A Low Glycemic Index Meal Before Exercise Improves Endurance Running Capacity in Men

Ching-Lin Wu and Clyde Williams

This study investigated the effects of ingesting a low (LGI) or high (HGI) glycemic index carbohydrate (CHO) meal 3 h prior to exercise on endurance running capacity. Eight male recreational runners undertook two trials (LGI or HGI) which were randomized and separated by 7 d. After an overnight fast (12 h) the subjects ingested either a LGI or HGI meal 3 h prior to running at 70% VO$_{2\text{max}}$ until exhaustion. The meals contained 2 g/kg body mass CHO and were isocaloric and iso-macronutrient with calculated GI values 77 and 37 for the HGI and LGI respectively. The run times for the LGI and HGI trials were 108.8 ± 4.1 min and 101.4 ± 5.2 min respectively (P = 0.038). Fat oxidation rates were higher during exercise after the LGI meal than after the HGI meal (P < 0.05). In summary, ingestion of a LGI meal 3 h before exercise resulted in a greater endurance capacity than after the ingestion of a HGI meal.

Key Words: carbohydrates, glycemic index, fatigue, insulinemia

Ingestion of carbohydrate (CHO) before exercise may result in an improved exercise performance when compared with exercise in the fasting state (3, 4, 15, 22, 24, 35). Paradoxically, ingesting CHO before exercise increases the rate utilization of this limited substrate store and yet still delays the onset of fatigue. This increased rate of CHO utilization is a consequence of a glucose-induced rise in plasma insulin concentration that, in turn, suppresses the rate of fatty acid oxidation (6, 16).

Strategies that help increase the contribution of fat metabolism to energy production during prolonged exercise will lead to a more economical use of the body’s limited CHO stores and consequently, an increase in endurance capacity. One such strategy is to use low glycemic index (LGI) carbohydrate foods in pre-exercise meals (2). Consuming LGI CHO foods results in lower glucose and insulin concentrations than after consuming high GI (HGI) CHO foods (17). Several studies have examined the effects of ingesting foods with different GI values on subsequent exercise performance (8, 11, 18-20, 25, 26, 28-30, 34) however only some have reported improvements in exercise performance (8, 18, 19, 20, 28, 34). The inconsistency

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in the results might be due to the differences in the amount and time at which the CHO is ingested, the GI values of food, and the type of exercise performance tests employed. Furthermore, most of these earlier studies used either single foods or drinks, rather than using a mixture of foods to form commonly available meals. Therefore, there is a need for studies that provide meals, rather than single foods, that are consumed 3 to 4 h before exercise because this nutritional preparation for heavy exercise is more frequently recommended, and most commonly adopted by sports people.

In an earlier study we investigated the influence of HGI and LGI meals on endurance running capacity 3 h later. We found no differences in run times to exhaustion (30). The meals in that study were iso-energetic but were only matched for CHO content and not for protein and fat. Furthermore, there were no changes in plasma glucose concentrations after the subjects ate the LGI meal that was composed entirely of lentils. Therefore in a more recent study we matched the HGI and LGI meals both for energy and for macro-nutrient composition using foods that are more commonly used for breakfast. Three hours after consuming either the HGI or LGI meals the subjects completed a 60 min treadmill run at 65% VO\textsubscript{2max} to establish whether there were any differences in fatty acid oxidation rates. We found that during exercise the overall fat oxidation was significantly higher after consuming the LGI meal compared with HGI meal (36). This greater rate of fat oxidation is of potential benefit during prolonged constant pace running because it should reduce the rate of carbohydrate oxidation and so delay the depletion of this limited fuel store.

Therefore the aim of the present study was to investigate the effects of ingesting low and high GI meals 3 h prior to exercise on endurance running capacity in men.

### Methods

#### Subjects

Eight healthy male recreational runners (age: 28.9 ± 1.5 y; mass: 70.5 ± 2.2 kg; height: 175.0 ± 1.9 cm; VO\textsubscript{2max}: 60.6 ± 1.5 mL · kg\textsuperscript{-1} · min\textsuperscript{-1}) participated in this study. All subjects were informed of the possible risks of the study and completed health questionnaires before signing an informed consent form. The protocols were approved by the Ethical Advisory Committee of Loughborough University.

