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Influence of CHO Ingestion on Exercise Performance and Fuel Utilization

Spyridon Zarogiannis

University of Glasgow, College of Medical, Veterinary & AMP; Life Sciences, Institute of Cardiovascular & AMP; Medical Sciences, Glasgow, Greece

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***Corresponding author:**

Spyridon Zarogiannis

University of Glasgow
College of Medical, Veterinary & AMP; Life Sciences
Institute of Cardiovascular & Amp;
Medical Sciences
Glasgow
Greece

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ABSTRACT

Background: It is known that CHO feeding can improve exercise performance. The aim of this study is to assess the effect of CHO ingestion on performance and on metabolic responses during exercise.

Methods: Thirteen healthy students from University of Glasgow completed two 1 d trials: carbohydrates and placebo ingestion, in a randomized, double-blind, cross-over design separated by 1 week. Subjects cycled for 90 minutes at 60% of VO_{2max} and then at 90% of VO_{2max} until exhaustion. They consumed a 250 ml drink (CHO or placebo) at the beginning and every 15 minutes until the end of 90 minutes period. The CHO drink contained 12.5% of CHO and was given 6 times during the 90 minutes of exercise (80 g•h^{-1}; 833ml•h^{-1}). Blood glucose, heart rates and RPE were taken at the beginning of the trial, every 15 minutes and at the point of exhaustion. Expired air samples were taken at 2-minute intervals every 15 minutes. Time to exhaustion was determined for each trial.

Results: Blood glucose levels were significantly higher (P=0.001) in CHO trial (5.7 ± 0.6 mmol/l) compared to placebo (5.0 ± 0.4 mmol/l). Despite the differences in blood glucose levels during the exercise, there were no significant differences in the time to exhaustion or rate of fuel oxidation between the two trials. No significant differences were observed in heart rates and RPE measurements.

Conclusion: These data suggest that CHO ingestion increased significantly blood glucose levels compared to placebo, but did not change exercise performance or fuel utilization.

INTRODUCTION

Carbohydrates and fat are the two predominant fuels oxidized by human skeletal muscles at exercise. Plasma free fatty acids provide the main fuel during low- to moderate-intensity exercise (25-65% of, VO_{2max}). However, endogenous muscle glucogen stores and plasma blood glucose are the main fuels for energy provision during moderate- to high-intensity exercise, contributing more than 50% in the total energy requirements (Romijn et al., 1993, Tsintzas et al., 1998, Cermak et al., 2013).

Carbohydrates ingestion can improve performance and endurance exercise capacity during moderate- to high-intensity exercise (>70% VO_{2max}) (Coyle et al., 1985, Jeukendrup et al., 2004). Fatigue during prolonged exercise is related to depletion of skeletal muscle glycogen stores and reduction of blood plasma glucose (Coggan et al., 1987, Nybo et al., 2003). Consequently, the ergonenic effect of carbohydrate feeding is related to preservation of skeletal muscle glucogen (Jeukendrup et al., 1999), maintenance of blood glucose levels (Coyle et al., 1985) and high rates of carbohydrates oxidation (Smith et al., 2010). Improvements in exercise performance occur when athletes consume 30-60 g of carbohydrates during prolonged (>60 min) moderate- to high-intensity exercise (Rodriguez et al., 2009).

Carbohydrates and fats differ in their chemical composition and in the amounts of O_2 needed and CO_2 produced when oxidized. Therefore, the rate of fat and carbohydrate oxidation during exercise can be estimated by an indirect measurement to quantify the CO_2 produced in relation to O_2 consumed in the tissue level (Jansson et al., 1982, Jeukendrup et al., 2005). It has been observed that variations in the fat and carbohydrate content of diet can influence gas exchange and therefore alter the proportion of fuel contribution during exercise (Maughan et al., 1978, Gollnick et al., 1972).

The aim of the study is to evaluate the effect of CHO ingestion compared to placebo on endurance exercise performance and estimate the alternations in contribution of fuels in exercise.

