The Effect of Carbohydrate Mouth Rinse on 1-h Cycle Time Trial Performance

JAMES M. CARTER, ASKER E. JEUKENDRUP, and DAVID A. JONES

Human Performance Laboratory, School of Sport and Exercise Sciences, The University of Birmingham, Edgbaston, Birmingham, UNITED KINGDOM

ABSTRACT

CARTER, J. M., A. E. JEUKENDRUP, and D. A. JONES. The Effect of Carbohydrate Mouth Rinse on 1-h Cycle Time Trial Performance. *Med. Sci. Sports Exerc.*, Vol. 36, No. 12, pp. 2107–2111, 2004. **Purpose and Method:** To investigate the possible role of carbohydrate (CHO) receptors in the mouth in influencing exercise performance, seven male and two female endurance cyclists ($\dot{V}O_{2max}$ 63.2 ± 2.7 (mean ± SE) $mL \cdot kg^{-1} \cdot min^{-1}$) completed two performance trials in which they had to accomplish a set amount of work as quickly as possible (914 ± 40 kJ). On one occasion a 6.4% maltodextrin solution (CHO) was rinsed around the mouth for every 12.5% of the trial completed. On the other occasion, water (PLA) was rinsed. Subjects were not allowed to swallow either the CHO solution or water, and each mouthful was spat out after a 5-s rinse. **Results:** Performance time was significantly improved with CHO compared with PLA (59.57 ± 1.50 min vs 61.37 ± 1.56 min, respectively, $P = 0.011$). This improvement resulted in a significantly higher average power output during the CHO compared with the PLA trial (259 ± 16 W and 252 ± 16 W, respectively, $P = 0.003$). There were no differences in heart rate or rating of perceived exertion (RPE) between the two trials ($P > 0.05$). **Conclusion:** The results demonstrate that carbohydrate mouth rinse has a positive effect on 1-h time trial performance. The mechanism responsible for the improvement in high-intensity exercise performance with exogenous carbohydrate appears to involve an increase in central drive or motivation rather than having any metabolic cause. The nature and role of putative CHO receptors in the mouth warrants further investigation. **Key Words:** EXERCISE, MALTODEXTRIN SUPPLEMENTATION, MOUTHWASH, MOUTH RECEPTORS

Carbohydrate (CHO) ingestion immediately before and during exercise of a relatively short (~1 h) and intense nature (>75% $\dot{V}O_{2max}$) has been reported to improve exercise performance. These reports include exercise performed in thermo-neutral (1,2,11,14,21) and hot ambient conditions (3,6,20), although there are also a few studies that have found no such effect (7,17,19).

The mechanism responsible for any improvement in high-intensity exercise with the ingestion of exogenous CHO is unclear. One possibility is the maintenance of high CHO oxidation rates, as in the case of CHO feeding during prolonged, moderate-intensity exercise (8,10). However, Jeukendrup and colleagues (14) have argued that this is unlikely to be the case in high-intensity exercise, as it was estimated that only 5–15 g of exogenous CHO are oxidized in the first hour of exercise. This relatively small contribution to the total CHO oxidation rate was thought too small to significantly improve exercise performance. Consequently, whereas the balance of opinion is that oral CHO supplementation is effective in improving 1-h high-intensity exercise performance, there is no clear metabolic explanation for this effect. Recently, we studied the effects of glucose infusion (as opposed to oral administration) on performance during a simulated 40-km time trial. This mode of administration was used partly to negate interindividual differences in the rate of glucose absorption. Surprisingly, although there was abundant available glucose in the circulation and evidence of a small but significant oxidation of exogenous CHO, performance was unaffected by infusion of glucose at a rate of 1 $g \cdot min^{-1}$ compared with saline (Carter et al., unpublished observations, 2004). These results suggest that oral CHO may exert its effects during high-intensity exercise through a central action, improving motor drive or motivation, mediated by receptors in the mouth or GI tract.

The aim of the present study was to investigate the effect of a CHO mouth rinse solution on performance of a 1-h high-intensity cycle time trial. The use of a mouth rinse treatment, which was spat out without swallowing, removes any influence of the gut and CHO oxidation on performance. It was hypothesized that time trial performance would be significantly improved during the CHO mouth rinse trial compared with the swilling of water.

Address for correspondence: A. E. Jeukendrup, Human Performance Laboratory, University of Birmingham, Edgbaston, B15 2TT, Birmingham, United Kingdom; E-mail: a.e.jeukendrup@bham.ac.uk.
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METHODS

Subjects. Seven male and two female endurance-trained volunteers gave their written informed consent to participate in the study that was approved by the local ethics committee. Their mean age, weight, and maximal oxygen uptake ($\dot{V}O_{2max}$) were 24.0 ± 3.8 yr, 70.5 ± 5.9 kg, and 63.2 ± 8.0 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively (mean ± SD). All subjects had previously been involved in cycle ergometry studies at this intensity in similar conditions, and were fully familiar with the experimental procedures.

