Effects of Carbohydrate Feeding Before and During Prolonged Exercise on Subsequent Maximal Exercise Performance Capacity

Mahmoud S. El-Sayed, Angelheart J.M. Rattu, and Ian Roberts

The study examined the effect of carbohydrate ingestion on exercise performance capacity. Nine male cyclists performed two separate trials at 70% \(\text{VO}_2\text{max}\) for 60 min followed by a maximal ride for 10 min. During trials subjects were fed either an 8% glucose solution (CHO) or a placebo solution (PL), which were administered at rest and during and immediately after submaximal exercise. Statistical analyses indicated that glucose levels at rest increased significantly 15 min after the ingestion of CHO compared to PL. At 30 and 60 min during submaximal exercise, plasma glucose levels decreased significantly in the CHO but not in the PL trial. Following the performance ride, glucose levels increased significantly only during the CHO test trial. Free fatty acids did not change significantly during testing trials. The maximal performance ride results showed that in the CHO trial, a significantly greater external work load was accomplished compared to the PL trial. It is concluded that CHO ingestion improves maximal exercise performance after prolonged exercise.

Key Words: glucose feeding, metabolic substrates, exhaustive physical exertion

Exogenous carbohydrate ingestion during prolonged exercise often improves exercise performance capacity (22). This has been shown in animals (2) and humans (15, 22, 23). It has also been demonstrated that fatigue during prolonged exercise is associated with depletion of the body's glycogen stores (19) and dehydration (26). Liver and muscle glycogen is an important source of energy during prolonged exercise, and the depletion of glycogen stores is associated with the onset of fatigue (19). The effects of carbohydrate feeding on exercise performance capacity have been the subject of numerous investigations (1, 5–8, 10–12, 15, 18, 20–23). Although many studies have shown that carbohydrate feeding before or during exercise significantly contributes to energy supply (for review, see 8, 20, 22), little information is available regarding the effect of

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carbohydrate supplementation on performance capacity during exercise bouts comparable to those usually performed in competitive sport activities. Cycling has acquired considerable popularity in recent years; particularly the 25-mile time trial has attracted a growing number of competitors. A pilot study, via a questionnaire, was carried out using 50 cyclists who had competed regularly at club level in the 25-mile cycling time trial to ascertain the protocol commonly employed during this race. The results showed that the average duration of this race is 60–70 min, and the racing protocol normally used to cover this distance is compatible with that described by Borysewicz and Pavelka (4). Therefore, the present study was designed to examine the metabolic and performance-related responses of carbohydrate ingestion during a bout of exercise that has external validity for the 25-mile cycling time trial.

Material and Methods

Subjects

Nine highly trained and competitive male cyclists (weekly mileage 100–150 miles) participated in the study. Each subject provided a written informed consent after being fully informed of the risks and stresses associated with the experiments. Subject characteristics are presented in Table 1.

Procedures

After familiarization with the laboratory environment and testing procedures, all subjects were tested to determine maximal oxygen consumption (VO₂ max) on a bicycle ergometer (Monark, Sweden) using an incremental exercise protocol. The information obtained from this test was used to calculate the external workload corresponding to 70% VO₂ max for each subject. A short-range radio telemeter (Sports Tester PE3000, Finland) was used for heart rate recording throughout the maximal test. A computerized on-line system (Metabolic Measurement Cart, Sensor Medics, USA) calibrated against a Tissot gas meter and three calibration gases of known concentration was used to measure oxygen consumption. Follow-

Table 1  Physical and Physiological Characteristics of the Subjects (N = 9)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>M</th>
<th>SE</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>23.8</td>
<td>4.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.5</td>
<td>7.3</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>69.9</td>
<td>7.8</td>
</tr>
<tr>
<td>Percent fat*</td>
<td>11.5</td>
<td>2.4</td>
</tr>
<tr>
<td>VO₂ max (ml/kg/min)</td>
<td>60.7</td>
<td>2.2</td>
</tr>
</tbody>
</table>

*Body fat percentage was determined according to the methods described by Durnin and Womersley (14).
ing a warm-up period of 5 min at a workload of 120 W, the workload was increased by 30 W every 2 min to exhaustion. It was judged that subjects had reached \( \text{VO}_2\text{max} \) when the following criteria were met: (a) a plateau of \( \text{VO}_2 \) with increasing work rate, (b) a respiratory ratio of 1:1, and (c) a heart rate within 5 beats/min of age-predicted maximum.

