Effect of Preexercise Glycemic-Index Meal on Running When CHO-Electrolyte Solution Is Consumed During Exercise

Stephen H.S. Wong, Oi Won Chan, Ya Jun Chen, Heng Long Hu, Ching Wan Lam, and Pak Kwong Chung

Purpose: This study examined the effect of consuming carbohydrate- (CHO) electrolyte solution on running performance after different-glycemic-index (GI) meals. Methods: Nine men completed 3 trials in a randomized counterbalanced order, with trials separated by at least 7 days. Two hours before the run after an overnight fast, each participant consumed a high-GI (GI = 83) or low-GI (GI = 36) CHO meal or low-energy sugar-free Jell-O (GI = 0, control). The 2 isocaloric GI meals provided 1.5 g available CHO/kg body mass. During each trial, 2 ml/kg body mass of a 6.6% CHO-electrolyte solution was provided immediately before exercise and every 2.5 km after the start of running. Each trial consisted of a 21-km performance run on a level treadmill. The participants were required to run at 70% \( \text{VO}_{2\text{max}} \) during the first 5 km of the run. They then completed the remaining 16 km as fast as possible. Results: There was no difference in the time to complete the 21-km run (high-GI vs. low-GI vs. control: 91.1 ± 2.0 vs. 91.8 ± 2.2 vs. 92.9 ± 2.0 min, n.s.). There were no differences in total CHO and fat oxidation throughout the trials, despite differences in preexercise blood glucose, serum insulin, and serum free-fatty-acid concentrations. Conclusion: When a CHO-electrolyte solution is consumed during a 21-km run, the GI of the preexercise CHO meal makes no difference in running performance.

Keywords: carbohydrate, endurance performance, sports drink

Fatigue in elite athletes during intense, prolonged exercise is associated with a decrease in blood glucose (Coyle, Coggan, Hemmert, & Ivy, 1986; Nuutila et al., 2000), depletion of glycogen stores (Noakes & Martin, 2002), and dehydration (Below, Mora-Rodriguez, Gonzalez-Alonso, & Coyle, 1995). Consumption of carbohydrate (CHO)-rich foods after such exercise appears to be desirable for meeting a complex array of nutritional requirements during the recovery period (Angus, Febrario, & Hargreaves, 2002; Siu et al., 2004). An athlete might also need to eat before prolonged exercise to prevent hunger and provide metabolized

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fuel during subsequent exercise bouts (Febbraio, Keenan, Angus, Campbell, & Garnham, 2000). It has been suggested that the glycemic index (GI) of a CHO-rich meal can be used as an indication of postprandial glucose and insulinemic responses, which affect subsequent metabolic responses (Brand-Miller, Burani, Foster-Powell, Lintner, & Burani, 2004; Chen, Wong, Xu, et al., 2008; Ludwig, 2003; McArdle, Katch, & Katch, 2006).

It has been shown that consuming a high-CHO meal before exercise causes hyperinsulinemia that might lead to hypoglycemia at the onset of exercise (Angus et al., 2002; Coyle, Coggan, Hemmert, Lowe, & Walters, 1985; Hawley, Dennis, & Noakes, 1992). This insulin surge inhibits lipolysis, increases the reliance on limited muscle glycogen reserve, and might cause earlier fatigue during exercise (Coyle et al., 1986). Consuming a low-GI meal before exercise, however, might slow down the release of glucose (Burke, Claassen, Hawley, & Noakes, 1998; DeMarco, Sucher, Cisar, & Butterfield, 1999; Febbraio et al., 2000; Thomas, Brotherhood, & Brand, 1991; Thorne, Thompson, & Jenkins, 1983; Wee, Williams, Gray, & Horabin, 1999; Wong et al., 2008; Wu & Williams, 2006), minimize hyperinsulinemia at the onset of exercise (Wee et al., 1999; Wong et al.), increase the concentration of blood free fatty acid (DeMarco et al.; Febbraio et al.; Wee et al., 1999; Wong et al.), and attenuate the rate of utilization of muscle glycogen during exercise (Wee, Williams, Tsintzas, & Boobis, 2005). Nevertheless, the influence of ingesting low-GI foods before exercise on enhancing exercise performance is inconsistent. Some studies have shown that endurance performance improved after preexercise ingestion of low-GI foods (DeMarco et al.; Thomas et al.; Wong et al.; Wu & Williams), whereas other studies showed no improvement in endurance performance despite changes in physiological responses (Febbraio et al.; Febbraio & Stewart, 1996; Wee et al., 1999). Regardless of any effects of preexercise feedings on subsequent metabolism, the most effective and common strategy used by endurance athletes to promote CHO availability during exercise is to ingest CHO-rich drinks or foods during the event. Many studies have found that consuming CHO during exercise improves performance by increasing time to exhaustion (Coyle et al., 1986) and increasing the amount of work that an individual can perform (Mitchell et al., 1988, 1989).