METHODS

Subjects

Fourteen healthy postgraduate students from University of Glasgow recruited for the study and 1 of them dropped out due to incomplete data. Thirteen subjects completed the study (six males and seven females). Their mean (± SD) age was 25.1 ± 2.9 years, height 169.1 ± 17.3 cm, waist circumference 73.8 ± 7.9 cm, hip circumference 94.6 ± 3.8 cm and body fat percentage measured by BIA 21.6 ± 5.7. There were no statistical differences in the weight for each participant at the two trials (66.9 ± 14.0 kg and 66.9 ± 14.6 kg for CHO and placebo trial, respectively, P=0.73). The VO_{2max} was determined on a bicycle ergometer and averaged at 3.66 ± 1.34 L•min^{-1}. Subject characteristics are presented in Table 1. All of the subjects were informed of the purpose and the procedure of the experiment by the laboratory manual and completed the Physical Activity Readiness Questionnaire for Everyone (PAR-Q), informing them about their physical activity level and allowing them to participate in the experiment. The subjects completed a consent form and they were free to withdraw their consent to participate at any time.

Pretrial Preparation

The Maximal Oxygen Uptake (VO_{2max}) and the work rate at VO_{2max} were calculated during an open-ended incremental cycle ergometer test. The test began with a 4-minute warm-up at a work rate of 30 Watts (0.5 kg load on Monark cycle ergometer at 60 rpm). Work rate was increased by 30 Watts per 2-minutes and the test was terminated when the subject could no longer sustain the required work rate (within 5 rpm) for longer than 5 seconds. During every second minute of each stage, expired air samples, heart rates and RPE were being measured. The results of this test were used to calculate the oxygen uptake at each work rate and the work rate that corresponded to 60% and 90% of each subject's VO_{2max}, which were then used in the main experimental protocol.

Experimental Protocol

The subjects undergo two trials, the carbohydrate and the placebo trial. The two trials were randomly assigned to subjects, conducted double blind and separated by 7 days. The subjects reported to the laboratory in the morning after an overnight fast or in the afternoon after a minimum of 6 hours fast.

On arrival at the laboratory, the body masses of the subjects were measured. During 5-minute resting, pre-exercise heart rates and finger-prick blood glucose sample were measured and a resting expired air sample was taken into Douglas bags. The subjects then drunk a 250 ml of carbohydrate drink for the CHO trial (containing ~20 g carbohydrate) or 250 ml of an artificially sweetened placebo drink for the placebo trial (containing <2 g carbohydrate). After consuming the first drink, they immediately started cycling for 90 minutes at 60% of VO_{2max} power. Every 15 minutes after the first drink and during exercise, subjects consumed a further 250 ml of carbohydrate or placebo drink, depending on the trial. In addition, expired air samples were taken at 13-15 mins, 28-30 mins, 43-45 mins, 58-60 mins, 73-75 mins and 88-90 mins during the cycle. Blood glucose samples, heart rate and RPE measurements were obtained at 15, 30, 45, 60, 75 and 90 minutes.

The workload was increased to 90% of VO_{2max} power after the end of the 90 minutes and the subjects cycled to exhaustion. Heart rates and RPE were obtained every minute and expired air samples were taken continuously during this final stage of the experiment. The exact time to exhaustion for every subject was measured and a final blood glucose sample and heart rates were obtained at the end of the exercise. The study protocol design is shown in Figure 1.

Table 1: Baseline characteristics of participants

	Participants (n=13)		
Males/Females	6/7		
Age (y)	25.1 ± 2.9		
VO2max (l·min-1)	3.66 ± 1.34		
Height (cm)	169.1 ± 17.3		
Waist (cm)	73.8 ± 7.9		
Hip (cm)	94.6 ± 3.8		
Body fat by BIA (%)	21.6 ± 5.7		
Body mass (kg)	**CHO trial**	**Placebo trial**	**P-value**
	66.98 ± 14.06	66.92±14.60	0.73

