Comparison Between Carbohydrate Feedings Before and During Exercise on Running Performance During a 30-km Treadmill Time Trial

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The purpose of this study was to compare the effects of a carbohydrate–electrolyte solution, ingested during exercise, with the effects of a preexercise carbohydrate meal on endurance running performance. Ten endurance-trained males completed two 30-km treadmill runs. In one trial subjects consumed a placebo solution 4 hr before exercise and a carbohydrate–electrolyte solution immediately before exercise and every 5 km (C). In the other trial, subjects consumed a 4-hr preexercise high-carbohydrate meal and water immediately before exercise and every 5 km (M). Performance times were identical for M and C, and there was no difference in the self-selected speeds. Oxygen uptake, heart rates, perceived rate of exertion, and respiratory exchange ratios were also similar. However, blood glucose concentration was higher in C during the first 20 km of the 30-km run. In M, blood glucose concentration was maintained above 4.5 mmol · L⁻¹ throughout exercise. Thus, the two conditions produced the same 30-km treadmill running performance time.

Key Words: preexercise meal, carbohydrate solution, endurance exercise

The effects of carbohydrate and fluid ingestion on performance during prolonged (i.e., more than 2 hr) moderately intense (i.e., 60–85% VO₂max) exercise have been extensively reviewed (3, 4, 9, 14, 18, 19). From the available literature it seems that ingestion of carbohydrate solutions during exercise is superior to ingestion of plain water (19). Carbohydrate–electrolyte solutions seem to delay the onset of fatigue by maintaining blood glucose concentration and carbohydrate oxidation during the latter stages of prolonged exercise (3, 4) and also help to minimize disturbances in fluid balance and thermoregulation, especially when exercise is performed in the heat (9, 14, 18).

Most studies have employed cycling as the exercise mode; in the studies in which running is the mode of exercise, the time to exhaustion at a constant speed is the most frequently used criterion of endurance capacity. In a previous...
study, the ingestion of carbohydrate–electrolyte solutions was found to enable runners to maintain their self-selected running speeds over the last 5 km of a 30-km treadmill run, which was not the case when the same subjects ingested only water (31).

Furthermore, it has been reported that when carbohydrate or carbohydrate solutions are consumed during exercise, endurance capacity is about 12% higher than the endurance capacity produced after subjects consume a liquid carbohydrate meal 3 hr before cycling to exhaustion (32). To the best of our knowledge no study has compared the effects of ingesting carbohydrate during exercise with the effects of ingesting a preexercise carbohydrate meal on endurance running performance. Therefore, the purpose of this study was to examine whether, after an overnight fast, the ingestion of a carbohydrate–electrolyte solution during running would be as effective as ingestion of a carbohydrate meal 4 hr before running.

Methods

Subjects

Ten male subjects volunteered for this study. They were club-level athletes who competed regularly over half and full marathon distances or completed these distances in training. Their age, weight, height, maximal oxygen uptake, and maximum heart rate were 28.7 ± 2.6 years, 67.4 ± 2.1 kg, 175.4 ± 2.1 cm, 62.21 ± 1.7 ml · kg⁻¹ · min⁻¹, and 189 ± 4 b · min⁻¹ (mean ± SE), respectively. All subjects were fully informed about the nature of the experiment and what was required of them before they gave formal consent. The study had the approval of the Ethical Advisory Committee of Loughborough University.

Experimental Design

Each subject was required to complete two 30-km treadmill runs, trying to achieve a personal best time during each run. The two trials were separated by 2 weeks. Four hours before each run the subjects consumed either a liquid placebo solution (C) or a high-carbohydrate meal (M). On the day when the runners consumed the liquid placebo, an isotonic lemon and lime carbohydrate–electrolyte solution was provided during the 30-km run (C), whereas when the meal was consumed only plain water was given during the 30-km run (M). The order of the two conditions was randomized.