It is the general practice of athletes to consume CHO before and during endurance exercise. The combination of consuming a preexercise meal and a CHO-electrolyte solution during exercise improves endurance capacity to a greater extent than a preexercise meal alone or a CHO-electrolyte solution alone (Chryssanthopoulos & Williams, 1997; Febbraio et al., 2000). The interaction of the preexercise GI meal and the CHO-electrolyte solution during exercise has received only brief attention, however. Burke et al. (1998) suggested that ingesting CHO during prolonged moderate-intensity cycling minimizes any differences in metabolic and performance responses arising from the choice of preevent meal. Theirs was the only study to examine the impact of a preexercise GI meal and CHO intake during an event on exercise metabolism and endurance cycling performance. Cycling and running have been shown to elicit different physiological responses (Gore, Scroop, Marker, & Catcheside, 1992). It has been proposed that CHO ingestion results in more marked elevations in blood glucose and insulin concentrations during running than during cycling at the same relative exercise intensity (Tsintzas & Williams, 1998). Therefore, the purpose of this study was to
investigate the effect of low- and high-GI preexercise meals on running performance when CHO-electrolyte solution is consumed during exercise. We hypothesized that varying the GI of the preexercise meal would have little impact on 21-km run performance when a CHO-electrolyte drink was ingested during exercise.

**Methods**

**Participants**

Nine male endurance runners ($M \pm SEM$ age 24 ± 2.4 years, body mass 62.0 ± 1.5 kg, percent body fat 8.6% ± 0.4%) were recruited from local distance-running clubs and university running teams. Mean maximal oxygen uptake ($VO_2_{max}$) was 58.4 ± 1.5 ml · kg$^{-1}$ · min$^{-1}$, and mean maximal heart rate was 185 ± 2 beats/min. This study was approved by the university clinical-research ethics committee. Written informed consent was obtained from each participant. Furthermore, all the participants were required to complete medical-history questionnaires and provide general details of their training background and running ability. Qualified participants had no history of diabetes mellitus. At the time of the study, all participants could maintain their regular training in endurance running at least three times per week, with at least 50 km of accumulated running distance.

**Preliminary Measurement**

The participants visited the laboratory for familiarization with laboratory procedures, as well as the 21-km-run exercise protocol on a motorized treadmill (LE 500C, Jaeger, Traustein, Germany). They completed two preliminary tests and a screening test of blood glucose response before undertaking the three main trials. The preliminary tests determined the participants’ $VO_2_{max}$ for running, which was modified from the work of Taylor, Buskirk, and Henschel (1955), and the speed–oxygen-uptake relationship. The purpose of the screening sessions was to ensure that the recruited participants responded normally to the prescribed GI meals. Data from the screening sessions were assessed by a physician to ensure that no participant was diabetic.

**Protocol**

Our protocol consisted of a 2-hr rest period followed by one bout of exercise. Participants were required to complete a 21-km performance run on a treadmill under three different conditions, with bouts of exercise separated by at least 7 days. A low-GI or high-GI meal or low-energy, sugar-free Jell-O was consumed 2 hr before the run after an overnight fast. Both the low-GI and high-GI meals (61% CHO, 14% protein, 25% fat) provided 1.5 g available CHO/kg body mass for each participant, and their energy content and amount of macronutrients were also similar (Table 1). The low-GI meal was composed of mung-bean thread noodles in clear chicken broth, hard-boiled egg, fish sticks, green peas, and soy milk. The high-GI meal was composed of fried rice with egg and ham, sliced parsnips, canned lychees, fish sticks, and orange soda (Table 1). All these meal components are representative of typical preexercise meal choices in this particular study pop-
The GI value of the meal was calculated by a method described by Wolever and Jenkins (1986). In addition to the two GI meals, a fat-free, sugar-free, low-calorie gelatin (Jell-O, USA), which would not cause any glycemic response, acted as the control meal in this study. The water content of all meals was standardized so that each provided the participant with 1,100 ml of fluid. A 6.6% CHO drink of 2 ml/kg body mass was given to the participants just before exercise and every 2.5 km throughout the run to prevent dehydration and ensure a continuous supply of substrate. The order of the trials was randomized in a counterbalanced crossover design. Running times and the hypothesis being tested were not disclosed to the participants. Moreover, the time they took to complete the 21-km run was used as a measure of running performance. The participants were asked to follow their normal training schedules during the experimental period and follow the same training schedule 3 days before each main trial. They were told to refrain from strenuous exercise for 2 days before each main trial. Furthermore, they were required to complete a consecutive 3-day weighed-food record before each main trial. Dietary records were analyzed with computer software (Food Processor 8.2, ESHA, USA). Participants were asked to repeat the same diet before each main trial to minimize the variation of their muscle and liver glycogen concentrations.

On the day of a main trial, participants reported to the laboratory at about 8 a.m. after 10–12 hr of overnight fasting. This was to ensure an empty stomach and minimize the effect of previous meals on the gastric emptying rate of the test meals. On arrival, participants rested for 15 min on an examination couch before a catheter was inserted into the antecubital vein of the forearm. Baseline capillary and venous samples and expired-air samples were then collected. Further blood samples and expired-air samples were collected at specific times, as shown in Figure 1.

