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Carbohydrate-Electrolyte Feedings Improve 1 h Time Trial Cycling Performance

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Carbohydrate-electrolyte (CE) feedings have been shown to improve endurance performance at moderate intensities (60–75 % $\dot{V}O_2max$) and of more than 2 h duration. The effects of CE feedings during high intensity exercise (i.e. ≥ 80 % $\dot{V}O_2max$) of shorter duration (~ 1 h) are less clear. Therefore the purpose of the present study was to investigate the effect of the ingestion of a 7.6 % CE solution during exercise on time trial cycling performance of approximately 1 h. This type of performance testing has been shown to be more reproducible (coefficient of variation 3.35 %) than the traditional exercise test to exhaustion. On two occasions and in random order nineteen endurance trained cyclists completed an exercise test requiring the accomplishment of a set amount of work as fast as possible (time trial) under strictly standardized conditions. At the start and during the trials they drank in total 14 ml/kg of either a 7.6 % CE solution or artificially flavored and colored water (placebo). Time to complete the set amount of work was significantly reduced and thus performance was significantly increased ($p < 0.001$) with the CE drink by 2.3 %. Time to complete the set amount of work was 58.74 ± 0.52 min with CE and 60.15 ± 0.65 min with placebo ($p < 0.001$). Average workload during the time trials was 297.5 ± 1.4 W and 291.0 ± 10.3 W, respectively. Subjects exercised at 76.4 ± 0.7 % of their maximal work rate (Wmax) with CE and at 74.8 % Wmax with placebo ($p < 0.001$). It was concluded tht also in relative short term (1 h) high intensity (75 % Wmax) cycling exercise ingestion of a carbohydrate-electrolyte solution compared to placebo improves performance.

Key words: Drinking, carbohydrate supplementation, carbohydrate-electrolyte solution, high intensity exercise

Introduction

Carbohydrate (CHO) feedings during exercise have been repeatedly shown to increase performance during exercise lasting longer than 2 hours at intensities of 50–70 % $\dot{V}O_2max$ (3, 4, 7–9, 13, 24, 26, 27). This has been attributed to maintenance of blood glucose levels and high rates of carbohydrate oxidation (4, 9). Numerous investigators reported increased performance with both simple and complex carbohydrate feedings when subjects were fed several hours prior to exercise or at the onset and during exercise (7, 24, 26, 27). Carbohydrate electrolyte solutions have been formulated to guarantee an optimal replacement of both water and carbohydrates. Very few studies, however, have investigated the effect of carbohydrate-electrolyte solutions with concentrations similar to available commercial sports drinks on performance during high intensity exercise (≥ 80 % $\dot{V}O_2max$ [2, 2, 19]). Little information is available on the effect of carbohydrate ingestion on performance during intense exercise lasting about 1 hour.

In the present study we therefore investigated the effect of CE feeding on time trial cycling performance (comparable to a 40 km time trial) under strictly standardized conditions, without additional measurements, to avoid disturbing effects on the subjects' performance ability. Previously we have shown that performance testing using a time trial approach (subjects have to accomplish a set amount of work as fast as possible) gives a much better reproducibility on repeated testing than the traditional time to exhaustion test (11). We and others (10, 22) believe that blood sampling and measurements of respiratory gas exchange increases variability (subjects ability to concentrate is diminished and they cannot push as hard as they could without any measurements) and therefore is avoided here during performance testing.

Methods

Subjects

Seventeen endurance trained male and 2 female cyclists who trained regularly more than 2 hours a day, 4–7 days a week, volunteered for this study which was approved by the local Medical Ethical Committee. Mean age, height and body mass of the male and female subjects are shown in Table **1**. Five to seven days prior to the first experimental trial, maximal oxygen consumption ($\dot{V}O_2max$), maximal workload (Wmax) and max-

Table 1 Characteristics of the male (n = 17) and female subjects (n = 2). Maximal oxygen consumption ($\dot{V}O_2max$) and maximal power output (Wmax) were measured during the incremental exercise test exhaustion.

	male (n = 17) mean ± SEM	female (n = 2) mean ± SEM
Age (yrs)	23 ± 1	21 ± 2
Height (m)	182 ± 2	173 ± 0.1
Body mass (kg)	70.4 ± 1.5	56.1 ± 11.2
$\dot{V}O_2max$ (ml/kg · min)	72.9 ± 1.4	64.2 ± 0.34
Wmax (W)	396 ± 11	288 ± 38

imal heart rate (HRmax) were determined in a stepwise incremental exercise test to exhaustion as described by Kuipers et al. (12). After a warm-up period of 5 min at 100 W, the workload was increased by 50 W every 2.5 min until a heart rate of 160 bpm was reached. Then workload was increased by 25 W every 2.5 min. The Wmax was determined using the following formula:

$$\text{Wmax} = \text{Wout} + (t/150) \cdot 25$$

where Wout is the last completed stage, t is the time in the final stage. All exercise tests were performed on an Excalibur Sport electromagnetically braked ergometer (Lode, Groningen, The Netherlands). Heart rate was continuously recorded by a Sporttester® (Polar, Kelmele, Finland).

