Carbohydrate mouth rinse enhances time to exhaustion during treadmill exercise

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Summary

Mouth rinsing with a CHO solution has been suggested to improve short (<1 h) endurance performance through central effect. We examined the effects of mouth rinsing with a CHO solution on running time to exhaustion on a treadmill. Six well-trained subjects ran to exhaustion at 85% VO_{2max}, on three separate occasions. Subjects received either an 8% CHO solution or a placebo (PLA) every 15 min to mouth rinse (MR) or a 6% CHO solution to ingest (ING). Treatments were assigned in a randomized, counterbalanced fashion, with the mouth-rinsing treatments double-blinded. Blood samples were taken to assess glucose (Glu) and lactate (Lac), as well as the perceived exertion (RPE). Gas exchange and heart rate (HR) were collected during all trials. Subjects ran longer ($P = 0{\cdot}038$) in both the MR (2583 ± 686 s) and ING (2625 ± 804 s) trials, compared to PLA (1935 ± 809 s), covering a greater distance (MR 9685 ± 3511·62 m; ING 9855 ± 4118·62; PLA 7295 ± 3727 m). RER was significantly higher in both ING and MR versus PLA. No difference among trials was observed for other metabolic or cardiovascular variables (VO_2, Lac, Glu, HR), nor for RPE. Endurance capacity, based on time to exhaustion on a treadmill, was improved when either mouth rinsing or ingesting a CHO solution, compared to PLA.

Introduction

Carbohydrate ingestion is a long-accepted nutritional strategy for enhancing long endurance performance. The American College of Sports Medicine recommends ingesting carbohydrate at a rate of 30–60 g h^{-1} for exercise durations of ~1 h or more (Sawka et al., 2007) to maintain blood glucose levels and sustain exercise performance.

Carbohydrate ingestion's potential to enhance the performance of shorter (≤1 h), intense (≥75% VO_{2max}) exercise is more controversial. Studies of carbohydrate ingestion's effect on this type of exercise have found mixed results, with a roughly equal number supporting improvement in the performance (Ball et al., 1995; Below et al., 1995; Jeukendrup et al., 1997; el-Sayed et al., 1997) versus those that do not (McConell et al., 2000; Backx et al., 2003; Desbrow et al., 2004). Given the adequacy of glycogen stores (Whitham & McKinney, 2007; Pottier et al., 2010) and the slow rate of exogenous carbohydrate absorption in the first hour of exercise (Below et al., 1995; el-Sayed et al., 1997; McConell et al., 2000; Carter et al., 2004b), it appears there is no metabolic need for exogenous carbohydrate to assist exercise of this duration. Thus, mechanisms behind an ergogenic effect of carbohydrate ingestion in these cases are likely based on a 'non-metabolic' or 'central effect'. Beyond carbohydrate's role as an energy substrate, the smell, taste and sight of food may act as positive reinforcements, playing a role in reward predictions, and thus may enhance motor performance (Jeukendrup & Chambers, 2010; Rollo & Williams, 2011).

In the last 10 years, carbohydrate (CHO) mouth rinsing has emerged as a sports nutrition strategy for endurance athletes. Carter et al. (2004a) published the first account of this technique, when they found mouth rinsing with a CHO solution yielded significant (~+3%) improvements in a cycling time-trial performance. The majority of subsequent studies have supported the efficacy of CHO mouth rinsing for increasing endurance performance. Specifically, the presence of carbohydrate in the mouth appears to activate an energy-signalling pathway capable of improving human performance. This pathway may form part of a system that governs and promotes feeding behaviour via the transduction of information specific to energetically useful nutrients (Sclafani, 2004). Turner et al. (2014) demonstrated that CHO in the mouth enhances task-specific activity in neural regions involved in motor control and perception.