### Table 1 Nutritional Composition of Preexercise Meals (for a 63-kg Participant)

<table>
<thead>
<tr>
<th>Meal</th>
<th>Content</th>
<th>Nutritional analysis</th>
<th>Estimated glycemic indexa</th>
<th>Estimated glycemic loada</th>
</tr>
</thead>
<tbody>
<tr>
<td>HGI</td>
<td>73 g parsnips, 30 g fish sticks, 84 g jasmine rice, 250 g orange soda, 50 g canned lychees, 34 g ham, 76 g egg, 618 ml water</td>
<td>604 kcal, 61.2% CHO (92 g), 14.1% protein (22 g), 24.7% fat (16 g)</td>
<td>82.9</td>
<td>68.1</td>
</tr>
<tr>
<td>LGI</td>
<td>240 g soy milk, 50 g hard-boiled egg, 260 g clear chicken broth, 30 g fish sticks, 40 g green peas, 72 g mung-bean thread noodles, 520 ml water</td>
<td>595 kcal, 61.3% CHO (92 g), 13.9% protein (20 g), 24.8% fat (16 g)</td>
<td>35.9</td>
<td>15.7</td>
</tr>
<tr>
<td>CON</td>
<td>8 g Jell-O, 700 ml water</td>
<td>32 kcal, CHO (0 g), protein (3 g), fat (0 g)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Note. HGI = high-glycemic-index; CHO = carbohydrate; LGI = low-glycemic-index; CON = control.

*aCalculated glycemic-index values were taken from Wolever and Jenkins (1986).
Figure 1 — Schematic representation of the experimental procedures (main trial).
After collection of baseline blood samples, participants consumed low-energy Jell-O, a low-GI meal, or a high-GI meal in a counterbalanced randomized order. All foods were consumed within 15–20 min. Participants remained seated in a quiet area of the laboratory, and their activity levels were minimal while blood glucose concentrations and perceived rating of gut fullness were recorded throughout a 2-hr postprandial period at specific time points (i.e., 15, 30, 45, 60, 90, and 120 min after the meal). To ensure adequate hydration and balance the water content of the meals, each participant ingested 450–750 ml of distilled water before the exercise bout (Convertino et al., 1996).

A standardized 5-min warm-up at 60% VO_{2\text{max}} was performed after the 2-hr preexercise resting period. Treadmill speed was increased to an intensity of 70% VO_{2\text{max}} immediately after the warm-up. For the first 5 km, the participants ran at a fixed intensity of 70% VO_{2\text{max}} (Wee et al., 1999). They then changed their running speeds ad libitum over the remaining distance of the whole 21-km performance run by pressing the control panel located beside them. Two milliliters per kg body mass of CHO-electrolyte solution (Lucozade Sport Body Fuel isotonic drink; 6.6 g CHO, 47 mg Na\textsuperscript{+}, and 0.96 mg K\textsuperscript{+} per 100 ml) was given to the participants every 2.5 km throughout the run to reduce the effect of dehydration. During each treadmill run, the participants were cooled by an electric fan and a wet sponge when necessary. Expired-air samples, heart rate, capillary-blood samples, and venous blood samples were obtained at specific times, as shown in Figure 1. Ratings of perceived exertion were estimated using the 6- to 20-point Borg scale (Borg, 1973). Rating of abdominal discomfort was assessed on a 10-point scale on which 1 was completely comfortable and 10 was very uncomfortable (Geliebter, 1998). Participants rated perceived thirst on a 10-point scale on which 1 was not thirsty and 10 was very thirsty (Wong et al., 2008).

**Measurements**

Heart rate was measured by heart-rate telemetry (Polar PE 4000 Sport Tester, Kempele, Finland), and expired gas-samples were analyzed by a metabolic cart system (MAX-1, Physio-Dyne, New York). Rates of CHO and fat oxidation were calculated from VO\textsubscript{2} and VCO\textsubscript{2} values, by applying the equation described by McArdle et al. (2006). A preexercise 50-μl arterialized capillary-blood sample was collected from the thumb of a prewarmed hand using a Softclix automatic lancet (Boehringer Mannheim, East Sussex, UK) and capillary dispensers (YSI, OH, USA) to determine blood glucose and blood lactate levels. Blood lactate and glucose concentrations were determined immediately by patented immobilized enzyme technology using a lactate analyzer (Model 1500, YSI, OH, USA) and a glucose analyzer (Model 1500 Sidekick, YSI). An indwelling cannula (Angiocath, 22GA 1.00-in.) was inserted into the antecubital vein of the forearm before warm-up. A 5-ml venous blood sample was dispensed into a nonheparinized plastic tube and left to clot at room temperature for 1 hr. Serum samples were then obtained, stored in microtubes in a −35 °C medical freezer, and later analyzed for concentrations of insulin (Insulin ELISA, Mercodia, Sweden), free fatty acid (FA 115 kit, Randox Laboratories Ltd., UK), and glycerol (GY 105 kit, Randox Laboratories Ltd.) using commercially available kits. Hematocrit was determined using a reader (Clay Adams, Autocrit Ultra 3, Englewood, NJ), and hemoglobin
concentration was determined by the cyanmethemoglobin method (RA-50 Chemistry Analyzer, Bayer Diagnostics, Leverkusen, Germany). The percentage change in plasma volume from rest was estimated from hemoglobin and hematocrit values (Wong et al., 2008). Concentrations of plasma sodium (Na⁺) and potassium (K⁺) were determined by direct potentiometric analysis (614 Na+/K+ Analyzer, Criron Diagnostics, Essex, UK).