Since solid food was used in the M condition, a double blind design was almost practically impossible. In order that the design be single blind, the subjects were told that the purpose of the study was to compare liquid and solid carbohydrates; they were not aware that the liquid placebo had no energy value because it had a similar taste to the carbohydrate-electrolyte solution given during exercise in the C condition. The subjects were also told that the amount of carbohydrates consumed before exercise (in reality the placebo solution) together with the carbohydrate ingested during exercise in C was equal to the amount of carbohydrates consumed in M before exercise and that water was given during M in order to control hydration.
Exercise Trial

After an overnight fast of approximately 10–12 hr each subject arrived at the laboratory between 7:00 and 8:00 a.m. and emptied his bladder, after which his nude body weight was obtained. While the subject stood quietly a 3-min expired air sample and duplicate 20-μl samples of capillary blood from the thumb of a prewarmed hand were collected. A further 10-ml venous blood sample was also taken from an antecubital vein. In order to standardize plasma volume changes the subjects were standing for 20 min prior to all the resting venous blood samples.

After resting blood and expired air samples were collected, subjects consumed either the placebo solution (C) or the high-carbohydrate meal (M). During the 4-hr postprandial period 5 subjects remained in the laboratory, whereas the other 5 subjects were involved with low physical level activities (e.g., attending lectures, doing office work, etc.) outside the laboratory. These activities were very similar in both experimental trials. Every hour, during the 4-hr postprandial period, capillary blood and expired air samples were obtained from the 5 subjects who remained in the laboratory. Before the initiation of exercise, nude body weight and further expired air, capillary, and venous blood samples were obtained. Subjects had a 5-min warm-up on the treadmill at a speed equivalent to 60% VO₂max, after which the running speed was increased to 70% VO₂max and was maintained for the first 5 km of the 30-km trial. Thereafter, the subjects were free to control their own speed, using a hand-held microswitch, in an attempt to complete each of the two runs as fast as possible. All subjects were highly motivated and were verbally encouraged throughout the 30-km trial. The treadmill (Quinton, Seattle, USA) was linked to a microcomputer (BBC computer), and the speed, time, and distance elapsed were displayed on the computer’s screen. This information was also stored on the computer for later analysis. Subjects did not know the exercise time, but they received information regarding distance covered and running pace.

Capillary blood and expired air samples were obtained every 5 km, and heart rate was monitored throughout exercise with short-range telemetry (Polar Electro Sports Testers PE 3000). Also, each subject’s perceived rate of exertion (PRE) was obtained using the Borg scale (2). Furthermore, two additional scales were used, one to monitor the subjects’ abdominal discomfort (AD) and the other to assess their sensation of gut fullness (GF). Both scales ranged from 0 (AD: completely comfortable; GF: empty) up to 10 (AD: unbearable pain; GF: bloated). These two scales were also used before and after the ingestion of the liquid placebo (C) and carbohydrate meal (M) as well as during the postprandial period.

Laboratory temperature and relative humidity were monitored and adjusted throughout each run. As a result of this approach C and M were conducted under the same laboratory temperatures, 21.6 ± 0.5 °C, and under relative humidity values of 48.5 ± 1.4% and 52.0 ± 2.7%, respectively (mean ± SE; n.s.). Wet sponges were provided for the subjects to use ad libitum throughout the exercise period. Immediately after the run was completed a venous blood sample was obtained; thereafter the subjects dried themselves, and postexercise nude body weight was recorded.
Carbohydrate Feedings

Four hours before each run subjects had to consume either 10 ml · kg⁻¹ BW of a liquid placebo (C), or a high-carbohydrate meal (M) designed to provide 2 g of carbohydrate per kilogram BW. We observed from dietary information obtained from club-level runners that their average consumption of carbohydrates during breakfast is similar to the amount of carbohydrates ingested in M. The average carbohydrate consumption in M was 135 ± 4.3 g. The meal consisted of white bread, jam, cornflakes, sugar, skimmed milk, and orange juice, which amounted to 86% of energy intake from carbohydrates, 11% from protein, and less than 3% from fat.

