehydration and hypovolemia might be responsible for a proportion of the faster rise in core temperature observed in the CES trial. A divergence in the rate of temperature increase is evident after 15 min of exercise, however, at a time when the difference in the total volume emptied between trials was about 50 mL, and over the 60 min of exercise the difference in fluid volume emptied totaled only about 100 mL. Clearly, of the $1.41 \pm 0.21$ L of test drink ingested in each trial, most of the volume was emptied during the exercise in the heat in the CES (69.2% ± 10.7%) and FW trials (74.3% ± 14.5%). The sweat loss in the CES trial exceeded that measured during the FW trial, suggesting that sweat production was not limiting heat loss in subjects in the CES trial. Subjective ratings of thermal comfort, thirst, and gastric fullness were also similar between trials. At the end of the 60 min of the LIST, urine osmolality was similar between trials and did not indicate that subjects were hypohydrated to a considerable degree with either solution. These results suggest that there was no significant difference in the rates of fluid delivery and absorption between dilute CES and energy-free placebo solutions during the LIST trial in the heat.

During the 60 min of exercise subjects sprinted 11 times during each of the 15-min periods of exercise. The total time spent sprinting during the hour of exercise in the present study was less when subjects ingested the CES. This suggests that overall sprint performance was improved when the CES was ingested compared with flavored water alone. This finding supports previous work that has demonstrated that carbohydrate ingestion during intermittent high-intensity exercise enhances performance (23, 32, 33) during activities related to field sports. Total carbohydrate intake over the 60 min of exercise in the CES trial was 87.9 g, of which
62.4 g were emptied from the stomach into the duodenum. The average amount of carbohydrate emptied into the small intestine during each 15-min period of the CES trial was 15.6 g. In total, approximately 62 g of carbohydrate were emptied into the small intestine during the CES trial. The present findings suggest that the availability of an exogenous supply of carbohydrate provided by the CES might have enabled subjects to perform at higher exercise intensities during the sprint phase of each exercise cycle.

The small additional amount of work performed while sprinting seems likely to have contributed to the higher core temperatures observed during the CES trial. At the end of exercise the difference in TBHC between trials was 130 KJ. The results of a previous study using a similar protocol (9) indicate a difference in estimated energy expenditure of 290 KJ between trials when similar volumes of a CES and FW were ingested. These differences in energy expenditure are accompanied by improvements in sprint performance that are comparable to those of the present study. It therefore seems reasonable to suggest that an increase in energy expenditure of the magnitude seen in the present study could account for the extra heat generated and stored during the CES trial. The increased sweat rates observed during the CES trial support this contention and are likely to be a consequence of the need to dissipate the additional metabolic heat generated.

Several studies have shown that ingesting carbohydrate drinks during intermittent exercise improves performance (23, 32, 33). These improvements in performance are normally seen near the end of a prolonged period of exercise and are attributed to attenuation of the fatigue process by sparing muscle glycogen or maintaining better hydration status (28, 29). In the present study, there was a tendency for intestinal temperature to be higher during the CES than the FW trial by the end of the first 15-min block of exercise. Although no statistical difference could be found in sprint speeds during this initial exercise block, of the 11 sprints undertaken in this period, 8 were faster during the CES than in the FW trial. This occurred over a time period when energy availability from muscle glycogen is likely to be similar between the 2 trials, and therefore one would not normally expect that exercise intensity would be different (22, 29). It is possible that these improvements in performance early in exercise are attributable to a CNS-mediated ergogenic effect of carbohydrate feeding.

No changes were apparent in subjective perception of exercise intensity between fluid conditions, although the performance data suggest that subjects were exercising at a slightly higher intensity when ingesting the CES solution. It may be that the perception scales used are not sensitive enough to highlight the minor changes in exercise intensity or that CES ingestion allows subjects to enhance performance without invoking a negative perception of the additional exercise load.

Over the relatively short duration of exercise employed in the present study, the additional heat stored appears to have been of no detriment to exercise capacity. During more prolonged exercise it is possible that this additional heat production could ultimately lead to a decrease in exercise capacity caused by attaining a capacity-limiting core temperature (10).

It seems most likely from the present study that the faster rise in core temperature when ingesting the CES was caused mainly by a small increase in energy expenditure during the sprinting phase of the protocol. Individuals might also have completed the running and jogging phases of the LIST faster or used an altered
running technique. Because gastric emptying, hydration values, and urine osmolality were not different between the CES and placebo trials in the present study, it is improbable that the faster rate of heat storage when carbohydrates are ingested is mainly a result of increased levels of dehydration.

References