Experimental design. All exercise tests were carried out on an electrically braked cycle ergometer (Lode Excalibur, Groningen, The Netherlands). The protocol consisted of four visits performed in a laboratory maintained at 17 ± 2°C with a relative humidity of 53 ± 4%. Visit 1 was an incremental exercise test to exhaustion to determine maximum oxygen uptake ($\dot{V}O_{2max}$) and maximum power output (W_{max}). Visits 2, 3, and 4 were the simulated time trials involving completion of a set amount of work in the shortest time possible. Visit two was a familiarization session. For the experimental trials (visits 3 and 4) subjects performed two rides, during which they were given either a 6.4% maltodextrin solution (CHO) or a water bolus (PLA) to rinse around their mouths at intervals. The study was carried out in a counterbalanced blind fashion, with each visit separated by 7 d.

Visit 1. Subjects performed an incremental exercise test to volitional fatigue at a self-selected cadence on a cycle ergometer. The appropriate seat position, handlebar height, and orientation were used during testing and replicated in each subsequent visit. The initial workload was 95 W, which was increased by 35 W every 3 min until fatigue. Ventilation, oxygen uptake ($\dot{V}O_2$), and carbon dioxide production ($\dot{V}CO_2$) were recorded continuously (Oxycon Pro, Jaeger, Germany), as was heart rate (Polar Vantage NV, Polar Electro Oy, Finland).

Visits 2–4. Subjects visited the lab after a 4-h fast, having abstained from caffeine, alcohol, tobacco, and exercise in the previous 24 h. On arrival at the laboratory the subjects were weighed, fitted with a heart rate transmitter and receiver, and seated on the cycle ergometer. Each subject performed their two time trials at the same time of day. After a brief warm-up (5 min at 40% W_{max}), subjects were asked to perform a certain amount of work (914 ± 40 kJ) as fast as possible. This test has been reported to be highly reproducible (15). The total amount of work was calculated according to the formula:

$$\text{Total work} = 0.75 \cdot W_{max} \cdot 3600$$

The ergometer was set in the linear mode so that 75% W_{max} was obtained when the subjects pedaled at their preferred cadence, determined during the $\dot{V}O_{2max}$ test. Self-selected cadences ranged from 80 to 100 rpm. The cycle ergometer was connected to a computer which calculated and displayed to the subject the amount of work performed. The only information the subject received during the test was the work performed and the percentage of work performed relative to the preset task (0% at the start, and 100% at completion of the trial). A fan in a standard position (100 cm in front of subject) provided some cooling and air circulation during the trials. Heart rate was recorded continuously throughout the test via telemetry (Polar Vantage NV). At set intervals during the trial (every 20% of the time trial completed), the subject was asked to rate their perceived exertion using the 6- to 20-point Borg scale (4).

Every effort was taken to ensure that the subject was not disturbed during the performance trials. An opaque screen surrounded the subject and the experimental set-up, separating the subject from the investigators. During each time trial, no interaction occurred between the subject and the investigators, except for Borg scale and mouth rinse administration. No encouragement was provided to the subjects, and they were kept unaware of performance-related information (exercise time, heart rate, and cadence) during the tests. Finally, all persons not involved in the study were excluded from the laboratory to prevent any external disruption.

Mouth rinse protocol. Each subject was given a 25-mL bolus of either 6.4% maltodextrin (CHO) or water (PLA) for every 12.5% of the time trial completed, including the warm-up. The subjects were instructed to rinse the fluid around their mouths for approximately 5 s, and then spit the fluid into a bowl held by an investigator. Maltodextrin is partially hydrolyzed starch that, when dissolved in water, is colorless and nonsweet. At the onset of the study each subject was told that he or she would receive two different rinse solutions; one would contain CHO, and one would not. The subjects were informed that both treatments had previously been proven to be independently beneficial during high-intensity exercise performance. The subjects were kept blind to the composition of the rinse treatments until their involvement with the study was complete. At the end of the second trial subjects were asked whether they could distinguish between rinse solutions; if so, they were asked to indicate which solution they thought contained the CHO.

Dietary procedures. To minimize differences in starting muscle glycogen concentrations, subjects were asked to record their diet before their first visit and avoid exercise in the 24-h period before each visit. The dietary was copied and returned to the subject with instructions to follow the same diet before each subsequent visit. Subjects were advised to eat a meal rich in carbohydrates the evening before the test. The average carbohydrate intake in the 24-h period before each time trial was 347 ± 25 g.