During exercise in C an isotonic lemon and lime carbohydrate-electrolyte solution was provided, whereas in M only plain water was given. The carbohydrate-electrolyte solution was a commercially available sports drink (Lucozade Sport), which contained 6.9% carbohydrates (dextrose, maltodextrin, and glucose syrup) and four electrolytes (24 mmol · L⁻¹ sodium, 2.5 mmol · L⁻¹ potassium, 1.2 mmol · L⁻¹ calcium, and 0.8 mmol · L⁻¹ magnesium). Immediately prior to the start of exercise subjects drank 8 ml · kg⁻¹ BW of the carbohydrate solution or equivalent amount of water, and 2 ml · kg⁻¹ BW of the assigned fluid every 5 km thereafter. The total amount of carbohydrate ingested in the C trial was 83.8 ± 2.6 g.

Preliminary Measurements

Before the two 30-km trials each subject performed three preliminary tests: (a) a 16-min incremental submaximal running test to determine the relationship between running speed and oxygen uptake, (b) an uphill treadmill running test to determine the subject’s maximum oxygen uptake, and (c) a 16-min incremental submaximal test at speeds equivalent to approximately 60%, 70%, 80%, and 90% VO₂max in order to calculate the running speeds equivalent to blood lactate concentrations of 2 mmol · L⁻¹ and 4 mmol · L⁻¹. All preliminary tests were conducted according to the procedures previously described (30). Finally, before the two 30-km trials the subjects undertook a 1-hr treadmill run in order to ensure that they were completely familiar with the procedures and measurements used during the 30-km trials.

Nutritional Status

In order to control preexercise nutritional status of subjects, we required them to record their training as well as to record and weigh their food intake during the 2 days prior to the first 30-km trial and to replicate this in the second trial. The dietary information obtained was then analyzed (23). There were no significant differences between the two trials in the average daily energy intake (C: 3,325 ± 283 kcal vs. M: 3,504 ± 245 kcal), carbohydrates (C: 501 ± 61 g vs. M: 514 ± 49 g), fat (C: 95 ± 16 g vs. M: 109 ± 16 g), or protein (C: 122 ± 7 g vs. M: 129 ± 11 g) consumed during 2 days prior to each 30-km trial (mean ± SE).
**Analyses and Statistics**

The method of collection and analysis of expired air samples was the same as previously described (30). Venous blood samples were collected into lithium heparin and serum tubes. Also, about 1 ml of blood was immediately placed into calcium heparin plastic tubes and centrifuged for 3 min at 1,200 rpm. The plasma obtained was stored at -70 °C and then analyzed within 48 hr for ammonia (10). Blood glucose, blood lactate, hemoglobin, hematocrit, and percentage changes in plasma volume were measured as previously described (31). Plasma serum was obtained by 15 min centrifugation at 6,000 rpm at a temperature of 3–4 °C, stored at -20 °C, and later analyzed for plasma free fatty acids (FFA) (Wako Chemicals GmbH kit), plasma glycerol (17), plasma urea (Boeringher Mannheim kit), and serum sodium and potassium by flame photometry (Corning 435 flame photometer). Serum samples were also stored at -70 °C and analyzed at a later date for serum insulin [125I radioimmunoassay; Coat-A-Count Insulin, DPC kit] using a gamma counter (Packard, Cobra 5000). The coefficients of variation for plasma urea, ammonia, FFA, and glycerol were 0.8%, 3.5%, 1.5%, and 2.6%, respectively, whereas coefficients for serum insulin, sodium, and potassium were 3.4%, 0.3%, and 0.3%, respectively. Also, the coefficient of variation for blood glucose was 1.2% and for blood lactate 1.8%.

Statistical analyses of the results were based on standard procedures (5). A two-way analysis of variance (ANOVA) for repeated measures on two factors (treatment by distance) was used to compare differences between performance times, cardiorespiratory responses, and metabolic responses between trials. Also, the Wilcoxon signed-rank test was used to compare the results between the two treatments obtained during the postprandial period. The remaining responses to the trials were examined using a Student’s t test for dependent samples. When significant differences were revealed, using the ANOVA, then a Tukey post hoc test was performed. The accepted level of significance was set at $p < .05$. Data are reported as means ± SE.