#### Preliminary Testing

Subjects visited the laboratory for preliminary tests and one familiarization run before the main performance trials. In the preliminary testing, maximal oxygen uptake (VO\textsubscript{2max}) was determined while they ran to exhaustion on a motorized treadmill (30). In the second preliminary test the oxygen cost of running over four submaximal running speeds was determined via indirect calorimetry. The initial speed was set at 8 to 9 km/h and then the speed was increased every 4 min by 1 to 1.5 km/h. The VO\textsubscript{2} was determined during the final minute of each stage and a linear regression was subsequently calculated to determine the VO\textsubscript{2}-speed relationship. One week prior to the experimental trials the subjects performed a familiarization run whereby they ran at 70% VO\textsubscript{2max} for 45 min.
Test Meals

The composition of the test meals is shown in Table 1. The HGI meal consisted of corn flakes (Kellogg’s Ltd., Manchester, UK), skim milk, white bread, jam, a glucose drink (Lucozade original, GlaxoSmithKline, Brentford, UK) and water (GI = 77). The LGI meal consisted of All Bran (Kellogg’s), skim milk, peaches, apples, and apple juice (GI = 37) (Table 1). Each meal provided 2 g/kg body mass of available CHO and had the same energy content (675/70 kg kcal or 9.6 kcal/kg body mass) and macronutrient composition (84% CHO, 12% protein, 4% fat). Wolever and Jenkins’ method was used to calculate the GI of the mixed meals (30). The individual GI values for the foods in the mixed meals were taken from Foster-Powell and Miller’s GI table (13).

Experimental Design

All subjects completed two experimental trials in a counterbalanced design separated by at least 7 d. All trials were completed in the same laboratory and under the same environmental conditions. The subjects were instructed to refrain from strenuous physical activities and also were asked to abstain from alcohol, caffeine, and tobacco consumption for 24 h before each main trial. They were also required to record their diet for 2 d before the first main trial using the food weighing method, and were asked to repeat the same diet for the 2 d before the second main trial. The runners arrived in the laboratory before each trial having fasted overnight (10 to 12 h). After completing the preparatory measurements and procedures they consumed the test meals 3 h before running to exhaustion at 70% VO$_{2\text{max}}$ on a motorized treadmill.

Procedures

On arrival at the laboratory the nude mass of the subjects were obtained after they voided. Then a cannula (Venflon 18G, Sweden) was inserted into a forearm vein and maintained patent with frequent flushing with sterile saline (0.9% w/v).

Fasting blood and expired air samples were obtained after each subject had sat for 10 min. The subjects then consumed the test meals within 20 min thereafter the 3 h postprandial period began during which they remained seated and avoided any unnecessary physical activity.

Immediately after a brief warm up consisting of stretching and a 10 min run on the treadmill (Technogym, Gambettola, Italy) at speeds equivalent to 60% VO$_{2\text{max}}$ the subjects ran to exhaustion at 70% VO$_{2\text{max}}$. To limit the onset of dehydration, subjects drank the equivalent of 2 mL/kg body mass of water every 15 min during the run to exhaustion. In addition, subjects were cooled by electric fans and wet sponges were also available for use ad libitum.

In an attempt to ensure that the subjects ran to exhaustion they were allowed to walk for 2 min at a speed of 5 km/h when they first declared that they could not run for much longer. Thereafter the speed was increased to its prescribed velocity, and the subject was encouraged to continue running as long as possible. When the subject signaled again that he could not continue, the treadmill speed was reduced to allow him to walk for a further 2 min. Finally when the subject signaled that he could not continue running for more than a minute, a final expired gas sample was collected and the trial was terminated. The subjects towed themselves dry before nude body mass was obtained.
Table 1  Characteristics of Test Meals (for 70 kg subject)