Procedure

Sixteen subjects were familiar with the exercise protocol. The other 3 subjects performed a familiarization trial. An exercise trial consisted of a simulated time trial in which the ergometer was set in the linear mode (workload increases as the pedalling rate increases). After a short warming-up (5 min 100 W) subjects were asked to perform a certain amount of work (equal to about 1 hour cycling) as fast as possible. The measurement of performance was the time to complete the set amount of work. This performance test has previously been shown to produce highly reproducible results (11). Coefficient of variation of this test in 5 repeated tests was 3.35 %. In addition, Palmer et al. (18) recently confirmed that this kind of test is highly reproducible. This total amount of work was based on the maximal workload (Wmax) and the total amount of work to be performed was calculated according to the formula:

$$\text{Total amount of work} = 0.75 \cdot \text{Wmax} \cdot 3600$$

The ergometer was set in the linear mode according to the formula

$$W = L \cdot (\text{rpm})^2$$

in which rpm is the pedalling rate and L is a linear factor. This factor was chosen in a way which would evoke a pedalling rate of 90 rpm at 70 % Wmax. In other words the linear factor was dependent on a subject's Wmax. This would mean that 75 % Wmax could be achieved at about 95 rpm which appeared to be the preferential pedalling rate of most cyclists. The ergometer was connected to a computer which on line recorded workload and the elapsed time and calculated the amount of work performed. The only information the subject received was the amount of work performed and the percentage of work performed relative to the preset amount of work (0 % at the start, 100 % at completion of the trial). This information was displayed on a computer screen in front of the ergometer. Subjects did not receive information on workload, pedalling rate, time or heart rate. A fan was placed in front of the subjects to provide some cooling during the tests.

To avoid any influence of circadian variance, subjects performed their tests at the same time of the day. Subjects were not allowed to train the day before the test. Two days before the test, exhaustive training was not allowed. Additionally, all subjects were instructed to eat quantitatively and qualitatively the same diet during the 24 h prior to the test. This was controlled by a registration procedure. They were advised to eat a meal rich in carbohydrate such as pasta the evening prior to the test. In the hour preceding the test, subjects were not allowed to eat. To further control carbohydrate and energy intake, food records were provided for the day prior to the test and the day of the test. During all tests environmental conditions were standardized, temperature was kept at 20 °C, relative humidity varied between 50 and 60 %. Subjects were encouraged by the same person for each test.

Beverages

Subjects received two types of drinks on different occasions, subsequent tests being separated by at least 5 days. The drinks consumed were (1) a 7.6 % (76 g/l) carbohydrate-electrolyte solution (Isostar, Sandoz Nutrition, Switzerland) or (2) artificially coloured and flavoured water to which a small amount of fructose (5 g/l) was added (for composition of test drinks see Table **2**). The drinks were indistinguishable to the subjects and provided in random order; 10 subjects receiving the CE solution as the first drink, 9 subjects receiving plcebo as the first drink. Subjects ingested 8 ml/kg of the 7.6 % CE solution or plcebo as a bolus during the 5 min warm-up period. Thereafter 2 ml/kg was ingested at achievement of 25 %, 50 % and 75 % of the set amount of work. Such a drinking pattern has previously been reported to result in high rates of gastric emptying throughout exercise (21).

Table 2 Test drink compositon per 100 ml.

	CE solution	Placebo
Carbohydrate (g)	7.6	0.5
Organic acid (g)	0.5	0.073
Sodium (mg)	69	–
Potassium (mg)	18	–
Calcium (mg)	1	–
Chloride (mg)	30	–
Vitamin C (mg)	10	–
Vitamin E (mg)	0.6	–
Beta carotene (mg)	0.33	–
Sweeteners (mg)	–	0.016
Flavor orange natural (mg)	0.032	0.064

Statistics

The presence of an order effect and the effect of the drinks on performance were tested by paired t-tests. All results are expressed as mean ± SEM.

Table 3 Average workload during the time trial and differences with CE or placebo ingestion (individual values). § denotes female subject.