**Results**

The running speeds corresponding to blood lactate concentrations of 2 mmol · L$^{-1}$ and 4 mmol · L$^{-1}$ were 4.03 ± 0.15 and 4.62 ± 0.09 m · s$^{-1}$, respectively. The running speed equivalent to 2 mmol · L$^{-1}$ was more strongly correlated with performance time ($r = -.88, p < .01$).

The overall performance times in C and M were identical (C: 121.7 ± 4.1 min; M: 121.8 ± 3.6 min). Neither was there an order effect between first (T1) and second (T2) trials (T1: 122 ± 10.2 min vs. T2: 121.5 ± 12.8 min; n.s.). The mean speed per 5 km ranged from 4.08 to 4.17 m · s$^{-1}$ in C and 4.08 to 4.16 m · s$^{-1}$ in M. No differences were found between the two trials in running speeds over each successive 5 km, or even when running speed was analyzed every kilometer. Also, the last 5 km during both trials were covered within almost identical times (C: 20.4 ± 1.0 min; M: 20.5 ± 1.1 min).

Oxygen uptake was similar during the preexercise period as well as during exercise between the two trials. During exercise oxygen uptake averaged 45.24 ± 0.52 ml · kg$^{-1}$ · min$^{-1}$ and 46.13 ± 0.55 ml · kg$^{-1}$ · min$^{-1}$ in M and C, respectively (n.s.). However, oxygen consumption was significantly higher ($p < .01$) in both
conditions at 30 km compared with the values obtained at the first 5 km. The relative exercise intensity at the first 5 km was 70.4 ± 1.6% VO\(_{2\text{max}}\) and 69.3 ± 0.7% VO\(_{2\text{max}}\) in C and M, respectively. These values were significantly lower (p < .05) than the corresponding ones at 30 km for both M (75.5 ± 2.9% VO\(_{2\text{max}}\)) and C (76.4 ± 2.0% VO\(_{2\text{max}}\)). No differences were found in the heart rate responses between the two trials (C: 170 ± 2 b · min\(^{-1}\); M: 166 ± 2 b · min\(^{-1}\)). However, heart rates were higher (p < .01) in both trials at 25 km and 30 km compared with the heart rates at 5 km. Perceived rates of exertion increased from 11.5 ± 0.5 and 11.4 ± 0.4 after 5 km of running to 17.2 ± 0.5 and 16.5 ± 0.7 at the end of 30 km in C and M, respectively (p < .01). However, there were no differences between trials.

The consumption of both the placebo (C) and the meal (M) produced an increase (p < .01, n = 10) in the sensation of gut fullness. However, 1 hr later GF was higher (p < .05) in M (2.0 ± 0.5) compared with C (0.8 ± 0.7, n = 6). During exercise GF was similar in both conditions apart from the end of the 30-km run, where GF was 3.6 ± 1.0 for C and only 1.6 ± 0.5 for M (p < .01). The abdominal discomfort response (AD) was the same in both conditions during the postprandial period as well as during the 30-km run. However, AD gradually increased during exercise and resulted in higher values at 25 km and 30 km compared with the first 5 km in both M and C (p < .01).

There was an average decrease in body mass of 3.0 ± 0.2 kg and 2.9 ± 0.2 kg during C and M, respectively (p < .01). This decrease represented a change of 4.2 ± 0.2% and 4.1 ± 0.2% for C and M, respectively, which was not significantly different between the two conditions. The mean change in plasma volume for C was 0.9 ± 1.7% whereas for M was −0.5 ± 2.0%. These changes in plasma volumes were not different.