<table>
<thead>
<tr>
<th>Food item</th>
<th>g/kg body wt</th>
<th>Weight required</th>
<th>Available CHO g/serving</th>
<th>GI of each food</th>
<th>GI contribution to the meal</th>
<th>Nutrient analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CHO (g)</td>
<td>Fat (g)</td>
<td>Protein (g)</td>
<td>Energy (kcal)</td>
</tr>
<tr>
<td><strong>Low GI meal</strong></td>
<td></td>
<td></td>
<td>CHO</td>
<td>Fat</td>
<td>Protein</td>
<td>Energy</td>
</tr>
<tr>
<td>All-Bran</td>
<td>1.14</td>
<td>80</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>215</td>
</tr>
<tr>
<td>Skim milk</td>
<td>2.86</td>
<td>200</td>
<td>10</td>
<td>36</td>
<td>36</td>
<td>68</td>
</tr>
<tr>
<td>Peaches</td>
<td>4.00</td>
<td>280</td>
<td>33</td>
<td>30</td>
<td>30</td>
<td>134</td>
</tr>
<tr>
<td>Apples</td>
<td>2.29</td>
<td>160</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>77</td>
</tr>
<tr>
<td>Apple juice</td>
<td>5.71</td>
<td>400</td>
<td>44</td>
<td>40</td>
<td>40</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>141*</td>
<td>37</td>
<td>141</td>
<td>675</td>
</tr>
<tr>
<td><strong>High GI meal</strong></td>
<td></td>
<td></td>
<td>CHO</td>
<td>Fat</td>
<td>Protein</td>
<td>Energy</td>
</tr>
<tr>
<td>Corn flakes</td>
<td>0.86</td>
<td>60</td>
<td>49</td>
<td>49</td>
<td>49</td>
<td>223</td>
</tr>
<tr>
<td>Skim milk</td>
<td>4.00</td>
<td>280</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>95</td>
</tr>
<tr>
<td>White bread</td>
<td>1.10</td>
<td>77</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>181</td>
</tr>
<tr>
<td>Jam</td>
<td>0.29</td>
<td>20</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>54</td>
</tr>
<tr>
<td>Lucozade</td>
<td>2.39</td>
<td>167</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>122</td>
</tr>
<tr>
<td>Water</td>
<td>5.71</td>
<td>400</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>141*</td>
<td>77</td>
<td>141</td>
<td>675</td>
</tr>
</tbody>
</table>

* calculated by method described in Wolver (1986) with GI values taken from Foster Powell and Brand Miller (1995).
Samples of expired gas were collected into Douglas bags using a lightweight mouthpiece, respiratory value, nose clip and tubing, at the following times: pre-meal, 15 min, 30 min, 60 min, 90 min, 120 min, 150 min, and 180 min during the postprandial period. During exercise expired air samples were collected at 15 min intervals during the first 90 min and during the final minute of the run (32). The ratings of perceived exertion (RPE) (1), perceived thirst (TS), and gut fullness (GFS) were recorded using 6-20 scales.

Blood Sample Collection and Analysis

Venous blood samples (10 mL) were obtained with subjects in the sitting position during the postprandial period. In addition to the basal blood sample, further samples were obtained at 15 min, 30 min, 60 min, 90 min, 120 min and 180 min during the postprandial period, and at 15 min, 30 min, 45 min, 60 min, 90 min, and at fatigue during the subsequent exercise.

Ten milliliters of venous blood was collected at each sampling time. Hemoglobin concentration was determined by the cyanmethemoglobin method (Boehringer Mannheim, Germany). Hematocrit values were determined in triplicate on samples of whole blood by microcentrifugation (Hawksley Ltd., Lancing, Sussex, UK). Changes in plasma volume were estimated from changes in hemoglobin concentrations and hematocrit values (9). Duplicated 20 µl blood samples were deproteinized in 200 µl of 2.5% perchloric acid and then centrifuged for 3 min at 13,000 rpm (10,250 g) before being frozen at −20 °C for later analysis of lactate (21) using a fluorometer (Locarte, model 8-9, UK). A 7 mL blood sample was transferred to an EDTA tube and centrifuged (Burkard Ltd.) at 3000 rpm (1500 g) for 10 min at 4 °C to obtain plasma for analysis of free fatty acids (FFA) (ACS-ACOD method, Wako NEFA C, Germany), glucose (GOD-PAP method, Randox, Ireland) and glycerol (GPO-PAP method, Randox) using an automatic photometric analyzer (Cobas-Mira, Roche Diagnostics). The remaining blood (~ 3 mL) was placed in a non-heparinized tube and left to clot for 1 h. Serum samples were then obtained after centrifugation (Burkard Ltd.) at 3000 rpm for 10 min at 4 °C. The aliquoted serum was stored at −70 °C and later analyzed for insulin by radioimmunnoassay (Coat-a-Count Insulin, ICN Ltd.), using a gamma counter (Cobra 5000, Packard, Pangbourne, UK).

Calculations

The energy expenditure, CHO, and fat oxidation rates were estimated from VO₂ and VCO₂ using stoichiometric equations (14). Total CHO and fat oxidation was estimated from the area under the rate of oxidation versus time curve for each subject.