Subjects served as their own controls and performed two identical 70-min exercise tests separated by 7 days so we could examine the effect of carbohydrate ingestion on metabolic substrate changes and maximal performance capacity. During the week between tests, the subjects were instructed to follow their normal diets and life activity patterns. Body weight was recorded before and after each exercise testing trial. Subjects abstained from exercise for 24 hr prior to each test and were fasted for 4 hr before the exercise test. Subjects rested in the supine position for 30 min before mounting the bicycle ergometer (Monark, Sweden) for a warm-up period of 5 min. Thereafter, they cycled continuously for 60 min at the external workload predicted to elicit 70% \( \text{VO}_2\text{max} \) followed immediately by a 10-min, self-paced, all-out effort performance ride. Subjects were continuously encouraged during the performance ride and were instructed regarding the time remaining in the ride but not the distance traveled. This exercise protocol was chosen because it resembles that usually performed during the 25-mile cycling time trial (4). Standard laboratory conditions were maintained during testing (22 °C and 50% humidity), and subjects were cooled by electric fans during the exercise trials.

The two experimental drinks were (a) an artificially sweetened, orange-flavored, glucose-free placebo and (b) a 7.5% (W/V) orange-flavored glucose. The experimental drinks were given in double-blind and randomized fashion and were served in plastic opaque squeeze bottles at room temperature. Prior to the main experiment, subjects were given small amount of the two experimental beverages and indicated their inability to distinguish between the two solutions. Subjects ingested an equal volume of the respective drink at exactly the same point in time during each testing trial. An initial portion of either glucose or placebo (3 ml \cdot kg\(^{-1}\) body weight) was administered 15 min before the commencement of exercise. The second, third, and fourth portions of the drink (3 ml \cdot kg\(^{-1}\) body weight) were given at 20, 40, and 60 min during the submaximal exercise test, respectively. The total volume of fluid administered during placebo and glucose trials was (mean ± SE) 839.3 ± 28.5 ml, and the mean total glucose consumed during the carbohydrate trial was 63 g.

Forearm venous blood was collected from an antecubital vein by repeated venipuncture with a 20-gauge needle and plastic disposable syringes. Blood samples were obtained at rest, 15 min before and 15 min after the administration of the beverages, then at 30 and 60 min during submaximal exercise, and finally upon completion of the maximal performance ride. Blood sampling during exercise was executed while the subject continued cycling at the predetermined exercise intensity. Aliquots of each blood sample were assayed in duplicate for lactate (Y.S.I. Model 2300 STAT analyzer, Yellow Springs USA), hemoglobin (Hemocue, B-Hemoglobin, Sweden), and hematocrit (Hawksley, England). Changes in plasma volume were calculated from hemoglobin and hematocrit values (13). Plasma samples were analyzed for glucose (Test-Combination, Boehringer Mannheim, Germany) and free fatty acids (NEFA C ACS-ACOD Method, Wako Chemicals GmbH, Germany). Glucose and free fatty acid concentrations during exercise were corrected for plasma volume changes.
Statistical Analyses

The statistical analyses of data were carried out using two-way analysis of variance (ANOVA) with repeated measurements. When ANOVA showed a significant difference, Tukey post hoc test was employed to ascertain which mean values were statistically significant. The alpha level of $P < .05$ was the minimum level required to reject the null hypothesis. Values in the text are mean ± SE unless otherwise stated.

Results

Exactly the same percentage of body weight loss ($1.0 \pm 0.1\%$) was observed during placebo and carbohydrate trials. There were no differences between carbohydrate and placebo trials for heart rate, lactic acid, or percentage change in plasma volume. Therefore, the data obtained during the two trials for these variables were combined and presented in Table 2. Heart rate increased to $152$ and $156$ beats/min at $30$ and $60$ min during submaximal exercise, respectively. After the performance ride, the mean heart rate was $187$ beats/min. Blood lactate increased slightly from $0.5$ at rest to $1.1$ mmol $\cdot$ L$^{-1}$ at the end of submaximal exercise; however, this increase was not statistically significant ($P > .05$).