Statistics. Data are reported as mean and standard error (mean ± SEM), unless otherwise stated. All time and effect data for both trials (PLA and CHO) were analyzed using a repeated measures ANOVA, with specific differences determined using a paired Student's *t*-test or Tukey's HSD as *post hoc*. The level of probability for rejecting the null hypothesis in all cases was set at $P < 0.05$.

RESULTS

Performance time and power output. Performance time was significantly faster in the CHO compared with the PLA trial (Fig. 1). Performance times in the CHO and PLA

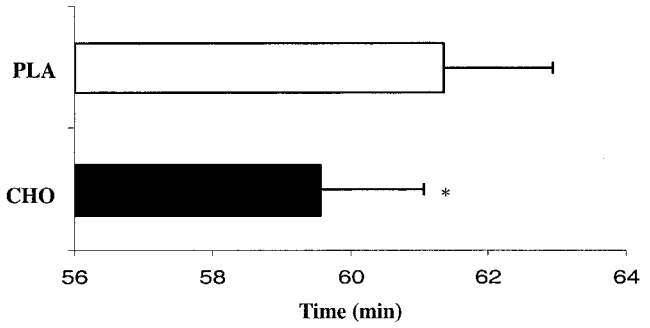

FIGURE 1—Mean performance time in the CHO and PLA trials. * Indicates significantly different from PLA ($P = 0.011$, $N = 9$).

trials were 59.57 ± 1.50 min and 61.37 ± 1.56 min, respectively ($P = 0.011$). This represented an average improvement of 2.9% in the CHO trial.

Power output during the two trials was 259 ± 16 W and 252 ± 16 W for CHO and PLA, respectively (Fig. 2, $P = 0.003$). When the time trial was divided into quarters, power output was significantly higher in the first three CHO quarters compared with PLA (Fig. 3, $P < 0.05$).

Heart rate, RPE, and body mass. Heart rate increased steadily throughout the performance time trials, reaching values of 182 ± 2 bpm and 179 ± 3 bpm at the end of the trial for CHO and PLA, respectively. There was no difference in heart rate response in the two trials (Table 1, $P > 0.05$). Values for RPE (Borg) increased throughout both trials, averaging 16 ± 1 for both CHO and PLA (Table 1). RPE values at the end of exercise were 18 ± 0.6 and 18 ± 0.4 for CHO and PLA trials, with no differences between trials at any time (Fig. 4, $P > 0.05$). Body mass loss for the two trials averaged 1290 ± 111 g and 1280 ± 118 g for CHO and PLA, respectively, with no difference between trials (Table 1, $P > 0.05$).

Rinse solution detection. Five of the nine subjects could not distinguish between the rinse solutions. The remaining four subjects indicated that they could detect a different feel or viscosity between the solutions, and correctly guessed that they were on CHO. Of these four subjects, three performed the time trial more quickly with CHO, and one performed it more slowly.

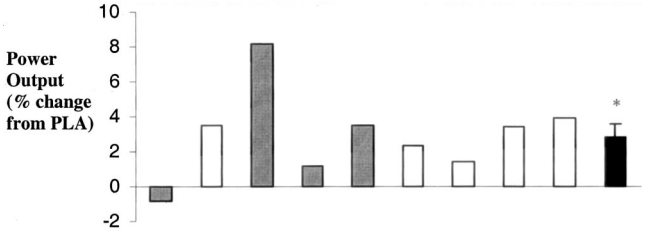

FIGURE 2—Individual and mean power output percent change from PLA for the CHO trial. Filled bar (■) indicates mean power output and shaded bars (▨) indicate those subjects who could distinguish a difference between drinks. * Indicates significant difference from PLA ($P < 0.003$).

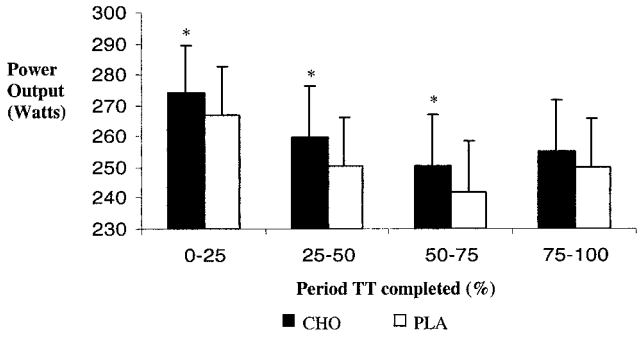

FIGURE 3—Mean power output during the four quarters of the CHO and PLA trials. * Indicates a significant difference from PLA ($P < 0.005$, $N = 9$).