The consumption of the high-carbohydrate meal resulted in higher postprandial respiratory exchange ratios (R) (Figure 1). However, 4 hr after the preexercise feeding R values were not different between the two conditions. Neither was there a difference during exercise between the two trials. The average carbohydrate oxidation rates were similar in both conditions (C: 2.2 ± 0.2 g · min\(^{-1}\) vs. M: 2.0 ± 0.3 g · min\(^{-1}\)). Also, in M the oxidation rate for carbohydrates did not decrease with distance and was maintained above 1.8 g · min\(^{-1}\) (range: 1.8–2.2 g · min\(^{-1}\)) throughout exercise.

Blood lactate concentration was higher 1 hr (M: 1.7 ± 0.1 mmol · L\(^{-1}\) vs. C: 0.9 ± 0.2 mmol · L\(^{-1}\), n = 6) and 2 hr (M: 1.1 ± 0.1 mmol · L\(^{-1}\) vs. C: 0.6 ± 0.1 mmol · L\(^{-1}\), n = 5) after the consumption of the carbohydrate meal (p < .05), whereas 4 hr later blood lactate concentration was similar in both trials (M: 1.0 ± 0.1 mmol · L\(^{-1}\); C: 0.9 ± 0.1 mmol · L\(^{-1}\), n = 10). During exercise blood lactate concentrations were similar in both trials and averaged 4.1 ± 0.2 mmol · L\(^{-1}\) and 4.5 ± 0.2 mmol · L\(^{-1}\) in C and M, respectively.

Blood glucose concentration was higher (p < .05) 1 hr after the ingestion of the meal (M: 6.0 ± 0.3 mmol · L\(^{-1}\); C: 4.3 ± 0.2 mmol · L\(^{-1}\), n = 6). During exercise, however, blood glucose was higher in C during the first 20 km (Figure 2). Nevertheless, mean blood glucose concentration did not decrease in M during exercise and was maintained above 4.5 mmol · L\(^{-1}\).

Although there was no difference between C and M in the plasma FFA concentration, when the mean delta values were compared (i.e., prefeeding to preexercise and postexercise to preexercise) plasma FFA concentration was lower
in M during the postprandial period (C: 0.33 ± 0.09 mmol·L⁻¹ vs. M: 0.07 ± 0.08 mmol·L⁻¹, *p < .05, n = 9), whereas it was lower in C during exercise (C: −0.05 ± 0.12 mmol·L⁻¹ vs. M: 0.40 ± 0.10 mmol·L⁻¹, *p < .05, n = 9).

There was an increase (*p < .01) in plasma glycerol concentration with exercise in both C and M by 0.42 mmol·L⁻¹ and 0.46 mmol·L⁻¹ (n = 9), respectively, but there was no difference between the two trials. The further 4 hr fasting in C produced a small but significant drop in serum insulin concentration (Table 1). Also, in M serum insulin concentration decreased with exercise. However, no differences were found between the two conditions.

Plasma ammonia, serum sodium, and serum potassium increased with exercise in both C and M (Table 1). However, there was no difference between the two treatments. Similarly, plasma urea concentrations were similar in both trials (Table 1). Nevertheless, the preexercise plasma urea concentrations were lower than the prefeeding values and returned to almost prefeeding levels after exercise.

**Discussion**

The main finding of the present study was that the ingestion of the carbohydrate-electrolyte solution throughout exercise produced the same 30-km treadmill running performance time as the carbohydrate meal ingested 4 hr before exercise.
The consumption of the meal 4 hr before exercise enabled the runners to maintain their self-selected speeds for the whole of the trial despite the fact that only water was ingested during M. In a previous study in which a similar experiment protocol was used, the subjects, after a 12-hr fast, could not maintain their self-selected speeds during the last 5 km of the 30-km run when only water was provided during exercise (31).