**Statistical Analysis**

Data are presented as \( M \pm SEM \). Dependent variables of the three trials (high-GI vs. low-GI vs. control), including performance time, total substrate oxidation, and macronutrient intake for 3 days before the main trial, were compared using a one-way analysis of variance (ANOVA) with Tukey’s post hoc test. Changes in concentrations of blood glucose, blood lactate serum insulin, free fatty acids, and glycerol and changes in respiratory-exchange-ratio, heart rate, rating of perceived exertion, perceived thirst, abdominal discomfort, and gut-fullness-scale values were analyzed by a factorial (two-way, Treatment \( \times \) Time) ANOVA with repeated measures, and a Tukey’s post hoc test was used to determine significant differences. Statistical significance was set at the .05 level.

**Results**

**Dietary Analysis**

There were no differences in daily energy intake and macronutrient composition of the participants’ diet during the 3 days before each trial (high-GI vs. low-GI vs. control: daily energy intake 2,669 ± 237 vs. 2,732 ± 261 vs. 2,595 ± 193 kcal; CHO 54.3% ± 1.2% vs. 53.3% ± 2.7% vs. 58.4% ± 1.8%; protein 19.1% ± 0.9% vs. 18.3% ± 1.2% vs. 17.7% ± 1.0%; fat 26.6% ± 0.9% vs. 28.4% ± 2.0% vs. 23.8% ± 1.1%; n.s.).

**Performance**

All participants completed the 21-km run in all trials. There were no differences in time to completion (high-GI 91.1 ± 2.0 min, range 82–103 min; low-GI 91.8 ± 2.2 min, range 81–104 min; control 92.9 ± 2.0, range 85–105 min; n.s.). Running speeds and percentage VO\(_{2\text{max}}\) throughout the performance run were similar among the three trials.

**Blood Metabolites**

Blood glucose response to the high-GI meal was the highest among the trials and peaked at 30 min (Figure 2). The blood glucose response in the high-GI group at 15, 30, and 45 min was significantly higher than that in the control group (\( p < .01 \)). In the low-GI group, blood glucose levels at 15 and 30 min were lower than those in the high-GI group but were higher than those in the control group (\( p < .01 \)). The 2-hr incremental area under the blood glucose curve after ingestion of the high-GI meal was the highest in the three prescribed meals (high-GI vs. low-GI...
Figure 2 — Blood glucose concentrations (mmol/L) during the 2-hr postprandial period and exercise in the high-glycemic-index (HGI), low-glycemic-index (LGI), and control (CON) trials ($N = 9; M \pm SEM$). $^\text{a}$p < .01 from premeal. $^\text{b}$p < .05 from premeal. $^\text{c}$p < .01 from HGI. $^\text{d}$p < .01 from CON. $^\text{e}$p < .01 from preexercise (120 min).
Figure 3 — Blood lactate concentrations (mmol/L) during the 2-hr postprandial period and exercise in the high-glycemic-index (HGI), low-glycemic-index (LGI), and control (CON) trials ($N = 9; M \pm SEM$). *p < .01 from preexercise.
Figure 4 — Serum insulin concentrations (mU/L) during the 2-hr postprandial period and exercise in the high-glycemic-index (HGI), low-glycemic-index (LGI), and control (CON) trials (N = 9; M ± SEM). *p < .01 from premeal. †p < .01 from HGI. ‡p < .01 from CON.
Figure 5 — Serum free-fatty-acid concentrations (mmol/L) during the 2-hr postprandial period and exercise in the high-glycemic-index (HGI), low-glycemic-index (LGI), and control (CON) trials ($N = 9; M \pm SEM$). $^a p < .01$ from premeal. $^b p < .05$ from premeal. $^c p < .01$ from CON. $^d p < .05$ from CON.
vs. control: 181.2 ± 8.4 vs. 46.6 ± 15.5 vs. 8.4 ± 5.8 mmol · min⁻¹ · L⁻¹, p < .01). The blood glucose level throughout exercise was similar to the preexercise level in the low-GI trial except at 21 km (p < .01), whereas blood glucose concentrations at 10 km, 15 km, and 21 km in the high-GI trial were higher than those at preexercise (p < .01). For the control trial, blood glucose concentrations were also higher at 10 km and 21 km than those at preexercise (p < .01).

The blood lactate level remained unchanged throughout the 2-hr postprandial period, and no differences were determined between trials (Figure 3). The lactate concentrations during exercise were higher than the preexercise value (p < .01) for all trials.