Most of the previous investigations focused on the effects of CHO mouth rinsing in time trials such as an endurance performance, where subjects had to perform a determined workload or distance as fast as possible, with a known end-point. To our knowledge, only one study investigated the effects of mouth rinsing on time to exhaustion, finding a positive effect (Fares & Kayser, 2011). The majority of previous studies were also conducted using a cycle ergometer (Carter et al., 2004b; Chambers et al., 2009; Pottier et al., 2010). Only a few investigations (Rollo et al., 2008; Rollo et al., 2010; Rollo et al., 2011; Whitham & McKinney, 2007) have examined the effects of CHO mouth rinsing on running. All modelled performance on a running time trial, with two studies found an ergogenic effect (Rollo et al., 2008; Rollo et al., 2010) and two not found (Whitham & McKinney, 2007; Rollo et al., 2011).

The aim of this study was to observe the effects of mouth rinsing with a carbohydrate solution on endurance capacity, using a model of running time to exhaustion on a treadmill at an intensity of 85% VO_{2max}. We hypothesized that mouth rinsing could prolong the time to exhaustion, above the time compared to placebo, and equal the effect of CHO ingestion.

Methods

Subjects

Six endurance-trained men (age = 26 ± 6 years, weight = 73·9 ± 7·6 kg, height = 177 ± 6·8 cm, body fat 11·6 ± 4%, VO_{2max} 67·5 ± 5·8 ml kg min^{-1}), without apparent skeletal muscle injuries or cardiovascular disease, participated in this study. The subjects were advised to abstain from alcohol and caffeine for 24 h prior to the tests. All subjects read and signed the consent form, and all experimental procedures concerning human subjects were approved by the local institutional ethics board.

Experimental design

Subjects completed four visits to the laboratory, with all exercise bouts carried out on a treadmill (Master Super ATL, Inbramed®, São Paulo, SP, Brazil), conducted at the same time of the day and with an interval of 7 days. The laboratory temperature ranged between 19 and 21°C, and the relative humidity was between 50% and 60%. In the first visit, subjects performed a maximal incremental test to determine maximal oxygen consumption (VO_{2max}) and underwent anthropometric measurements, including a skinfold assessment estimating percentage fat (Jackson & Pollock, 1978). They were asked to record their food intake on the day prior to the first visit and to repeat that on the other 3 days prior to the next visits.

For visits II, III and IV, subjects arrived after an overnight fast and performed exercise at a treadmill speed corresponding to 85% VO_{2max}. Fifteen minutes prior to the exercise bout, subjects received a solution (mouth rinse – MR, placebo – PLA or ingestion – ING) where they had to rinse their mouths and then spit into a previously weighed receptacle, or to ingest the solution.

Every 15 min during the test, heart rate, perceived exertion (6–20 points on the Borg scale) and blood samples were collected for lactate and glucose analysis. Immediately after, the solutions (MR, PLA or ING) were administered. Expired gas was collected during the whole trial. The exercise bouts were interrupted when subjects reached volition fatigue and could no longer maintain the preset intensity.

The study was carried out in a counterbalanced, randomized double-blind design.

Visit I

Subjects completed an incremental step treadmill test for exhaustion to determine VO_{2max}. Ventilation and expired gases were continuously measured. The test consisted of 3-min stages, with equal length intervals, at a fixed gradient of 5·25%, with the additions of 0·9 km h^{-1}. The initial speed was set between 8 and 12 km h^{-1}, according to the subjects' discretion. To ensure that each individual achieved maximal exertion, at least three of the following four criteria were met by the subjects: (i) a plateau in VO_2 with increasing exercise intensity (<100 ml); (ii) a respiratory exchange ratio of at least 1·15; (iii) a maximal respiratory rate of at least 35 breaths min^{-1}; and (iv) a rating of perceived exertion of at least 18 units on the Borg scale.

Visits II–IV

Subjects arrived at the laboratory in the morning, after an overnight fast, having abstained from alcohol, caffeine and exercise in the previous 24 h. Given their food records, they were asked to empty the bladder and then were weighed. Rest samples of lactate (Lac), glucose (Glu), heart rate (HR) and expired gas were taken. Fifteen minutes prior to the test, subjects received a solution to rinse their mouths (MR, PLA) or to ingest (ING). Subjects performed an exercise in which treadmill velocity was adjusted corresponding to 85% of VO_{2max} at 1% gradient and remained constant. Not having access to any information about velocity and time passed, they were asked to cover as much distance as possible, and they were also told that each solution given to them was intended to improve the exercise performance. Every 15 min after start, HR, perceived exertion and blood samples were collected for lactate and glucose analysis, and immediately after, the solutions (MR, PLA or ING) were administered. Expired gas was collected during the whole trial (Vacumed® Mini Vista-CPX, Ventura, CA, USA). At the end of the trial, subjects were weighed again. All trials were conducted with a fan placed in front of the treadmill, which provided air circulation and cooling for the participants.