Subject	Average Workload (W) CE	placebo	Difference
1	290.2	281.3	8.9
2	321.1	316.8	4.3
3	325.9	305.9	20.0
4	310.3	295.0	15.4
5	309.4	303.3	6.1
6	308.0	310.5	-2.5
7	368.7	359.6	9.2
8	297.1	294.2	2.9
9	307.2	303.6	3.6
10 §	183.4	172.8	10.7
11	351.7	336.2	15.5
12 §	228.7	220.7	8.0
13	311.6	306.6	5.0
14	301.6	295.9	5.7
15	330.5	325.7	4.8
16	230.6	223.5	7.0
17	253.5	248.9	4.7
18	298.9	297.7	1.2
19	324.6	330.8	-6.1
Mean	297.5	291.0	6.5
SEM	10.3	10.3	1.41

Results

Analysis of dietary records revealed that the meals ingested the day before the two experimental trials and also the diets on the day of the experiment were similar for each subject. Mean daily carbohydrate intake was from 367 ± 18 g before the CE trial and 341 ± 22 g before the placebo trial. Carbohydrates provided 55 ± 1 % of total energy intake the day before the CE experiment and 57 ± 2 energy% CHO the day before the placebo experiment.

As previously reported we did not observe a test order effect, meaning that subjects rode the first test as fast as the second. Performance, however, was significantly improved through the CE feedings by 2.3 % (Fig. 1). In Fig. 1 individual changes in the times to complete the set amount of work are presented. With placebo, subjects needed 60.15±0.65 min, and with CHO they needed 58.74±0.52 min to complete the set amount of work. Seventeen subjects responded with improved performance to the CE solution whereas 2 subjects showed decreased performance. Individual data are shown in Tables **2** and **3**. The average workload during the time trial was 291.0 ± 10.3 and 297.5 ± 10.3 with placebo, and CE respectively. Subjects exercised at 76.4 ± 0.7 % of their maximal work rate (Wmax) with CE and at 74.8 %±0.8 Wmax with placebo. No differences in heart rate were observed among the two experiments (Fig. 2).

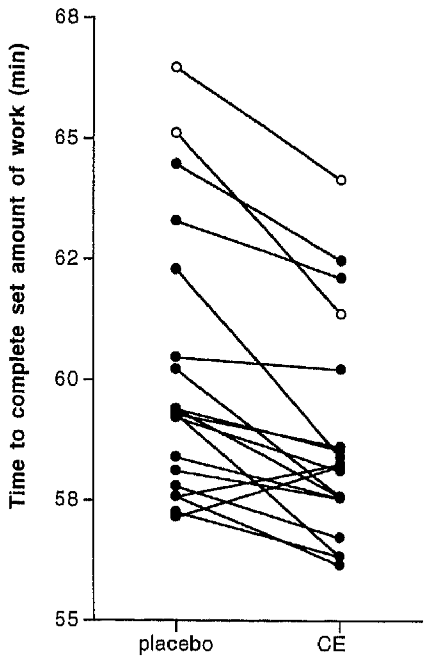

Fig. 1 Time trial performance: differences in the time to complete a set amount of work (min) between CE and placebo. Subjects were significantly faster with ingestion of a 7.6 % CE solution compared to placebo. 17 subjects responded with increased performance whereas 2 subjects responded with decreased performance. Male subjects are indicated by ● and female subjects by ○.

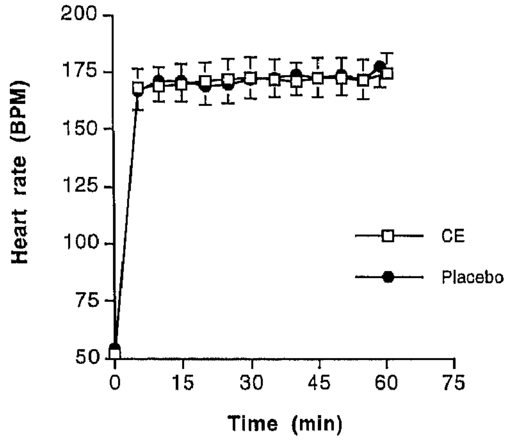

Fig. 2 Heart rate during time trial (mean ± SEM). No significant differences were observed between the CE and the placebo trial (n = 19).

Discussion

In this investigation, 19 endurance trained subjects (Table **1**) performed a set amount of work was fast as possible (about 1 h duration) in a moderate enviroment (20 °C) while receiving either a 7.6 % CE solution or placebo. The purpose of the experiment was to investigate the effect of CE feedings on performance during intense exercise of relative short duration (1 hour) using a previously validated endurance performance test. Therefore we decided to only measure time to complete the set amount of work and heart rate because other measurements might have interfered with the subjects' ability to concentrate during cycling at high intensity (~85 % $\dot{V}O_2max$) as suggested by Coyle and Hamilton (10) and Robinson et al. (22).