Values are means ± SD; Maximal Oxygen Uptake (VO_{2max}); Bioelectrical Impedance Analysis (BIA); Carbohydrate Trial (CHO)

Data Collection

Body composition and anthropometric data: Body mass was determined with an electronic scale to the nearest 0.1 kg with subjects being barefoot and wearing only light clothing. Barefoot standing height was measured with a stretch stature method. Waist and hip circumference were measured two times with measurements not differing more than 0.5 cm. Body fat percentage was calculated by three different methods. Biceps, triceps, subscapular and suprailiac skinfolds measurements by a caliper to the nearest 0.1 mm were used to estimate adiposity and fat-free body mass by the predictive equations as described before by Durnin and Wormersley (1974). Bioimpedance analysis was used to determine the body resistance and then estimate the percentage body fat using a Tanita TBF-300 body composition analyzer by the equation of Brozek et al. (1963). Air-displacement plethysmography method was used to determine body density and then percentage body fat using the Siri et al. (1961) equation. Body fat percentages were used in data analysis by BIA measurements. It has better reproducibility than Skinfolds, which makes it more suitable in the present study and it can accurately measure the TBW and ECW in normal-weight persons (Lee et al., 2008).

Metabolic Data: Expired air samples were collected in plastic Douglas air bags and a dry gas meter was used to measure volume and temperature of the samples. Oxygen concentration was measured by a parametric analyzer and carbon dioxide by an infrared analyzer. The rate of fat and carbohydrate oxidation and energy expenditure were calculated from VO_2 consumption and VCO_2 production assuming that there is no protein oxidation during exercise (Frayn et al., 1983). Throughout the trial the subjects provided rating of exertion by a Rated Perceived Exertion (RPE) scale from 6-20. Blood glucose levels were determined by ACCU-Check glucose analyzer and heart rates were recorded by a heart rate monitor.

Statistical Analysis

The trapezoid method was used to calculate Area Under the Curve (AUC) as a summary measure of the fat oxidation, carbohydrate oxidation and energy expenditure. All of the data were analyzed by paired t-test comparing the mean differences of HR, RPE, glucose and differences of AUC for fat oxidation, carbohydrate oxidation and energy expenditure between the CHO trial and placebo trial using Microsoft Office Excel 2007. A difference between two mean values was significant at the $P < 0.05$ and data are presented in the text and tables as mean ± SD.

RESULTS

Physiological responses during 90 min at 60% VO_{2max}

During the first part of the experiment (90 min at 60% VO_{2max}), CHO effect neared significance (P=0.07) for RPE differences between the two groups. There were no significant differences (P>0.05) for heart rates (CHO trial, 153 ± 15 bpm; Placebo trial, 148 ± 21 bpm; P=0.167). Results are shown in Table 2.

Metabolic responses during 90 min at 60% VO_{2max}

Figure 2 shows the mean ± SE changes in glucose levels, rate of fat oxidation, rate of carbohydrate oxidation and rate of energy expenditure in response to CHO and placebo drinks during the 90