Following the performance ride, blood lactate concentration increased significantly and reached a value of $5.3$ mmol $\cdot$ L$^{-1}$. Hemoglobin and hematocrit increased significantly ($P < .05$), indicating that the glucose and free fatty acid concentrations were affected by a reduction in plasma volume. Plasma volume decreased $-10\%$, $-11\%$, and $-16\%$ at $30$ and $60$ min during submaximal exercise and following the performance ride, respectively. Therefore, plasma glucose and free fatty acid values were adjusted for the percentage changes in plasma volume. Two-way ANOVA showed a significant difference in glucose mean values between trials ($F = 12.6$, $P = .00$) and across time ($F = 9.6$, $P = .00$) with a significant interaction between treatment and time ($F = 6.4$, $P = .00$). Post hoc analyses indicated that glucose levels at rest increased significantly ($P < .05$) 15

### Table 2 Physiological Responses During Prolonged Submaximal Exercise and Performance Ride ($N = 9$)

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>Submaximal exercise</th>
<th>Performance ride</th>
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<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SE$</td>
<td>$M$</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>58</td>
<td>7</td>
<td>152$^a$</td>
</tr>
<tr>
<td>Lactic acid (mmol/L)</td>
<td>0.5</td>
<td>0.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>42.1</td>
<td>2.3</td>
<td>44.8$^a$</td>
</tr>
<tr>
<td>Hemoglobin (mg/dl)</td>
<td>14.2</td>
<td>0.9</td>
<td>15.3$^a$</td>
</tr>
<tr>
<td>Plasma volume loss (%)</td>
<td>−10.2</td>
<td>3.6</td>
<td>−11.6</td>
</tr>
</tbody>
</table>

$^a$Statistically higher value ($P < .05$) than that observed at rest. $^b$Response to performance ride higher than that found at $30$ min and $60$ min during submaximal exercise.
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min after the ingestion of the first portion of glucose compared with placebo. In addition, 30 min into and immediately after submaximal exercise during the carbohydrate trial, glucose mean values decreased \( (P < .05) \) and then increased \( (P < .05) \) following the performance ride (Figure 1). No significant \( (P > .05) \) changes were observed in free fatty acids between trials or across time (Figure 2). The mean performance distances covered during the 10-min performance ride in the carbohydrate and placebo trials are shown in Figure 3. Compared with the ingestion of a carbohydrate-free drink, glucose consumption before and during submaximal exercise resulted in a significantly longer distance during the performance ride.

**Discussion**

The major finding of the present study was that glucose ingestion before and during submaximal exercise improved subsequent maximal cycling capacity. Although the present study was not designed to elucidate the mechanisms underlying the improvement in performance with carbohydrate feeding, carbohydrate ingestion before and during exercise may have provided a readily available source of fuel during exercise. The greater work accomplished during the maximal performance test observed in the glucose trial compared with the placebo trial

![Figure 1](image-url) - Blood glucose concentration (mean ± SE) at rest (A and B), at 30 and 60 min during submaximal exercise (C and D), and immediately after the performance ride (E). Open bars represent the placebo trial, while shaded bars represent the carbohydrate trial. *Significantly higher \( (P < .05) \) mean value than that observed during placebo trial. $Significantly lower \( (P < .05) \) mean value than that observed at rest after drink administration during the carbohydrate trial. +Significantly higher \( (P < .05) \) mean value than that observed at 30 min and 60 min during the submaximal test with carbohydrate feeding.
Figure 2 — Nonesterified fatty acid concentration (mean ± SE) at rest (A and B), at 30 min and 60 min during submaximal exercise (C and D), and immediately after the performance ride (E). Open bars represent the placebo trial, while shaded bars represent the carbohydrate trial.

Figure 3 — The distance (km) covered (mean ± SE) during the performance ride in the carbohydrate and placebo trials. *Significantly different from placebo (P < .05).
Concurs with previous reports (15, 21, 25) that showed improvement in performance capacity with carbohydrate feeding. This is also very similar to the findings reported recently by Below et al. (3), who determined the effects of carbohydrate ingestion on a maximal performance test following high-intensity submaximal exercise for 50 min. The authors showed that consumption of 45 g carbohydrate prior to exercise, compared to the consumption of an equal amount of water, enabled the subjects to accomplish 10% more work during the maximal performance test.