Solutions and mouth-rinsing protocol

The carbohydrate mouth rinse (MR) consisted of an 8% dextrose solution (Dextrose Neo Nutri®, São Paulo, SP, Brazil). Placebo (PLA) was a commercially available non-caloric sweetener, not different from MR in flavour and appearance. Subjects received 25 ml of MR or PLA and rinsed the fluid around the mouth for 10 s and then spit it out into a pre-weighed bowl. Individuals received the solutions 15 min prior to the test and every 15 min during it.

The ingested solution (ING) was composed by a 6% dextrose carbohydrate (Dextrose Neo Nutri®). Subjects received a 2 ml kg^{-1} (~150 ml) 15 min before the test and every 15 min during it.

Blood glucose and lactate concentration

To determine the blood glucose, 10-μl blood samples were collected from a fingertip and were immediately analysed by the photometric method of reflection (Accu-Chek Active; Roche®, Basel, Switzerland). For blood lactate determinations, 25-μl samples were collected from the ear lobe and were immediately analysed by the electro-enzymatic method (1500 SPORT Lactate Analyser, YSI® Inc., Yellow Springs, OH, USA).

Statistical analysis

To determine the sample size, we used previously reported differences in heart rate and perceived exertion during an exercise session (Rollo *et al.*, 2010). We calculated that six subjects were needed to detect this association with a two-tailed $\alpha = 0{\cdot}05$ and $1\text{-}b = 0{\cdot}85$ (Dupont & Plummer, 1990).

Values are presented as means ± SD. Total distance and time completed were analysed by one-way ANOVA with repeated measures. To analyse lactate, glucose, heart rate, RER and VO_2, a two-way ANOVA with repeated measures was used, with Geisser–Greenhouse correction index, followed by Tukey's *post hoc* test. Borg data were analysed by the Friedman test. The significance level was set at ≤0·05.

Results

Time to exhaustion and total distance covered

A significant effect was found between treatments for time and distance ($F = 5{\cdot}510$, $P = 0{\cdot}027$; $F = 4{\cdot}902$, $P = 0{\cdot}038$, respectively), with time to exhaustion being greater in MR and ING trials than PLA. Values are presented in Table 1. For distance, MR and PLA trended to significance ($P = 0{\cdot}054$). Individual data for time to exhaustion are displayed in Fig. 1.

Table 1 Time to exhaustion and total distance (mean ± SD).

	MR	ING	PLA
Time (s)	2625 ± 804	2583 ± 686	1935 ± 809
Distance (m)	9855 ± 4119	9685 ± 3512[a]	7295 ± 3727

[a]Significant difference from PLA ($P<0{\cdot}05$).

Metabolic variables

Heart rate, lactate and glucose are shown in Table 2. Statistical analyses revealed no significant difference between treatments and no interaction for heart rate ($F = 0{\cdot}102$, $P = 0{\cdot}843$; $F = 3{\cdot}286$, $P = 0{\cdot}067$, respectively), lactate ($F = 2{\cdot}384$, $P = 0{\cdot}149$; $F = 1{\cdot}028$, $P = 0{\cdot}390$, respectively) and glucose ($F = 3{\cdot}324$, $P = 0{\cdot}122$; $F = 1{\cdot}073$, $P = 0{\cdot}374$). Perceived exertion data are shown in Table 3. There was no significant difference between treatments ($\chi^2 = 1{\cdot}077$).

Solution

When asked which solutions contained CHO or not, subjects were not able to distinguish between them, reinforcing the fact that they were flavoured and had the same taste.