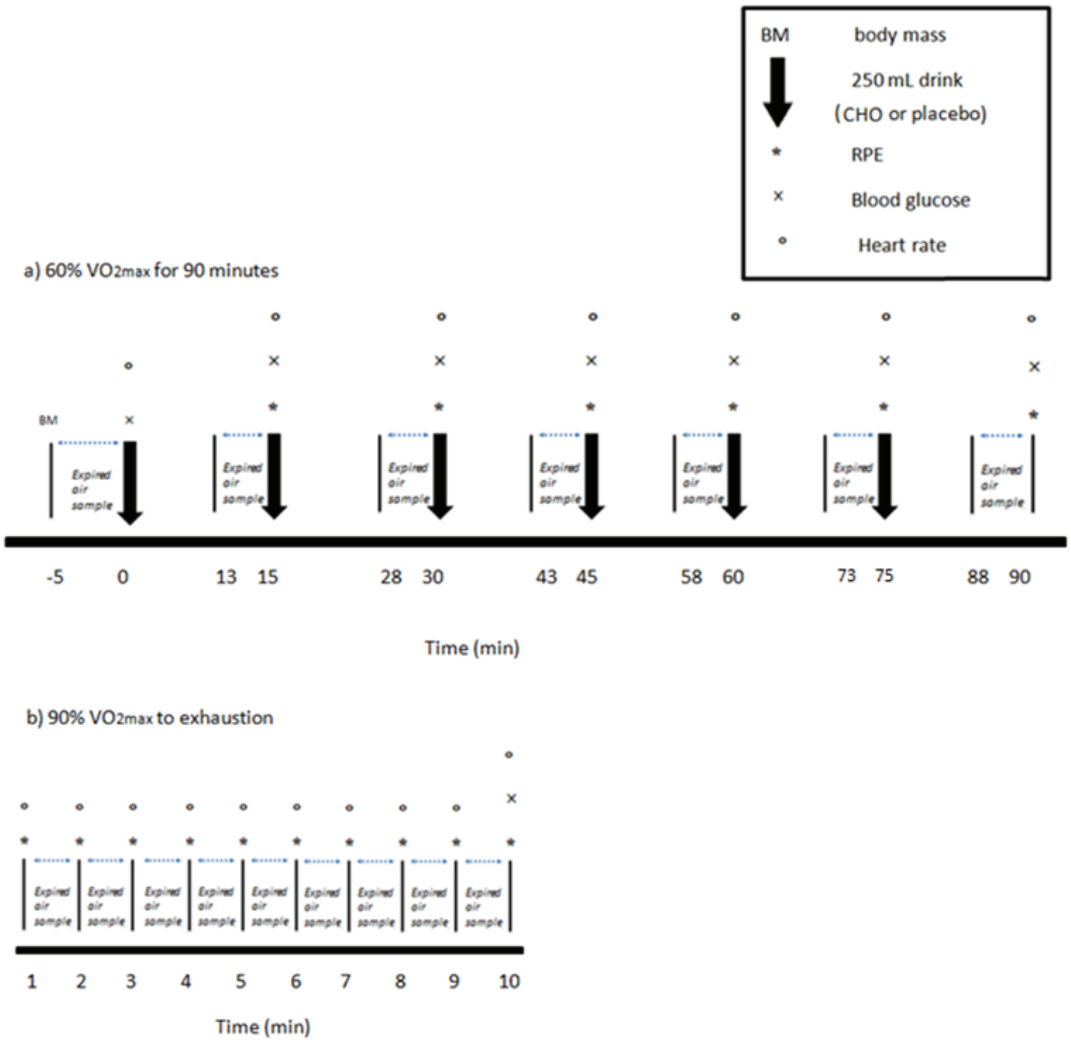

Figure 1: Study protocol design. Participants completed two separate trials: CHO and placebo. At the first part, participants cycled for 90 minutes at 60% of VO2max (a). After the end of first part, participants cycled to exhaustion at 90% of VO2max (b)

minutes of cycling. Blood glucose levels (Figure 2) in CHO trial increased (5.7 ± 0.6 mmol/l) after the first drink and remained significantly higher compared to placebo trial (5.0 ± 0.4 mmol/l) throughout the 90 minutes of cycling (P=0.0019). The values of AUC for fat oxidation, carbohydrate oxidation and energy expenditure were no statistical different between the two trials during exercise (Figure 2). VO_2 and VCO_2 didn't change significantly between the CHO and placebo trial during the exercise. Results are shown in Table 2.

Physiological responses at the point of the exhaustion at 90% of VO_{2max}

The mean values of time to exhaustion (TTE) are shown in Table 3. Compared with ingestion of the water placebo drink, CHO consumption resulted in not statistically significant difference in TTE (CHO trial, 4.66 ± 3.17 min; Placebo trial, 4.27 ± 1.9 min; P=0.604). There were no significant differences for heart rates (P=0.658) and for RPE (P=0.586) at the point of the exhaustion at 90% of VO_{2max} between CHO and placebo trial.