The incremental area under the plasma glucose and serum insulin response curves after ingestion of each meal were calculated for the 180 min postprandial period using the trapezoidal rule with the fasting values taken as the baseline and ignoring negative areas, i.e., below baseline values (33).
Statistical Analysis

Data were analyzed using SPSS for Windows version 10.0 (SPSS, Inc., Chicago, IL). A two-way (time and treatment) ANOVA with repeated measures was used to analyze the overall differences in the physiological and biochemical responses to the two main trials. When a significant difference was found, the Tukey post hoc test was used to locate the differences in means at specific time points. For non-time dependent variables, Student’s t-test for paired observations was used. Significance was set at the 0.05 level of confidence. Results are presented as means ± standard error of the mean.

Results

There were no differences in laboratory temperature during each trial (HGI: 19.1 ± 0.7 °C; LGI: 19.6 ± 0.9 °C, P > 0.05) nor in humidity (HGI: 50.9 ± 1.1%; LGI: 52.0 ± 1.6%; P > 0.05).

Endurance Capacity

All subjects completed two experimental trials. Six out of eight subjects ran longer in the LGI trial. The average running time of LGI trial (108.8 ± 4.1 min) (range: 84 to 121 min) was significantly longer than HGI trial (101.4 ± 5.2 min) (range: 76 to 120 min) (P = 0.038) (Figure 1). There was no trial order effect (Trial 1: 104 ± 4.4 min; Trial 2: 105.3 ± 5.3 min, P > 0.05). The protocol used to determine the

Figure 1 — Individual values for endurance capacity (min) and mean endurance capacity (min) during HGI and LGI trials.
endurance capacity of the runners allowed them to walk for 2 min when they first reported that they felt that they could not run any longer. The duration of the run to this point was also significantly longer in the LGI trial (92.9 min) than in the HGI trial (84.7 min) \( (P < 0.033) \).

**Plasma Glucose and Serum Insulin**

Following ingestion of the HGI and LGI meals, plasma glucose concentrations increased sharply and in both trials peaked at 15 min during the postprandial period (8.0 ± 0.2 mmol/L and 6.9 ± 0.2 mmol/L, respectively; see Figure 2). The plasma glucose concentration in the HGI trial was significantly higher at 30, 60, and 90 min during the postprandial period compared to the LGI trial \( (P < 0.05; \text{Figure 2}) \). The LGI trial maintained higher concentrations of plasma glucose during the first 30 min into exercise \( (P < 0.05; \text{Figure 2}) \). However, there were no differences in these values between the two trials during exercise after the first 30 min of each run \( (P > 0.05; \text{Figure 2}) \).

Serum insulin concentration peaked at 15 min during the postprandial period after both test meals but there were no significant differences in these responses \( \text{HGI: } 140.9 ± 15.2 \text{ mIU/L; LGI: } 133.4 ± 12.5 \text{ mIU/L; } P > 0.05, \text{Figure 3}) \). However there were significantly higher serum insulin concentrations in the HGI trial at 30, 60, 90, and 120 min during the postprandial period compared to the LGI trial \( (P < 0.05; \text{Figure 3}) \). There were no differences in serum insulin concentrations between the two trials during exercise.

**Figure 2** — Plasma glucose concentration (mmol/L) during the HGI (●) and LGI (○) trials (mean ± standard error of the mean). * Significantly different from LGI, \( P < 0.05 \).
The incremental area under the curve (IAUC), over the postprandial period, for both glucose (HGI: 134.2 mmol.min/L; LGI: 57.5 mmol.min/L) and insulin (HGI: 13,298 mIU.min/L; LGI: 7445 mIU.min/L) were higher during the HGI than LGI trial ($P < 0.01$). The ratio of glucose IAUC between HGI and LGI was 2.3:1, which was similar to the estimated test meal GI ratio of 2.1:1.

**Plasma Free Fatty Acid (FFA) and Glycerol**

Plasma FFA concentrations were suppressed following ingestion of both test meals (Figure 4). There were no significant differences between the two trials during the postprandial period. At onset of exercise, plasma FFA concentrations increased gradually in both HGI and LGI trials. However, they were higher during the LGI trial than during the HGI trial throughout the exercise period ($P < 0.05$; Figure 4).