Figure 2 shows the VO_2 at each 10% of the total time. There was no significant difference between treatments ($F = 1{\cdot}922$, $P = 0{\cdot}197$), being the higher values in the PLA trial. Significance was found for percentage of the test ($F = 4{\cdot}539$, $P = 0{\cdot}025$).

Figure 3 shows the RER at each 10% of the total time. A significant difference ($F = 8{\cdot}962$, $P = 0{\cdot}020$) was found between PLA and MR and PLA and ING, being the lower values in the PLA trial. Difference was also found in the consumption percentage during the whole trial ($F = 4{\cdot}882$, $P = 0{\cdot}022$).

Discussion

The main finding of our study is that subjects were able to run ~29% longer with both ingestion and mouth rinsing, when compared to placebo. As a result, greater distance was covered. This finding supports our hypothesis and corroborates other studies that found performance was improved by mouth rinsing (Chambers *et al.*, 2009; Rollo *et al.*, 2010; Rollo *et al.*, 2011; Fares & Kayser, 2011).

The likely explanation behind these results is a central mechanism. As previous studies from Chambers *et al.* (2009) and Turner *et al.* (2014) have found, CNS activity was altered by the presence of carbohydrates in the oral cavity, independent of ingestion. Specifically, Chambers *et al.* (2009), using

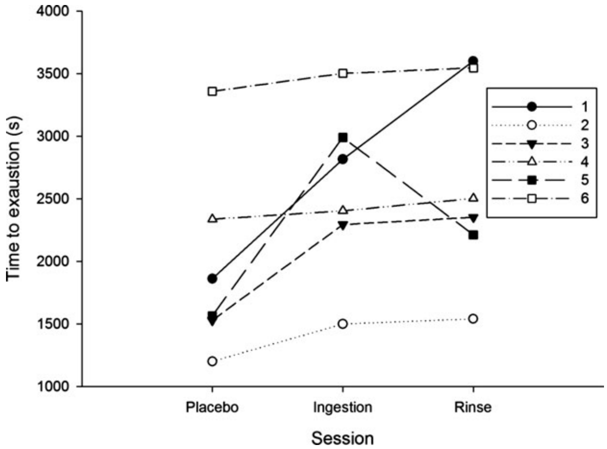

Figure 1 Individual performances in run time to exhaustion in subjects ($n = 6$) during placebo, CHO ingestion and CHO mouth-rinsing conditions.

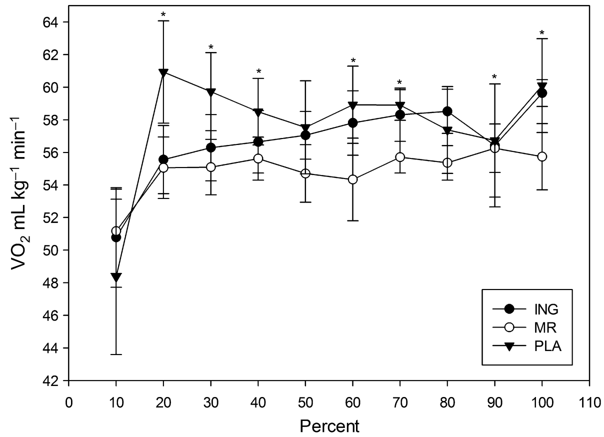

Figure 2 Mean (±SD) of VO_2 at each 10% of the total time. *Significant difference from 10% ($P<0·05$).

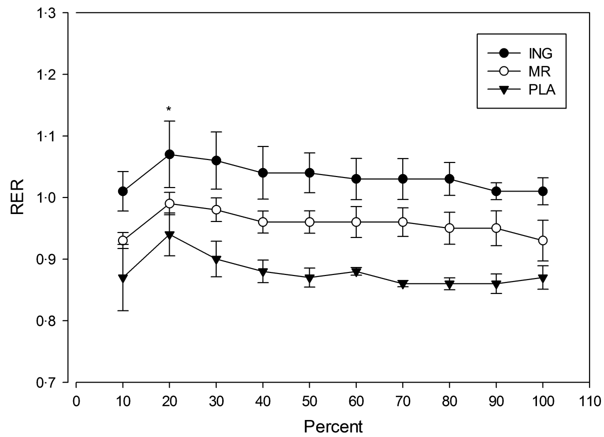

Figure 3 Mean (±SD) of RER at each 10% of the total time. *Significant difference from 10% ($P<0·05$).