Metabolic responses at the point of the exhaustion at 90% of VO_{2max}

Statistical analysis of variables measured at the point of the exhaustion showed that mean blood glucose levels were significantly higher (P<0.001) in CHO trial (6.3 ± 0.9 mmol/l) compared to placebo trial (5.3 ± 0.3 mmol/l). No statistically significant differences were observed for rate of fat oxidation (P=0.635), rate of carbohydrate oxidation (P=0.705) and rate of energy expenditure (P=0.758) at the point of the exhaustion at 90% of VO_{2max} between CHO and placebo trial. Results are shown in Table 3.

DISCUSSION

The present study was designed to assess the effect of CHO ingestion (~120 g) on exercise endurance and on metabolic responses during 90 minutes of exercise at 60% VO_{2max} followed by exhaustion at 90% VO_{2max}. The main finding of the present study is that CHO ingestion (80 $g \bullet h^{-1}$) during exercise increased blood glucose levels compared to placebo. Although the fuel utilization and the performance between the two trials were not significantly different, these results provide additional evidence of the effect of carbohydrate ingestion on metabolic responses and endurance exercise capacity.

Metabolic responses and exercise performance

Previous studies have shown that CHO ingestion can result in increased blood glucose levels (Hargreaves et al., 1984). It has been suggested that elevated blood glucose levels with CHO consumption can delay the onset of fatigue during prolonged exercise (Coyle et

Table 2: Mean values during the 90 min cycling at 60% of VO_{2max}

	CHO trial	Placebo trial	P value
Heart rate (bpm)	153 ± 15	148 ± 21	0.167
RPE	11.7 ± 1.2	12.4 ± 0.9	0.074
Glucose (mmol/l)	5.7 ± 0.6	5.0 ± 0.4	0.0019*
VO_2 ($l \cdot min^{-1}$)	2.01 ± 0.69	1.93 ± 0.68	0.247
VCO_2 ($l \cdot min^{-1}$)	1.68 ± 0.62	1.64 ± 0.61	0.444
AUC for fat oxidation (g/90 min)	52.0 ± 20.4	45.7 ± 21.8	0.276
AUC for carbohydrate oxidation (g/90 min)	103.4 ± 67.5	110.3 ± 70.4	0.556
AUC for energy expenditure (kJ/90 min)	3644.6 ± 1268.1	3507.6 ± 1250.4	0.265

Values are means ± SD; Rated Perceived Exertion (RPE); Oxygen Uptake by the Lungs (VO_2); Carbon Dioxide Elimination by the Lungs (VCO_2); Area Under the Curve (AUC)
*Statistical significant difference between the mean value