Serum insulin concentrations rose after consumption of a preexercise low-GI or high-GI meal compared with control and peaked at 60 min for both trials (Figure 4). There were differences between trials at 60 min and 120 min into the postprandial period (high-GI vs. low-GI vs. control: 60 min, 38.4 ± 2.4 vs. 22.6 ± 6.9 vs. 8.8 ± 0.8 mU/L, p < .01; 120 min, 24.8 ± 4.9 vs. 14.5 ± 1.6 vs. 8.9 ± 0.4 mU/L, p < .01). A greater change was found in high-GI than in the other two trials, whereas insulin levels remained unchanged throughout the control trial.

Serum free-fatty-acid concentrations were similar between the high-GI and low-GI trials (Figure 5). Free-fatty-acid level was higher at 60 min and 120 min in control than in high-GI and low-GI (high-GI vs. low-GI vs. control: 60 min, 0.10 ± 0.02 vs. 0.13 ± 0.01 vs. 0.48 ± 0.19 mmol/L; 120 min, 0.15 ± 0.03 vs. 0.22 ± 0.04 vs. 0.61 ± 0.15 mmol/L; p < .05). Free-fatty-acid concentrations peaked at 21 km and were significantly different from those premeal (p < .01) for all the trials.

Serum glycerol concentrations remained at a level similar to those during the postprandial period and went up at the onset of the exercise (Figure 6). Serum glycerol concentrations were higher throughout exercise in control than in high-GI (p < .05), whereas serum glycerol concentrations were higher at 10 km, 15 km, and 21 km in control than in low-GI (p < .05).

Blood osmolality during exercise was higher than the premeal level in the control (p < .05). In the high-GI group, osmolality was higher than premeal at 5 km and 21 km, whereas it was relatively constant throughout the low-GI trial. No differences were observed in plasma Na⁺ and K⁺ concentrations in the three trials (Table 2). In addition, percent body-mass change (high-GI vs. low-GI vs. control: −2.1% ± 0.2% vs. −2.22% ± 0.2% vs. −2.44% ± 0.2%, n.s.) and sweat loss (high-GI vs. low-GI vs. control: 1.42 ± 0.16 vs. 1.49 ± 0.12 vs. 1.62 ± 0.12 kg, n.s.) during exercise were similar in all trials.

**CHO and Fat Oxidation**

The respiratory-exchange ratios were similar between trials (Table 3) and peaked at 5 km for all the trials. There were no differences in CHO and fat oxidation rate during the trials. CHO oxidation rate during exercise was greater than in the 2-hr postprandial period (p < .01) and peaked at 5 km for all the trials. Fat oxidation rates at 10 km, 15 km, and 21 km were higher than in the 2-hr postprandial period (p < .01) and peaked at 21 km for all three trials. Although a smaller amount of CHO was used in the control group, there were no differences between trials (Table 4).
Figure 6 — Serum glycerol concentrations (mmol/L) during the 2-hr postprandial period and exercise in the high-glycemic-index (HGI), low-glycemic-index (LGI), and control (CON) trials ($N = 9$; $M \pm SEM$). $^a p < .01$ from premeal. $^b p < .01$ from CON. $^c p < .05$ from CON.
<table>
<thead>
<tr>
<th></th>
<th>Premeal</th>
<th>60 min</th>
<th>120 min</th>
<th>5 km</th>
<th>10 km</th>
<th>15 km</th>
<th>21 km</th>
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<tbody>
<tr>
<td>Blood osmolality</td>
<td></td>
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<tr>
<td>HGI</td>
<td>282 ± 2.0</td>
<td>284 ± 1.9</td>
<td>284 ± 2.1</td>
<td>291 ± 1.5*</td>
<td>290 ± 2.5</td>
<td>291 ± 2.0</td>
<td>292 ± 2.6*</td>
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<tr>
<td>LGI</td>
<td>284 ± 3.5</td>
<td>284 ± 2.5</td>
<td>286 ± 2.6</td>
<td>290 ± 3.8</td>
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<tr>
<td>CON</td>
<td>276 ± 2.1</td>
<td>282 ± 3.4</td>
<td>278 ± 2.4</td>
<td>286 ± 2.2*</td>
<td>287 ± 2.7**</td>
<td>286 ± 2.8*</td>
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<tr>
<td>HGI</td>
<td>142.4 ± 0.6</td>
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<td>LGI</td>
<td>141.3 ± 1.1</td>
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<td>CON</td>
<td>140.8 ± 0.8</td>
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<tr>
<td>Plasma K⁺</td>
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<td>HGI</td>
<td>4.42 ± 0.23</td>
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<td>6.05 ± 0.50</td>
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<td>LGI</td>
<td>5.62 ± 0.71</td>
<td>4.47 ± 0.14</td>
<td>5.57 ± 0.51</td>
<td>6.24 ± 0.57</td>
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<tr>
<td>CON</td>
<td>5.92 ± 0.66</td>
<td>6.53 ± 0.68</td>
<td>5.52 ± 0.58</td>
<td>7.00 ± 0.43</td>
<td>6.93 ± 0.37</td>
<td>6.09 ± 0.18</td>
<td>5.12 ± 0.31</td>
</tr>
</tbody>
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Note. HGI = high-glycemic-index; LGI = low-glycemic-index; CON = control.