Plasma glycerol concentrations showed similar responses to the changes in plasma FFA concentrations (Figure 5). There were no significant differences between trials during the postprandial period. However during exercise, plasma glycerol concentrations were higher during the LGI trial at 45, 60, and 90 min and at fatigue than during the HGI trial ($P < 0.05$; Figure 5).

**Blood Lactate**

Blood lactate concentrations increased significantly after ingestion of the LGI meal (Figure 6). The values were higher in the LGI trial than in the HGI trial at 15, 30,
**Figure 4** — Plasma FFA concentration during the HGI (●) and LGI (○) trials (mean ± standard error of the mean). * Significantly different from HGI, $P < 0.05$.

**Figure 5** — Plasma glycerol concentration during the HGI (●) and LGI (○) trials (mean ± standard error of the mean). * Significantly different from HGI, $P < 0.05$. 
Endurance Running Capacity in Men  519

60, and 90 min during the postprandial period ($P < 0.01$; Figure 6). There were no significant differences between trials during exercise.

Substrate Utilization

There were no significant differences between trials for VO$_2$ and VCO$_2$ during postprandial period nor during exercise ($P > 0.05$; Table 2). However, RER values were higher during the first 90 min of exercise in the HGI trial ($P < 0.05$; Table 2).

The rate of CHO oxidation increased after eating the meals, nevertheless there were no differences in fat and CHO oxidation rates during the postprandial periods ($P > 0.05$; Figures 7 and 8).

During exercise, the rate of fat oxidation was significantly higher in the LGI trial at 15, 45, 60, 75, and 90 min during exercise than during the HGI trial ($P < 0.05$; Figure 7). In contrast, the estimated CHO oxidation rates were lower in the LGI trial during exercise ($P < 0.05$; Figure 8). Fat oxidation rates increased and the CHO oxidation rates decreased gradually during the exercise (Figures 7 and 8). The total fat and CHO oxidation during the first 75 min of exercise in the LGI trial was $24.9 \pm 2.8$ g and $208.4 \pm 14.5$ g, respectively. Whereas the total fat and CHO oxidation during the HGI trial was $10.5 \pm 1.3$ g and $237.4 \pm 11.5$ g, respectively.

Other Physiological Variables

There were no significant differences in heart rates (HR) or ratings of perceived exertion (RPE) between the two trials (Table 3).
Table 2  Oxygen Uptake (VO\textsubscript{2}), Carbon Dioxide Expired (VCO\textsubscript{2}), and the Respiratory Exchange Ratio (RER) During HGI and LGI Trials

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meal</th>
<th>Resting</th>
<th>Postprandial period</th>
<th>Exercise period (to 90 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO\textsubscript{2} (l/min)</td>
<td>HGI</td>
<td>0.25 ± 0.01</td>
<td>0.30 ± 0.01</td>
<td>2.93 ± 0.10</td>
</tr>
<tr>
<td></td>
<td>LGI</td>
<td>0.28 ± 0.01</td>
<td>0.31 ± 0.01</td>
<td>3.01 ± 0.11</td>
</tr>
<tr>
<td>VCO\textsubscript{2} (l/min)</td>
<td>HGI</td>
<td>0.22 ± 0.01</td>
<td>0.28 ± 0.01</td>
<td>2.87 ± 0.09</td>
</tr>
<tr>
<td></td>
<td>LGI</td>
<td>0.23 ± 0.01</td>
<td>0.28 ± 0.01</td>
<td>2.81 ± 0.09</td>
</tr>
<tr>
<td>RER</td>
<td>HGI</td>
<td>0.85 ± 0.03</td>
<td>0.95 ± 0.02</td>
<td>0.98 ± 0.01*</td>
</tr>
<tr>
<td></td>
<td>LGI</td>
<td>0.81 ± 0.03</td>
<td>0.93 ± 0.01</td>
<td>0.94 ± 0.01</td>
</tr>
</tbody>
</table>

Note. Values are means ± standard error of the mean;* significantly different from LGI, P < 0.05.

Figure 7 — CHO oxidation rate (g/min) during the HGI (●) and LGI (○) trials (mean ± standard error of the mean). * Significantly different from HGI, P < 0.05.
After ingestion of LGI meal, gut fullness was rated higher at 15, 30, and 60 min during the postprandial period ($P < 0.05$; Table 3). Gut fullness also tended to be rated higher during exercise in the LGI trial ($P < 0.05$ at 75 min; Table 3). There were no significant differences in thirst sensation between the two trials (Table 3). The changes in body mass (~1.8%) and plasma volumes were not different between trials.