Improvements in cycling performance have been reported when liquid carbohydrate meals were ingested 3–4 hr before exercise, providing 4.5–5.0 g of carbohydrate per kilogram BW (26, 32). However, when subjects were fasted the ingestion of carbohydrate (175 g) during exercise was not found to be superior, in terms of performance, to the consumption of a meal (333 g) 3 hr before exercise (32). In the present study the meal provided 2 g of carbohydrate per kilogram BW. The average carbohydrate consumption for M was 135 ± 4.3 g, whereas for C the subjects consumed 83.8 ± 2.6 g of carbohydrate. Interestingly, in both the present study as well as in Wright and colleagues’ study (32) performance was similar despite the fact that carbohydrate intake was lower during exercise. In the present study, carbohydrate was consumed during exercise at a mean rate of 42 g · hr⁻¹. However, a dose–response relationship does not exist between exercise performance and the amount of carbohydrate consumed during (21) or 4 hr before exercise (26). It seems that the amount of carbohydrate ingested in the C trial exceeded the threshold response of the body above which no additional benefit was gained when more carbohydrate was provided.
Table 1  Plasma Ammonia, Urea, Insulin, Sodium, and Potassium Concentrations Before Feeding and Before and Immediately After Exercise in C and M Trials

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<th>Prefeeding</th>
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<td>C</td>
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<td>M</td>
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<tr>
<td>Ammonia (μmol · L(^{-1}))</td>
<td>42.8 ± 8</td>
<td>39.2 ± 7</td>
<td>39.0 ± 6.7</td>
<td>33 ± 5.5</td>
<td>141.8 ± 27.8(^{a})</td>
<td>101.7 ± 18.4(^{b})</td>
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<td>Urea (mmol · L(^{-1}))</td>
<td>5.8 ± 0.3</td>
<td>5.9 ± 0.4</td>
<td>5.2 ± 0.2(^{c})</td>
<td>5.3 ± 0.3(^{a})</td>
<td>5.9 ± 0.2(^{a})</td>
<td>6.1 ± 0.3(^{e})</td>
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<tr>
<td>Insulin (mU · L(^{-1}))</td>
<td>7.6 ± 0.6</td>
<td>7.9 ± 0.9</td>
<td>6.3 ± 0.6(^{c})</td>
<td>8.7 ± 0.9</td>
<td>5.2 ± 0.7</td>
<td>4.5 ± 0.2(^{e})</td>
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<td>Sodium (mmol · L(^{-1}))</td>
<td>141.3 ± 0.5</td>
<td>141.4 ± 0.2</td>
<td>141.4 ± 0.5</td>
<td>140.8 ± 0.5</td>
<td>144.5 ± 0.8(^{a})</td>
<td>144.1 ± 0.6(^{c})</td>
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<td>Potassium (mmol · L(^{-1}))</td>
<td>4.7 ± 0.1</td>
<td>4.8 ± 0.1</td>
<td>4.6 ± 0.1</td>
<td>4.7 ± 0.1</td>
<td>5.4 ± 0.2(^{a})</td>
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\(^{a}\)p < .01 from preexercise (n = 10). \(^{b}\)p < .05 from preexercise (n = 8). \(^{c}\)p < .05 from prefeeding (n = 10). \(^{d}\)p < .05 from prefeeding (n = 9). \(^{e}\)p < .01 from preexercise (n = 9).
Coyle and his colleagues (7) reported a 42% increase in the glycogen concentration of vastus lateralis muscle in subjects fed 4 hr prior to exercise compared with a condition in which subjects were fasted. However, Neufer and his co-workers (22) found a nonsignificant 15% increase in the muscle glycogen concentration when subjects consumed 200 g of carbohydrates 4 hr before exercise. It should be noted that the type and size of the meal in the present study were very similar to that used by Coyle et al. (7). It is still not clear whether a meal providing only 2 g of carbohydrates per kilogram BW can increase muscle glycogen levels, or whether the carbohydrates consumed will be stored in the form of liver glycogen.