*p < .05 from premeal. **p < .01 from premeal.
Table 3  Respiratory-Exchange Ratio and Carbohydrate and Fat Oxidation Rates During the 2-hr Postprandial Period and Exercise in the HGI, LGI, and CON trials ($N = 9, M \pm SEM$)

<table>
<thead>
<tr>
<th></th>
<th>Premeal</th>
<th>60 min</th>
<th>120 min</th>
<th>Warm-up</th>
<th>5 km</th>
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<th>15 km</th>
<th>21 km</th>
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<td>**Respiratory-</td>
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<tr>
<td>HGI</td>
<td>0.87 ± 0.03</td>
<td>0.87 ± 0.01</td>
<td>0.86 ± 0.02</td>
<td>0.92 ± 0.02</td>
<td>0.96 ± 0.01**</td>
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<td>LGI</td>
<td>0.83 ± 0.02</td>
<td>0.87 ± 0.02</td>
<td>0.84 ± 0.02</td>
<td>0.94 ± 0.02**</td>
<td>0.97 ± 0.01**</td>
<td>0.94 ± 0.02**</td>
<td>0.92 ± 0.02**</td>
<td>0.93 ± 0.02**</td>
</tr>
<tr>
<td>CON</td>
<td>0.87 ± 0.03</td>
<td>0.80 ± 0.03</td>
<td>0.81 ± 0.03</td>
<td>0.90 ± 0.01</td>
<td>0.95 ± 0.01**</td>
<td>0.93 ± 0.01</td>
<td>0.92 ± 0.01</td>
<td>0.91 ± 0.02</td>
</tr>
<tr>
<td>**Carbohydrate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>oxidation (g/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HGI</td>
<td>0.19 ± 0.03</td>
<td>0.26 ± 0.03</td>
<td>0.27 ± 0.05</td>
<td>1.90 ± 0.19**</td>
<td>2.76 ± 0.18**</td>
<td>2.33 ± 0.13**</td>
<td>2.48 ± 0.15**</td>
<td>2.35 ± 0.24**</td>
</tr>
<tr>
<td>LGI</td>
<td>0.16 ± 0.02</td>
<td>0.25 ± 0.03</td>
<td>0.20 ± 0.05</td>
<td>1.85 ± 0.16**</td>
<td>2.81 ± 0.19**</td>
<td>2.34 ± 0.13**</td>
<td>2.31 ± 0.26**</td>
<td>2.32 ± 0.24**</td>
</tr>
<tr>
<td>CON</td>
<td>0.21 ± 0.04</td>
<td>0.17 ± 0.04</td>
<td>0.19 ± 0.07</td>
<td>1.63 ± 0.07**</td>
<td>2.50 ± 0.15**</td>
<td>2.17 ± 0.10**</td>
<td>2.12 ± 0.16**</td>
<td>2.04 ± 0.16**</td>
</tr>
<tr>
<td>**Fat oxidation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HGI</td>
<td>0.08 ± 0.02</td>
<td>0.11 ± 0.02</td>
<td>0.10 ± 0.01</td>
<td>0.29 ± 0.06**</td>
<td>0.17 ± 0.04</td>
<td>0.34 ± 0.04**</td>
<td>0.31 ± 0.04**</td>
<td>0.42 ± 0.07**</td>
</tr>
<tr>
<td>LGI</td>
<td>0.11 ± 0.02</td>
<td>0.12 ± 0.02</td>
<td>0.11 ± 0.02</td>
<td>0.27 ± 0.05**</td>
<td>0.12 ± 0.03</td>
<td>0.33 ± 0.06**</td>
<td>0.34 ± 0.08**</td>
<td>0.38 ± 0.05**</td>
</tr>
<tr>
<td>CON</td>
<td>0.07 ± 0.01</td>
<td>0.13 ± 0.02</td>
<td>0.12 ± 0.01</td>
<td>0.35 ± 0.04**</td>
<td>0.24 ± 0.05*</td>
<td>0.32 ± 0.04**</td>
<td>0.36 ± 0.03**</td>
<td>0.46 ± 0.06**</td>
</tr>
</tbody>
</table>

*Note. HGI = high-glycemic-index; LGI = low-glycemic-index; CON = control.
*p < .05 from premeal. **p < .01 from premeal.
Table 4 Total Carbohydrate and Fat Oxidized at Rest and During Exercise

<table>
<thead>
<tr>
<th></th>
<th>Total Carbohydrate Oxidized (g)</th>
<th>Total Fat Oxidized (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rest</td>
<td>Exercise</td>
</tr>
<tr>
<td>HGI</td>
<td>31.08 ± 4.57</td>
<td>230.63 ± 10.63</td>
</tr>
<tr>
<td>LGI</td>
<td>27.30 ± 4.75</td>
<td>228.03 ± 12.19</td>
</tr>
<tr>
<td>CON</td>
<td>21.34 ± 6.01</td>
<td>208.89 ± 11.18</td>
</tr>
</tbody>
</table>

Note. HGI = high-glycemic-index; LGI = low-glycemic-index; CON = control.