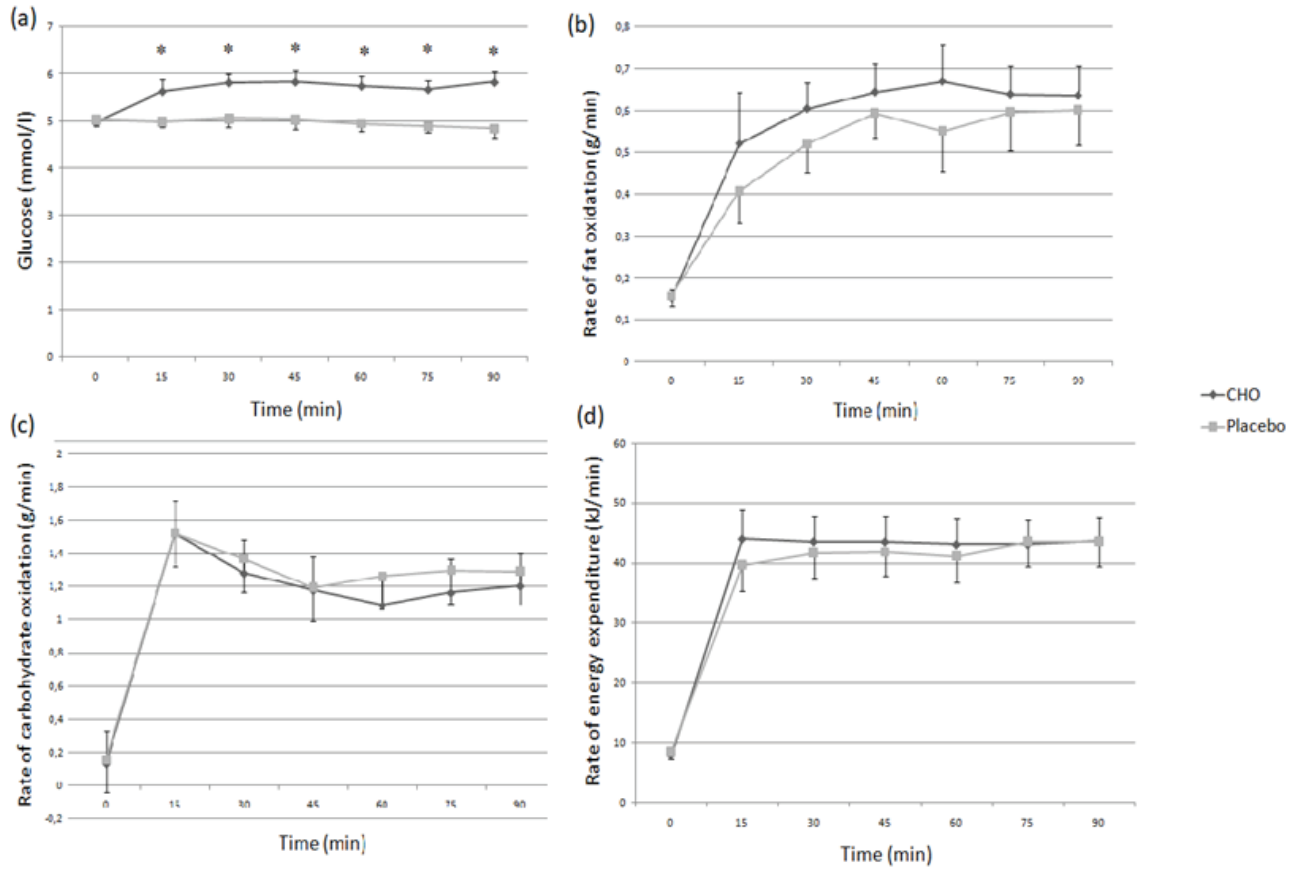

Figure 2: Blood glucose levels (a), rate of fat oxidation (b), rate of carbohydrate oxidation (c) and rate of energy expenditure (d) after CHO or placebo drink during the 90 min cycling at 60% VO_{2max}.
*Significantly different from Placebo; P<0.05. Values are means ± SE represented by vertical bars

al., 1985, Coggan et al., 1987, Cermak et al., 2013). In the present study, there appeared to be a statistically significant difference in glucose levels during the exercise between CHO consumption compared to placebo. However, despite the differences in blood glucose levels between the two trials, there were no differences in times to exhaustion or in rated perceived exertion (RPE) during the exercise. These results indicate that the performance was not significantly different between the two trials. The observation that increased blood glucose levels do not improve exercise performance is supported by Felig et al. (1982). The reason for these results is not obvious but may be related to the relatively higher fat oxidation during the placebo exercise and therefore, contribution of muscle glucogen to muscle substrate supply was lower. These results are in conflict with the work of Coyle (1985) and Coggan (1987), where decreased blood glucose levels resulted in earlier fatigue. However, these studies explained fatigue based on euglycemic vs. hypoglycemic conditions. In the present study, despite of the difference in glucose levels between the two groups, glucose levels in both CHO and placebo trials were normal, suggesting that fatigue is not unequivocal related to decreased blood glucose levels.