DISCUSSION

To our knowledge, this is the first study that has investigated the role of the mouth as a factor in CHO supplementation during high-intensity exercise performance. Numerous studies have reported that exogenous CHO taken orally can improve performance of relatively short (~1 h), intense (>75% $\dot{V}O_{2max}$) exercise (1–3,6,11,14,20,21). However, the mechanism responsible for this improvement remains elusive.

A contribution to total CHO oxidation rates has been suggested (11,21). However, this is thought unlikely due to the small amount of exogenous CHO reported oxidized, or available for oxidation, in the first hour of exercise (14,19). This is supported by those studies of a similar, high-intensity nature, where no differences in RER values between PLA and CHO conditions were seen (3,11,20). Further evidence suggesting that an enhanced rate of CHO oxidation is not responsible for the improvement was provided by a recent study in our laboratory (Carter et al., unpublished observations, 2004). Infusion of CHO delivering glucose to the circulation at a rate of 1 g·min^{-1} did not improve performance of a 1-h simulated cycle time trial. This was despite exogenous CHO oxidation contributing ~17% to total CHO oxidation during the latter stages of the time trial. It must be mentioned that the gas analysis procedure, combined with regular blood sampling, may have caused distraction to the subjects in the glucose infusion study. The presence of such a distraction could help explain why a significant performance effect was not reported with CHO. However, several precautions were taken to prevent undue subject disruption, including a thorough habituation trial, the use of extension lines for blood sampling, and a head cradle worn by the subject to support the weight of the mouthpiece that the subject breathed through for expired air collection.

TABLE 1. Mean HR, power output, % $\dot{V}O_{2max}$ and weight loss during the CHO and PLA trials.

	CHO	PLA
HR (bpm)	172 ± 1	171 ± 1
Average power (W)	259 ± 16*	252 ± 16
RPE (Borg)	16 ± 1	16 ± 1
Body mass loss (g)	1290 ± 111	1280 ± 118

* Indicates a significant difference from PLA ($P < 0.05$, $N = 9$).

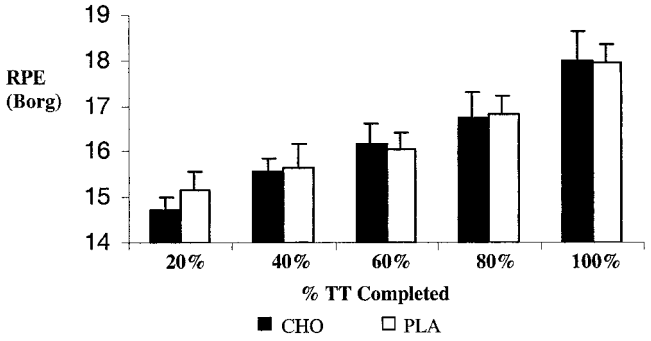

FIGURE 4—Mean RPE during the CHO and PLA trials ($P > 0.005$, $N = 9$).

In the present study, frequent rinsing of a CHO-containing solution around the mouth improved 1-h time trial performance compared with the rinsing of water. Spitting out the CHO solution from the mouth makes it unlikely that the improvement in performance was related to a metabolic action of the CHO, as minimal quantities of the maltodextrin would have entered the gut. As is often found with time trials of 1-h duration, power output declined during the first three quarters before increasing slightly in the last quarter. The power output, although declining in both CHO and PLA trials, was significantly better maintained during the first three quarters of the CHO time trial compared with PLA. However, despite this enhanced power output, RPE was not different between time trial conditions (this is a feature of self-paced exercise, as subjects tend to increase their workload and keep the RPE constant (9)).

Alternatives to the conventional metabolic explanations for improvement of high-intensity exercise with exogenous CHO are not readily apparent. In a recent study, the authors recognized that the mechanism responsible for the improvement of high-intensity performance studies with exogenous CHO may be "nonmetabolic" (19). This has been supported by previous studies of a similar nature, in which there has been speculation about a central component (2,11,14). Furthermore, in a recent study of intermittent exercise, it was reported that physical and mental performance was improved with carbohydrate supplementation, and the authors speculated that an elevated plasma glucose concentration, and perhaps an improved delivery of glucose to the brain, may have enhanced central nervous system function (31). Although delivery of exogenous glucose to the brain was unlikely to have occurred in the present study, it may be possible that afferent signals from CHO receptors in the mouth could have played some role. Different foods can be distinguished in the mouth because of differences in their taste and texture, and oropharyngeal mechanisms are known to have important roles in perceptual responses during rehydration and exercise in the heat. Oral hydration, as opposed to direct intravenous infusion, has been reported to reduce values for RPE and thirst sensation during exercise (74% $\dot{V}O_{2peak}$) to volitional fatigue in the heat (18). These findings are supported by reports of temporary thirst reductions as a result of gargling tap water (28).