**Discussion**

The aim of this study was to investigate the effects of ingesting either a low or high GI meal 3 h prior to exercise on endurance running capacity. We found that the ingestion of the LGI CHO pre-exercise meal resulted in a longer run time (~8 min) to exhaustion compared with the ingestion of the HGI CHO pre-exercise meal. In the protocol used to assess the endurance running capacity we allowed the runners to walk for 2 min when they first reported that they felt that they could not continue running. Thereafter the treadmill speed was increased to the prescribed value and they continued running. It is important to note that had we used the run time to this “first walk” as a measure of the endurance capacity it would have not changed the overall conclusion because the time to this point was significantly longer in the LGI trial than in the HGI trial ($P < 0.033$).
<table>
<thead>
<tr>
<th>Variable</th>
<th>Meal</th>
<th>Resting</th>
<th>Postprandial period (min)</th>
<th>Exercise period (min)</th>
<th>Fatigue</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>HGI</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>LGI</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>RPE</td>
<td>HGI</td>
<td>–</td>
<td>–</td>
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<td>–</td>
</tr>
<tr>
<td></td>
<td>LGI</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>GF</td>
<td>HGI</td>
<td>7 ± 0</td>
<td>13 ± 1*</td>
<td>13 ± 1*</td>
<td>11 ± 1</td>
</tr>
<tr>
<td></td>
<td>LGI</td>
<td>7 ± 0</td>
<td>15 ± 1</td>
<td>14 ± 1</td>
<td>13 ± 1</td>
</tr>
<tr>
<td>TS</td>
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<td>7 ± 0</td>
<td>8 ± 0</td>
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</tr>
<tr>
<td></td>
<td>LGI</td>
<td>9 ± 1</td>
<td>7 ± 0</td>
<td>8 ± 0</td>
<td>8 ± 0</td>
</tr>
</tbody>
</table>

Note. Values are means ± standard error of the mean; *significantly different from LGI, P < 0.05.
It is difficult to make a direct comparison between the results of the present and earlier studies because of the different modes of exercise, feeding times, and prescribed foods. Most of the previous studies used prolonged cycling rather than running followed by a performance test, i.e., the subjects had to complete as much work as possible in a set time (8, 10, 11, 26, 34) rather than exercising at a constant pace to exhaustion (18, 19, 20, 28). Furthermore, they used single foods rather than meals and these foods were consumed no longer than 90 min before exercise.

A typical example is a recent study by Febbraio and colleagues who reported that trained cyclists completed three trials in which they consumed a HGI, a LGI, and control food (diet jelly) 30 min before exercise (10). The cyclists were randomly assigned to the three trials and the glycemic indices for the HGI and LGI foods were 80 and 52, respectively. The carbohydrate load of HGI and LGI foods was equivalent to 1 g/kg body mass and provided approximately 5 kcal/kg body mass. After consuming the food their subjects cycled for 120 min at an intensity equivalent to 70% $VO_{2peak}$ and then, as a performance test, they increased their exercise intensity to complete as much external work as possible in 30 min. There were no differences between the three trials in the total work completed in 30 min (10). However in this and in an earlier study (11) the rate of carbohydrate metabolism during submaximal exercise was greater following the ingestion of the HGI food compared with the ingestion of the LGI food. Therefore there are similarities in the metabolic responses to the submaximal exercise between these studies and those of the present submaximal running study. However, the methods of assessing exercise performance along with the type and timing of food intake are clearly quite different, hence the difficulty in comparing the results of these earlier studies with those of the present study.

In an earlier running study we investigated the effects of consuming different GI foods 3 h before exercise on endurance running (30). However, we found no differences in endurance capacity between the HGI and LGI trials. One reason for the difference between the previous and present results might be differences in the glycemic responses to the pre-exercise meals. In the earlier study the LGI pre-exercise meal consisted entirely of lentils, however there was no change in plasma glucose concentrations during the postprandial period or throughout exercise (30). In the present study the meals were matched for energy and macronutrient composition and made up of foods that are commonly used in a normal breakfast. Unlike our earlier running study there was a significant increase in plasma glucose concentrations following the consumption of the LGI breakfast but these changes were less than after the HGI breakfast.