Previous studies have demonstrated that relatively large doses of carbohydrates (>100 g) can improve exercise performance, alter fuel contribution and conserve muscle glucogen storage in prolonged exercise (Hargreaves et al., 1984, Coyle et al., 1985, Jeukendrup et al.,

Table 3: Mean values at the point of the exhaustion at 90% of VO_{2max}

	CHO trial	Placebo trial	P value
TTE (min)	4.66 ± 3.17	4.27 ± 1.9	0.604
Heart rate (bpm)	183 ± 14	183 ± 14	0.658
RPE	19.5 ± 0.6	19.6 ± 0.5	0.586
Glucose (mmol/l)	6.3 ± 0.9	5.3 ± 0.3	0.0001*
VO_2 ($l \cdot min^{-1}$)	2.93 ± 1.20	3.00 ± 1.08	0.728
VCO_2 ($l \cdot min^{-1}$)	2.83 ± 1.30	2.83 ± 1.04	0.971
Rate of fat oxidation (g/min)	0.17 ± 0.45	0.29 ± 0.59	0.570
Rate of carbohydrate oxidation (g/min)	3.44 ± 2.28	3.20 ± 1.84	0.622
Rate of energy expenditure (kJ/min)	60.6 ± 25.4	61.7 ±22.3	0.774

Values are means ± SD; Time to Exhaustion (TTE); Rated Perceived Exertion (RPE); Oxygen Uptake by the Lungs (VO_2); Carbon Dioxide Elimination by the Lungs (VCO_2)
*Statistical significant difference between the mean values

2004). In the present study, there were no significant differences in the rate of fat and carbohydrates oxidation or in the rate of energy expenditure between the two groups, suggesting that CHO ingestion doesn't influence carbohydrate oxidation. Romjin et al. (1993) supported that carbohydrates becomes the most important fuel in exercise intensities above 65% of VO_{2max}. In this study, subjects were cycling for 90 minutes in 60% of VO_{2max}, so fat was the dominant fuel in this period and therefore carbohydrates didn't contribute largely to energy expenditure. Therefore, CHO ingestion may not influence CHO oxidation because the large contribution of fat.

Many studies have suggested that ingestion of high amounts of CHO may affect negatively performance by reducing gastric emptying rate and impairing fluid replenishment (Mitchell et al., 1989, Jeukendrup et al., 2004). This is in agreement with the findings of Maughan et al. (1987) who noted that consumption of 16% CHO drink (96 $g \bullet h^{-1}$; 600$ml \bullet h^{-1}$) slowed absorption and decreased plasma volume compared with consumption of 3.6% CHO drink (22 $g \bullet h^{-1}$). Similarly, Davis et al. (1988) demonstrated that ingestion of 12% CHO drink (99 $g \bullet h^{-1}$; 825 $ml \bullet h^{-1}$) resulted in greater incidences of gastrointestinal distress compared with consumption of 6% or water placebo. Therefore, it is suggested that performance benefits can be observed with relatively small amounts of CHO (16 $g \bullet h^{-1}$) and ingestion of higher amounts cannot improve performance (Jeukendrup et al., 2004) and the optimal CHO availability is achieved at ingestion of 40 to 75 $g \bullet h^{-1}$ availability (Coggan et al., 1992). In the present study, the CHO drink that was used contained 12.5% of CHO and was given 6 times during the 90 minutes of exercise (80 $g \bullet h^{-1}$; 833 $ml \bullet h^{-1}$). Therefore the reason for the unchanged performance could be large amount of CHO obtained, resulting in impaired fluid replenishment in the CHO trial.

Strengths and Limitations

The main strength of the study is the randomized, cross-over design and the double-blinded allocation of the drinks. However, an important limitation of the study is the small sample size. The lack of sample size calculation may be the reason for the no statistically significant results. The researchers were not experts in measuring and collecting the data. The participants had different training status and they might not reach the 90% of the maximal workrate and their 90% VO_{2max}. The researchers, who took the measurements during the trials, also analyzed the data and there was no blinding.

CONCLUSION

In summary, the ingestion of 80 $g \bullet h^{-1}$ of CHO during 90 minutes of cycling at 60% of VO_{2max} increased significantly blood glucose levels compared to placebo. However, this change did not affect exercise performance or the fuel utilization.

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