Table 2 Heart rate, lactate and glucose (mean ± SD).

	Rest	15 min	30 min
HR (bpm)			
MR	63 ± 9[a]	179 ± 9[a]	185 ± 10[a]
ING	64 ± 10[a]	176 ± 11[a]	184 ± 12[a]
PLA	62 ± 11[a]	172 ± 12[a]	190 ± 9[a]
Lac (mmol l^{-1})			
MR	0·88 ± 0·21[a]	5·00 ± 2·13[a]	5·71 ± 2·88[b]
ING	1·04 ± 0·33[a]	4·96 ± 1·90[a]	5·58 ± 1·81[b]
PLA	0·79 ± 0·25[a]	6·06 ± 2·07[a]	6·29 ± 1·77[b]
Glu (mmol l^{-1})			
MR	4·8 ± 0·6[a]	7·05 ± 2·1[c]	8·05 ± 1·4[d]
ING	5 ± 0·3[a]	6·7 ± 1·7[c]	7·4 ± 1·5[d]
PLA	5 ± 0·5[a]	6·05 ± 1·6[c]	7·05 ± 1·6[d]

No difference between treatments was found, neither the interactions.
[a]Significant difference from others.
[b]Significant difference from rest and 15 min.
[c]Significant difference from rest and 45 min.
[d]Significant difference from rest.

Table 3 Perceived exertion (median).

MR	6[a]	13[a]	15[a]
ING	6[a]	13[a]	15[a]
PLA	6[a]	14[a]	16[a]

No difference between treatments.
[a]Significant difference from others.

functional magnetic resonance imaging (fMRI), observed that CHO could activate the dorsolateral prefrontal cortex and striatum, which are related to motor drive, reward modulation and behavioural responses, stimulated by oral stimuli (Jeukendrup & Chambers, 2010). Turner *et al.* (2014), also using fMRI, found CHO mouth rinsing after 8 h of fasting augmented the activity in brain regions involved in motor control, visual perception and the processing of affective, taste stimuli. Integration of forthcoming energy may prime the sensorimotor cortex, resulting in increased motor output and enhanced performance of physical activity (Chambers *et al.*, 2009; Rollo *et al.*, 2010, Rollo *et al.*, 2011).

In addition, Turner *et al.* (2014) found that regions activated independently of sweet taste were identified in a number of non-movement areas including the right intercalcarine and temporal occipital fusiform cortices, the right lingual gyrus and the bilateral superior frontal gyri. The intercalcarine and temporal occipital fusiform cortices and the lingual gyrus may be involved in recognition of the visual cue prompting performance of the task.

This was confirmed by Gant *et al.* (2010), who found that corticomotor output was facilitated, both in fatigued and rested muscles when the subjects' mouth was rinsed with CHO. It was speculated that mouth receptors activate facial, glossopharyngeal and vagus nerves, afferent pathways which project to the solitaries nucleus, where they might have an opportunity to influence descending motor activity (Yates & Stocker, 1998).

Distinct activation of brain areas effectively begins in the mouth, with the first detection of the taste stimulus. The taste stimulus initiates with the activation of G-protein-coupled receptors (T1R2 and T1R3) on the tongue. The next step in this process depends on the characteristics of the sweet compound. A saccharide compound will activate adenylate cyclase, synthesizing cAMP, which leads to the activation of the protein kinase A (Schiffman, 1997; Jeukendrup & Chambers, 2010; Rollo *et al.*, 2011). A non-saccharide compound (artificial sweetener) in the mouth promotes the G-protein that activates inositol-triphosphate, synthesized by phospholipase A, which binds to receptors in the endoplasmic reticulum, triggering the mobilization of calcium (Schiffman, 1997; Simon *et al.*, 2006). These differing mechanisms could explain the result observed in this study between CHO and placebo treatments, where distinct pathways are activated depending on the stimulus. An improvement of 29% was registered in the CHO MR treatment, compared to placebo. The concentration and composition of the sweet solution could determine the intensity of the stimulus. In this study, an 8% dextrose was used. The majority of other studies have used a commercial sports drink (CHO and electrolytes), so it is still not known whether the other compounds influence the taste stimulus and responses.