The present study included the cereal All Bran in the LGI breakfast, however a recent study reported that the ingestion of this cereal resulted in a high rather than low rate of glucose disappearance (23). The authors suggested that the traditional view that this cereal has a low absorption rate and so classified as a low GI food may not be the case. Our data showed a transient but unexpected hyperinsulinemia in the early stages of the postprandial period in the LGI trial (Figure 3). However, unlike the results reported by Schenk and colleagues, the insulin concentrations decreased as expected following the fall in plasma glucose (23). Therefore further studies are required to reevaluate the accepted view that this cereal is a LGI food. Nevertheless, the overall glycemic responses to the meals in the present study were different and consistent with the calculated GI values. Some support for the valid-
ity of these values is evident when the glycemic responses to the two pre-exercise meals are compared by examining the ratio for the integrated areas under the curve (IAUC) for glucose following the two pre-exercise meals. This ratio is 2.3:1 for the HGI and LGI meals respectively and compares favorably with the ratio of the calculated GI values for the two meals, i.e., 2.1:1.

In studies that have shown improvements in exercise performance following the ingestion of a LGI pre-exercise meal the authors have suggested that an increased fat oxidation plays an important role. The lower insulin-induced inhibition of fatty acid mobilization leads to a higher rate of fat oxidation that was evident in the LGI trials in the present and in our earlier studies (27, 30, 36) compared with HGI trials. The higher rate of fat oxidation in the present study (Figure 7) was also accompanied by increased concentrations of plasma FFA and glycerol (Figures 5 and 6). One possible explanation for the greater endurance running capacity in the LGI trial is that as the oxidation of muscle glycogen decreased towards the end of exercise there was a rapid compensatory rise in fat oxidation that was able to sustain energy production at the required rate longer than in the HGI trial. In contrast the greater CHO and lower fat oxidation rates throughout exercise in the HGI trial may have resulted in an inadequate compensatory “up-regulation of fat metabolism” to cover the decrease in muscle glycogen availability. This may in turn have lead to an unsustainable greater turnover of blood glucose in working muscle to make up the deficit in energy production (37).

Some support for these proposals is provided by the results from a recent study (31) in which we obtained muscle biopsy samples from a group of runners before and 3 h after they consumed HGI and LGI breakfasts, and again after 30 min of treadmill running at 70% \( VO_{2\max} \). We found that there was an increase in muscle glycogen concentration (15%) in the vastus lateralis muscle after the HGI meal but not after the LGI meal. Furthermore there was a greater rate of degradation of muscle glycogen during the 30 min treadmill run following the HGI pre-exercise meal than following the LGI meal. Therefore, this information allows us to speculate that in the present study the subjects began exercise with a higher muscle glycogen concentration in the LGI trial than in the HGI trial and consequently may have used more glycogen during prolonged exercise. In the LGI trial the lower rate of glycogenolysis and higher rate of fat oxidation may have allowed a more rapid “up-regulation” of fat metabolism that was sufficient to support energy expenditure for longer than during the HGI trial. Furthermore, any increase in the turnover of blood glucose to cover the deficit in the contribution of fat to energy production may also have been less in the LGI trial compared with the HGI trial and so reduced the demands on the limited CHO stores.

Plasma glucose concentrations were higher for the first 60 min of exercise in the LGI trial compared with the HGI trial (Figure 2). Several studies have shown differences in endurance capacity during cycling (5, 7) and during prolonged intermittent high intensity running (12) when muscle glycogen concentrations are reduced to similar values. The differences in endurance capacity were attributed to better maintained blood glucose concentrations as a result of CHO ingestion throughout exercise. Therefore the results of the present study suggest that in the presence of normal and stable plasma glucose concentrations higher fat oxidation rates towards the end of exercise, when CHO oxidation rates were reduced (< 3.0 to 3.5 g/min), may have contributed to the improved endurance capacity during the LGI trial.
Clearly, these suggestions about the possible mechanism underlying the differences in endurance running performance in the two trials are at best only reasonable speculation. Obtaining a greater insight would require that the subjects begin exercise with similar glycogen stores and that several muscle biopsy samples are taken up to and including the point of fatigue in both trials.

In summary, the ingestion of a mixed LGI high CHO meal 3 h before exercise resulted in a greater endurance capacity than following the ingestion of a mixed HGI CHO meal. The differences in endurance capacity may be a consequence of the greater rate of fat oxidation in the presence of adequate blood glucose concentrations during exercise following the LGI CHO meal.

References