Table 5 Ratings of Perceived Exertion, Perceived Thirst, and Abdominal Discomfort During the 2-hr Postprandial Period and Exercise in the HGI, LGI, and CON trials (N = 9, M ± SEM)

<table>
<thead>
<tr>
<th></th>
<th>Preexercise</th>
<th>5 km</th>
<th>10 km</th>
<th>15 km</th>
<th>21 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratings of perceived exertion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HGI</td>
<td>6 ± 0</td>
<td>12 ± 0**</td>
<td>14 ± 1**</td>
<td>15 ± 1**</td>
<td>17 ± 0**</td>
</tr>
<tr>
<td>LGI</td>
<td>6 ± 0</td>
<td>12 ± 1**</td>
<td>13 ± 1**</td>
<td>15 ± 1**</td>
<td>16 ± 1**</td>
</tr>
<tr>
<td>CON</td>
<td>6 ± 0</td>
<td>11 ± 1**</td>
<td>13 ± 1**</td>
<td>15 ± 1**</td>
<td>17 ± 1**</td>
</tr>
<tr>
<td>Perceived thirst</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HGI</td>
<td>3 ± 1</td>
<td>2 ± 0</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>3 ± 1</td>
</tr>
<tr>
<td>LGI</td>
<td>3 ± 0</td>
<td>3 ± 1</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
</tr>
<tr>
<td>CON</td>
<td>3 ± 1</td>
<td>2 ± 0</td>
<td>2 ± 0</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
</tr>
<tr>
<td>Abdominal discomfort</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HGI</td>
<td>0 ± 0</td>
<td>1 ± 0</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
</tr>
<tr>
<td>LGI</td>
<td>1 ± 0</td>
<td>2 ± 1</td>
<td>3 ± 1**</td>
<td>3 ± 1**</td>
<td>3 ± 1**</td>
</tr>
<tr>
<td>CON</td>
<td>0 ± 0</td>
<td>1 ± 0</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>4 ± 1**</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HGI</td>
<td>54 ± 3</td>
<td>161 ± 3**</td>
<td>165 ± 3**</td>
<td>170 ± 3**</td>
<td>178 ± 3**</td>
</tr>
<tr>
<td>LGI</td>
<td>54 ± 3</td>
<td>162 ± 3**</td>
<td>166 ± 2**</td>
<td>167 ± 2**</td>
<td>173 ± 3**</td>
</tr>
<tr>
<td>CON</td>
<td>51 ± 3</td>
<td>160 ± 4**</td>
<td>167 ± 3**</td>
<td>170 ± 4**</td>
<td>174 ± 4**</td>
</tr>
</tbody>
</table>

Note. HGI = high-glycemic-index; LGI = low-glycemic-index; CON = control.
**p < .01 from preexercise.

Perceptual Scales

There were similar ratings between trials in perceived exertion, abdominal discomfort, and perceived thirst (Table 5). An increasing trend was observed in all trials in ratings of perceived exertion. As for abdominal discomfort, it was higher at 10 km, 15 km, and 21 km than the preexercise value in low-GI (p < .01), whereas...
at 21 km, it was higher than the preexercise value in the control \((p < .01)\). Greater satiety was shown for the low-GI meal, which could be reflected in the gut-fullness scale (Table 6), on which ratings were higher in low-GI than in the control at 60 min, 90 min, and 120 min after the meal \((p < .05)\).

**Discussion**

The major finding of the current study is that when a CHO-electrolyte solution (~0.8 g CHO/min) was consumed during a 21-km run, performance time and metabolic changes during exercise were similar irrespective of consuming a high- or low-GI preexercise meal providing 1.5 g CHO/kg body mass. Seven of nine participants achieved their best performance with a combination of CHO supplementation (high-GI or low-GI trial) before and during exercise as compared with those in the control trial (CHO-electrolyte solution ingestion during exercise alone).

The current study is an extension of a previous study from our laboratory (Wong et al., 2008) that examined the influence of preexercise consumption of low- \((GI = 37)\) and high-GI \((GI = 77)\) meals on 21-km running performance. A similar exercise protocol and preexercise nutritional GI treatments were used in both studies, but distilled water in the previous study and 6.6% CHO sports drink in the current study was ingested during the half-marathon endurance run. In the previous study, a higher running speed and more favorable metabolic responses were observed with the low-GI meal than with the high-GI meal. Blood glucose concentration throughout exercise decreased gradually in the high-GI trial and was lower than preexercise values at 15 km and 21 km of the performance run; it even dropped to about 3.5 mmol/L at 15 km in the high-GI trial in some participants (Wong et al.). A shift in substrate utilization from CHO to fat was also observed, as in some other studies (DeMarco et al., 1999; Thomas et al., 1991; Wee et al., 1999; Wong et al.). This performance enhancement was suggested to be attributable to less fluctuation in glycemic and insulimemic responses in the low-GI trial than in the high-GI trial, and hence there was maintenance of the blood glucose level during exercise. In the current study, blood lactate, serum insulin, \(\% VO_{2max}\), CHO oxidation, rating of perceived exertion, perceived thirst, and heart rate were all similar at the commencement of the performance run in the three trials. When a CHO-electrolyte solution was consumed during exercise as in