RER was the only variable, other than performance, that differed between PLA and ING or MR. The lower RER observed in PLA vs. either MR or ING contradicts the previous findings of Rollo *et al.* (2010) who found equal RER in CHO or PLA in a running time trial. We attribute this difference to the measurement times, as RER was averaged over the duration of the run, and the data shown in Fig. 1 represent percentages of a shorter total time frame and less work in PLA. Subjects in MR and ING were able to work maintaining the exercise intensity for a longer duration and thus oxidized a greater proportion of CHO during the run. This was true even in MR, when subjects were not actually consuming a higher level of CHO.

The exercise model employed in the present study consisted of a run to exhaustion at 85% VO_{2max}. This marks the highest relative intensity run that has been documented to be enhanced through CHO mouth rinsing. Previous studies of the effect of CHO mouth rinsing on running have uniformly employed performance tests consisting of time trials, allowing their subjects to self-select a speed to cover as much distance as possible (Whitham & McKinney, 2007; Rollo *et al.*, 2008; Rollo *et al.*, 2010; Rollo *et al.*, 2011). Two of these studies found no enhancement of performance after CHO mouth rinsing (Whitham & McKinney, 2007; Rollo *et al.*, 2011). Gas exchange was measured during the performance trial in one of these studies, with an intensity of 74–75% VO_{2max} (Rollo *et al.*, 2011). The two studies that did find CHO mouth rinsing enhanced the running performance used also used the self-selected pace (Rollo *et al.*, 2008; Rollo *et al.*, 2010). Of these, one measured VO2 during the run and found an average intensity of 77–78% VO_{2max} (Rollo *et al.*, 2010). The present study presented a unique challenge, in that the pace was of equal intensity throughout the duration of the exercise. The enhancement of performance at a higher than previously recorded relative exercise intensity presents a novel finding of the present study. Further, given that faster runners may maintain a pace ~75% VO2max for the duration of a marathon (Maughan & Leiper, 1993), the higher intensity employed in the present study may present the practical advantage of better matching the intensity of competitive endurance events <1 h in duration.

The model of a run to exhaustion, used in the present study, as compared to the time-trial protocols used in previous research does present some limitations, though. Time to exhaustion tests are more susceptible to variation than time-trial tests (Jeukendrup *et al.*, 1996; Hopkins *et al.*, 2001; Laursen *et al.*, 2007). The large (+29%) performance improvement evoked by MR in the present study greatly exceeds previously reported margins (+1·5–3%) of time-trial running performance enhancement attributed to CHO mouth rinsing. The closest documented elevation in performance following CHO mouth rinsing is an +11·59% increase in cycling performance (Fares & Kayser, 2011), which was also a time to exhaustion model. Thus, it appears that the time to exhaustion model lends itself to large performance differences. Rollo *et al.* (2010) remarked that effect sizes from CHO mouth rinsing, as measured by time-trial performance, are small and may easily be obscured by factors such as manual selection of speed or pre-exercise meals. The large magnitude improvement seen following mouth rinsing in the present study is contradictory to that assessment, but likely an artefact of the time to exhaustion model we employed.

Mouth rinsing with a carbohydrate solution for 10 s, every 15 min of exercise, improved time to exhaustion on a treadmill at 85% VO_{2max}, compared to placebo. Subjects' performances were similar with mouth rinsing to carbohydrate ingestion. Additionally, an 8% CHO mouth rinse solution can be used to provide an ergogenic effect. The mechanisms behind this benefit likely include the activation of areas in the brain related to reward and behavioural responses. However, subjects' perception of effort during the exercise was not affected. More research is needed to elucidate details for CHO mouth-rinsing strategies, such as optimal frequency and time of mouth rinsing, a comparison between different concentrations of CHO, as well quantifying the influence of the CNS fatigue.

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Conflict of interest

The authors have no conflict of interests.

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