Carbohydrate ingestion can maintain normal blood glucose, thus reducing the likelihood of hypoglycemia-induced central fatigue (5). The increase in plasma glucose concentration in response to glucose feeding has been repeatedly demonstrated in previous studies, and the improvement in maximal cycling capacity observed may partly be due to maintenance of plasma glucose levels (6, 7, 10, 11). Coyle et al. (11) suggested that the enhanced performance capacity with carbohydrate administration compared to placebo during cycling at 70% VO\textsubscript{2}max could be the result of blood glucose maintenance. Although some previous studies indicated that carbohydrate ingestion during exercise would be of little benefit because muscle glucose uptake is minimal (10), several studies have unequivocally shown that carbohydrate ingestion improves cycling time to exhaustion (9, 11, 12). Similar results have been reported by Gleeson et al. (16), who showed 12% improvement in endurance capacity when subjects consumed 1 g carbohydrate/kg body mass. In the present study, data indicated no differences in glucose concentration between glucose and placebo trials at 30 and 60 min during submaximal exercise, thus suggesting no relationship between carbohydrate feeding and blood glucose concentration. Although a significant increase in glucose level was observed immediately after the performance ride in the carbohydrate trial but not the placebo trial, this was likely due to the administration of the last portion of the glucose drink.

Coyle et al. (11) and Coggan and Coyle (5) showed that fatigue occurring during exercise without carbohydrate feeding coincided with a substantial decrease in blood glucose level. In addition, the enhanced endurance performance capacity with glucose feeding is also attributed to a sparing of muscle and liver glycogen. In the present study, the exercise protocol employed during submaximal exercise did not require the subjects to reach the point of absolute fatigue or hypoglycemia. What was observed was a greater power output during maximal cycling exercise when subjects were fed glucose compared with placebo. Therefore, it is not possible to suggest that the ergogenic effect of glucose ingestion is related to the maintenance of the normal level of blood glucose. When endogenous carbohydrate stores are not depleted, which is the likely event in the present experiment, increasing the availability of blood glucose via exogenously administered carbohydrate may still supplement these stores sufficiently to increase carbohydrate oxidation (25) and to enhance performance during very high intensity exercise (15, 18).

Hargreaves et al. (18) reported muscle glycogen sparing and improved end-exercise sprint cycling performance as a result of carbohydrate feeding. The improved performance was attributed to reduced glycogen utilization resulting from liquid carbohydrate administration. Fielding et al. (15) repeated the Hargreaves experiment using solid carbohydrate feeding and demonstrated enhanced performance capacity without glycogen changes. As muscle glycogen levels are
reduced during exercise, the reliance on blood glucose for energy production is increased (11). If carbohydrate is administered, a large percentage of it could be made available for utilization by working muscles (17). Muscle glycogen was not assessed in the present study; however, the possibility that muscle glycogen concentration may have been spared during the carbohydrate trial cannot be entirely dismissed. This postulate is supported by animal studies showing that blood glucose can largely replace muscle glycogen as the source of carbohydrate during strenuous exercise when muscle glycogen is used (24).

It is apparent that before and during exercise, carbohydrate feedings can exert an ergogenic effect on maximal cycling performance capacity after prolonged submaximal exercise. Notably, the increase in maximal performance capacity following carbohydrate feeding occurred in the absence of a significant change in plasma free fatty acids (Figure 2). This may suggest that the increase in performance capacity could have been mediated by changes in the availability of plasma glucose, thus indicating that carbohydrate ingestion may have been related to the relative changes in carbohydrate availability rather than the absolute level of blood glucose or carbohydrate utilization per se. Blood glucose concentration reflects the equilibrium between glucose uptake by tissues and glucose output by the liver. The prior elevation of insulin in response to carbohydrate administration before exercise may have increased muscle glucose uptake during exercise and suppressed liver glucose output (1). Therefore, it could be suggested that carbohydrate supplementation may have partially or completely replaced hepatic glycogenolysis and/or gluconeogenesis as a source of blood glucose (27). Regardless of the exact mechanisms responsible, carbohydrate ingestion decidedly improved maximal exercise performance capacity after prolonged submaximal exercise.

In summary, the ingestion of 62.9 ± 6.4 g of carbohydrate before and during submaximal exercise significantly increased subsequent maximal performance capacity in trained cyclists. However, it is not fully understood how exogenous carbohydrate administration contributed to the enhanced maximal performance capacity after prolonged submaximal exercise.

References