Although several studies have shown that performance is increased after carbohydrate ingestion during moderate intensity exercise (50-70 % $\dot{V}O_2max$) of long duration (> 2 h), little information is available on the effect of carbohydrates on high intensity exercise of about 1 h duration. We found that carbohydrate ingestion during exercise (~ 1 h) decreased time to complete a set amount of work by 2.3 %. Results are in agreement with a study of Below et al. (2) who showed a 6.3 % increased performance when subjects had to accomplish a set amount of work as fast as possible (approximately 10 min) after

50 min of intense exercise (85 % VO_2max). In a study of Powers et al. (19) subjects exercised at an initial workload of 85% VO_2max until exhaustion. In this experiment exhaustion was defined as a 10 % decline in the power output below the initial value. Subjects ingested either a beverage with carbohydrates and electrolytes, with electrolytes only, or a placebo. Although 7 of 9 subjects worked longer with the carbohydrate drink, the difference was not statistically significant. Neufer et al. (16) showed improved performance in short term high-intensity exercise following carbohydrate ingestion. Well-trained cyclists exercised 45 min at 80 % VO_2max followed by an exercise bout requiring the accomplishment of the most possible work in a 15 min period. With ingestion of a carbohydrate solution (45 grams of carbohydrate) just prior to the exercise bout, subjects completed 10 % more work compared to the placebo trial.

From the present study and the few available studies, it can be concluded that CHO feedings not only improve exercise performance during long lasting submaximal exercise (3,4,7–9, 13,24,26,27), but also during 1 h high intensity exercise. With prolonged exercise it has been shown that carbohydrate feedings improve performance by maintaining euglycemia (4,9,15) and high rates of carbohydrate oxidation (4,9). During high intensity exercise, there is no evidence that carbohydrate ingestion exerts its beneficial effect by raising blood glucose conentration and carbohydrate oxidation (2). During high intensity exercise blood glucose levels do not drop, but are often even increased towards the end of exercise (2,5,6). In the study of Neufer et al. (16) and of Below et al. (2) carbohydrate ingestion improved performance despite the fact that no differences in carbohydrate oxidation were observed between the CHO trial and placebo during the initial 45–50 min of steady state exercise. Studies using ^{13}C-labelled carbohydrates to measure exogenous carbohydrate oxidation have shown that with a similar feeding schedule to the one applied in the present study about 10–20 % of the ingested carbohydrates are oxidized during the first hour of exercise at 60–70% VO_2max (20,23,25). This means that only a small amount of exogenous carbohydrates (~5–20 g) is available for oxidation during the first hour after ingestion (these calculations take into account the underestimation due to the temporary loss of $^{13}CO_2$ in the bicarbonate pool). This makes it unlikely that carbohydrate ingestion exerts its beneficial effect through a contribution to energy expenditure.

Coggan and Coyle (5) suggested that the key to the improved performance at these high intensities may be the 'relative' CHO availability, i.e., that although CHO availability may not appear limiting in an absolute sense, increasing CHO oxidation may provide the ability to increase the power output (or to tolerate high intensities longer). This effect may be mediated by CHOs promoting the synthesis of TCA-cycle intermediates via the alanine-amino transferase reaction, thereby increasing the capacity of aerobic ATP production.

Although it seems most likely that CHO are responsible for the improved performance after ingestion of the CE solution, with the present study design it cannot be excluded tht the electrolytes in the drink may be partially responsible for the observed improvements.

Electrolyte ingestion, especially sodium and potassium, has been associated with increases in plasma volume. This effect has primarily been observed post-exercise (14,17) and to our knowledge no data are available to support the idea that increases in plasma volume would also occur when electrolytes are ingested during exercise. Moreover, if indeed sodium and/or potassium would have caused a better maintenance of plasma volume in the present study, this could theoretically lead to increased performance at similar heart rates because of a larger cardiac output. However, Powers et al. (19) did not observe changes in plasma sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and chloride (Cl^-) when electrolytes were ingested in amounts similar to the amounts ingested in the present study. Although plasma electrolyte concentrations increased during exercise, the increase was the same when water was ingested compared to ingestion of a CE solution. In addition no effect on plasma volume or exercise performance was observed when only electrolytes were ingested.

It was concluded that carbohydrate feedings ingested during exercise improve time trial cycling performance of about 1 h duration (high intensity exercise; ~80 % VO_2max). However, the explanation for this increased performance remains to be established.

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