<table>
<thead>
<tr>
<th>Gut-Fullness Scales During the 2-hr Postprandial Period in the HGI, LGI, and CON Trials ((N = 9, M \pm SEM))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Premeal</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>HGI</td>
</tr>
<tr>
<td>LGI</td>
</tr>
<tr>
<td>CON</td>
</tr>
</tbody>
</table>

*Note. HGI = high-glycemic-index; LGI = low-glycemic-index; CON = control.

*p < .05 from preexercise. **p < .01 from preexercise. †p < .05 from CON. ††p < .01 from CON.
the current study, the differences in the metabolic and performance responses arising from the GI meal were minimized. Similar to the study of Burke et al. (1998), who used a cycling exercise model, there were no differences in concentrations of blood glucose, serum free fatty acids, respiratory-exchange ratio, or total CHO oxidation during the 21-km endurance run.

Preexercise feeding might increase preexercise liver or muscle glycogen concentrations, and feedings during exercise might provide a readily absorbable source of CHO (Burke et al., 1998; Chen, Wong, Wong, et al., 2008). These patterns of CHO ingestion can delay the point in time at which reduced body CHO reserves produce fatigue (Coyle et al., 1986). As in other studies (Burke et al.; DeMarco et al., 1999; Thomas et al., 1991; Wong et al., 2008; Wu & Williams, 2006), the high-GI meal in the current study triggered higher glycemic and insulinemic responses during the postprandial resting period than the low-GI meal. Insulin increased CHO oxidation (Febbraio & Stewart, 1996) and suppressed lipolysis (Horowitz, Mora-Rodriguez, Byerley, & Coyle, 1997). The effect of insulin on lipolysis might be responsible for the trend toward lower plasma glyceral concentrations in the different GI meals than in the control meal. However, it seems that blood glucose levels remained above 4 mmol · min⁻¹ · L⁻¹, and there were no signs of hypoglycemia either postprandially or at the onset of exercise, particularly after ingestion of the high-GI meal. Although the total amount of CHO oxidized was lower and the total amount of fat oxidized was higher in the control, the differences did not reach significance and did not influence performance as compared with the GI meals. This suggests that the CHO-electrolyte drink consumed during exercise was able to maintain CHO availability to an extent that performance would not be detrimentally affected even when no CHO was provided 2 hr before the 21-km run.

Despite a higher rating on the gut-fullness scale in the low-GI trial than in the control, which might imply that the low-GI meal produced a greater satiety as shown in previous clinical studies (Warren, Henry, & Simonite, 2003), it ultimately did not have a significant impact on the subsequent exercise metabolic responses and run performance. Thus, it was not surprising that performance times were similar among the three trials (Mitchell et al., 1989; Nybo, 2003).

The volume of CHO-electrolyte solution consumed in the current study (~0.8 g/min, ~12.4 ml/min) was prescribed according to the ACSM 1996 position stand and is close to the maximal rate of ingested CHO oxidation during prolonged moderate-intensity exercise (Hawley et al., 1992). It has been suggested that running reduces the desire to drink more than cycling, but this response appears to be individual, and there are no clear associations between volume of fluid ingested and symptoms of gastrointestinal distress (Convertino et al., 1996). Both runners and cyclists developed symptoms of “fullness” when drinking fluid at rates equal to or greater than 800 ml/hr (Noakes & Martin, 2002). The amount of fluid provided for all the participants during the run in the current study was within 800 ml/hr. However, 2 participants still reported that the amount of fluid ingested during the trials was much greater than in their actual race such that they felt slightly uncomfortable. This amount of CHO and fluid ingestion might not be realistic for all endurance runners. Thus, individual dietary experience before or during endurance running should be taken into consideration.
Reduced body mass resulting from dehydration has been theorized, yet not proven, to have less of a negative effect on running performance because of assumed concomitant reductions in energy expenditure (Coyle, 2004). Fluid replacement should balance sweat and urinary losses and at least maintain hydration at less than 2% body-mass reduction (Noakes & Martin, 2002). Body-weight change during the three trials ranged from −2.1% to −2.44%. This implies that the amount of fluid provided (2ml/kg body mass every 2.5 km) during the 21-km run managed to maintain the hydration status of the participants in a temperate environment, that is, ~21 °C.

Conclusion

When a CHO-electrolyte solution of ~1,121 ml, ~74 g of CHO, was consumed during a 21-km run, performance time and metabolic changes during exercise were similar irrespective of whether a high- or low-GI preexercise CHO meal was ingested.

References