It has been suggested that a preexercise liquid meal providing 4.5–5.0 g of carbohydrates per kilogram body mass improves cycling performance (26, 32). The improvement in performance is attributed to increased carbohydrate oxidation during exercise. However, this may not be the result of an immediate preexercise increase in muscle or liver glycogen concentrations. It has been proposed that a considerable amount of the preexercise carbohydrate meal may still be in the stomach at the onset of exercise and could, therefore, continue to provide substrate for working muscle throughout exercise (26, 32). Nevertheless, it has been found that a meal providing 2–2.5 g carbohydrate per kilogram BW (7, and Chryssanthopoulos et al. unpublished data) can influence muscle glycogen concentration. Therefore, in the present study the meal’s influence on performance could be attributed not only to an enhanced availability of substrate for working muscle throughout exercise but also to elevated muscle glycogen stores before exercise.

Various studies have shown an improvement in performance during cycling (1, 6, 8, 20, 22) as well as during running (25, 27, 29) when carbohydrates were consumed during exercise compared with control conditions. However, there is controversy over the mechanism by which ingestion of exogenous carbohydrates improves performance. Some investigators have concluded that the main contribution of exogenous carbohydrates is to maintain blood glucose concentration and a high rate of carbohydrate oxidation by the working muscle (6, 15, 20). Other investigators, however, have suggested that carbohydrate intake during exercise may reduce the rate of muscle glycogen utilization and spare the limited muscle glycogen stores (1, 12, 16). In a recent study from our laboratory, a 28% reduction in muscle glycogen utilization was found as a result of carbohydrate ingestion when compared with water ingestion, hence providing evidence of glycogen sparing (28).

In the present study, blood glucose was higher in C during the first 20 km. On the other hand, blood glucose in M was maintained above 4.5 mmol·L⁻¹ throughout exercise. When subjects were fasted for about 12 hr before exercise in a similar study, blood glucose concentration decreased during the last 10 km of a 30-km treadmill run when only water was ingested (31). It seems that the ingestion of the meal 4 hr before the initiation of exercise maintained euglycemia and the substrate availability for working muscles throughout the 30-km run and enabled the subjects to maintain their pace close to the pace selected in C. Carbohydrate availability is also reflected by the maintenance of the R values during exercise in M (Figure 1) and hence by the similar average rate of carbohydrate oxidation between the two conditions (C: 2.2 ± 0.2 g·min⁻¹ vs. M: 2.0 ± 0.3 g·min⁻¹).
The prolonged fasting in C elevated the preexercise plasma FFA concentration. This finding is consistent with the results of Wright and his co-workers (32), who reported that after 13 hr fasting plasma FFA concentrations were higher than the plasma FFA concentrations found after only a 3-hr fast. During exercise the delta plasma FFA concentrations (i.e., postexercise to preexercise) were lower in C. Plasma FFA concentrations decrease when carbohydrate solutions are consumed during exercise compared with placebo or control conditions (6, 25, 32), indicating a reduced fatty acid mobilization. The fact that oxidation of fat and carbohydrate was the same in both trials in the present study seems to suggest either that the depression of FFA concentrations in C was not strong enough to deny this substrate to the working muscle, or that an alternative source, such as intramuscular triglycerides, was used during exercise (24).

It is important to realize, however, that the consumption of carbohydrate during exercise has been shown to improve endurance capacity (29) to a greater extent than endurance performance (27). When we consider endurance performance, carbohydrate availability is not the only factor for success. Factors such as the utilization of a large percentage VO₂max (11) as well as the highest exercise intensity an individual can sustain while still maintaining a metabolic steady state (13) seem to strongly influence performance in aerobic exercise. The latter is also confirmed by the strong correlation (r = -.88, p < .01) between performance time and running speed equivalent to 2 mmol·L⁻¹ blood lactate concentration found in the present study.

In summary, the ingestion of a carbohydrate meal before exercise maintained euglycemia throughout the 30-km treadmill run. Furthermore, the ingestion of the carbohydrate–electrolyte solution throughout exercise proved to be as good as the ingestion of 2 g carbohydrates per kilogram BW 4 hr before exercise in maintaining the self-selected running speeds of runners during the entire period of exercise.

References