As a result of our present study, we would speculate that triggering of receptors within the oral cavity by the CHO could have resulted in the stimulation of the reward and/or pleasure centers in the brain. Such responses are known with other substances. For instance, eating chocolate has been reported to produce an immediate increased activation of those areas of the brain associated with reward (29). Receptors for glucose are known to exist in the human body, including within the gut (26) and brain (24). It is also well recognized that various taste receptors exist in the oral cavity of humans, including those detecting sweet foodstuffs located on the apical surface of taste receptors in the tongue (16), and there is a clear evolutionary advantage to being able to select molecules that serve as energy carriers (5). It is unlikely, however, that sweet receptors were involved in the present study, because the maltodextrin was not sweet tasting, but rats are known to possess receptors for polycose, partially hydrolyzed starch similar to that used in the present study (27). In a series of studies comparing the preferences and aversions of rats to polycose and various sugars, it was found that polycose was preferred to sucrose, maltose, glucose, and fructose at low concentrations, and only sucrose was preferred at high concentrations (27). This preference was not associated with viscosity or sweetness, as polycose does not present a sweet taste to rats (22). It was hypothesized that rats possess two separate CHO receptors in the oral cavity, one being the "sweet" receptor, and the other the polysaccharide receptor (22). Although there are reports of polysaccharide receptors in other species, including gerbils, mice, and hamsters (12), it is not known whether such receptors exist in humans.

All subjects were kept blind to the composition of each rinse, and all subjects were informed that both solutions were independently beneficial. However, four of the nine subjects correctly identified a difference between rinse solutions, and three of these performed more quickly on CHO. Consequently, although measures were taken to guard against a placebo effect, the possibility of one occurring cannot be ruled out. Nevertheless, the percent improvement with CHO of those subjects correctly distinguishing between solutions was 3.0 ± 3.8% ($N = 4$), compared with 2.9 ± 1.0% ($N = 5$) of those subjects who did not distinguish between solutions.

Although sweetness was not a factor mentioned by those subjects distinguishing between drinks, a different "feel" between the drinks may have been evident. Therefore, one further factor that must be considered is the effect of drink viscosity and texture, referred to by Katz and colleagues (16) as the "mouth feel phenomenon." It is thought that humans are able to detect fat in foods by the feel of the food in the mouth, perhaps involving stimulation of cortical taste neurones (26). Furthermore, neurones in the orbitofrontal cortex are known to respond to a variety of viscosities of foodstuffs in the mouth (30).

It has been reported that the tasting of saccharin and glucose by rats produces a significant rise in insulin concentrations as quickly as 1–1.5 min after the taste stimulus (13). This response, known as the cephalic phase of insulin release (CPIR), is a parasympathetic reflex caused by the taste, smell, and sight of food (23). It was further reported

that hepatic glucose production and the rate of disappearance of glucose was significantly increased in both lean and obese rates after the ingestion of saccharin (1 mL) compared with water (13). Similar responses have also been shown to occur in human experiments. Robertson and colleagues (25) reported that within 15 min of a modified sham feeding technique, in which subjects chewed nutrients without swallowing, plasma insulin peaked at 250% of baseline concentrations compared with water ingestion.

It is possible, therefore, that in the present study swilling of the maltodextrin solution caused a cephalic response in those subjects detecting a difference in viscosity between conditions. Subsequently, the resulting increases in insulin and glucose concentrations could have enhanced glucose uptake into the active muscles and maintained CHO oxidation rates compared with the water trial. However, firm conclusions cannot be drawn regarding a CPIR response, as blood sampling did not occur in the present study. Furthermore, as discussed above, intravenous delivery of a large amount of glucose did not affect 1-h time trial performance compared with saline infusion (Carter et al., unpublished observations, 2004). This was despite an increased availability and oxidation of exogenous CHO.

In conclusion, rinsing the mouth with a CHO-containing solution during a 1-h cycle time trial improved performance compared with a water rinse. The mechanism responsible for the improvement in high-intensity exercise performance with exogenous carbohydrate is unknown, but may involve CHO receptors in the oral cavity modulating central pathways associated with motivation. The existence of such CHO receptors in the mouth, and their effect on performance, warrants further investigation. These additional studies should involve a variety of rinse formulations and should rule out the possibility of potential placebo effects.

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