

No Dose Response Effect of Carbohydrate Mouth Rinse on Cycling Time-Trial Performance

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The aim of the current study was to investigate the influence of mouth rinsing carbohydrate at increasing concentrations on ~1 hr cycle time trial performance. Eleven male cyclists completed three experimental trials, following an overnight fast. Cyclists performed a ~1 hr time trial on a cycle ergometer, while rinsing their mouth for 5 s with either a 7% maltodextrin solution (CHO), 14% CHO or a taste-matched placebo (PLA) after every 12.5% of the set amount of work. Heart rate was recorded every 12.5% of the time trial, while RPE and GI comfort were determined every 25% of the time trial. The mouth rinse protocol influenced the time to complete the time trial ($p < .001$), with cyclists completing the time trial faster during 7% CHO (57.3 ± 4.5 min; $p = .004$) and 14% CHO (57.4 ± 4.1 min; $p = .007$), compared with PLA (59.5 ± 4.9 min). There was no difference between the two carbohydrate trials ($p = .737$). There was a main effect of time ($P < 0.001$) for both heart rate and RPE, but no main effect of trial ($p = .107$ and $p = .849$, respectively). Scores for GI comfort ranged from 0–2 during trials, indicating very little GI discomfort during exercise. In conclusion, mouth rinsing and expectorating a 7% maltodextrin solution, for 5 s routinely during exercise was associated with improved cycle time trial performance approximately 1 h in duration. Increasing the carbohydrate concentration of the rinsed solution from 7% to 14% resulted in no further performance improvement.

Keywords: Maltodextrin, endurance exercise performance, oral cavity

The ingestion of carbohydrate during prolonged exercise has been reported to delay the onset of fatigue and enhance endurance capacity (Coggan & Coyle, 1987; Tsintzas & Williams, 1998). Carbohydrate exerts its effect by maintaining blood glucose concentrations and providing an exogenous substrate for metabolism in the later stages of exercise (Coyle et al., 1986; Jeukendrup, 2004; Neuffer et al., 1987). Furthermore, carbohydrate ingestion may result in a more gradual depletion of endogenous glycogen stores (Tsintzas et al., 1996). However, improvements in endurance capacity have also been reported without evidence of glycogen sparing (Coyle et al., 1986).

During shorter duration exercise (≤1 hr), endogenous stores of carbohydrate are unlikely to be limiting. Therefore, there is no clear metabolic rationale for ingesting carbohydrate. Nevertheless, some studies (Below et al., 1995; Carter et al., 2003; Jeukendrup et al., 1997; Neuffer et al., 1987; Rollo & Williams 2009) but not all (Anantaraman et al., 1995; Desbrow et al., 2004; Widrick

et al., 1993) have shown a performance benefit of ingesting carbohydrate during short-duration, high-intensity exercise such as time trials of ≤1 hr duration.

Since the first study by Carter et al. (2004), several studies have shown that mouth rinsing a carbohydrate solution without ingestion is associated with similar improvements in self-selected endurance (~1 hr) performance as observed when carbohydrate is ingested (Chambers et al., 2009; Lane et al., 2013; Rollo et al., 2010). The mechanism(s) by which mouth rinsing with a carbohydrate solution influences self-selected power output and thus endurance performance are unknown. The expectoration of carbohydrate solution prevents substrate delivery to the systemic circulation, and as such it has been speculated that carbohydrate recognition in the oral cavity evokes a central effect during exercise (Jeukendrup et al., 2013; Rollo & Williams, 2011). The first study to draw the association between a central response and exercise performance was completed by Chambers et al. (2009). The authors reported that mouth rinsing with both a sweet and a nonsweet carbohydrate solution (6.4% glucose and maltodextrin, respectively) was associated with improved 1 hr cycling time trial performance. In addition, mouth rinsing with an 18% maltodextrin solution was reported to activate regions of the brain associated with reward (Chambers et al., 2009; Rolls, 2007). Interestingly, the activation of reward centers in the brain have been reported to be sensitive to the caloric value of the maltodextrin ingested (Smeets et al., 2005; van Rijn

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et al., 2015). Thus, if the concentration of carbohydrate rinsed in the mouth activates a central reward response in a dose-dependent manner, there may be a subsequent dose-response associated with improvements in exercise performance.

To date, three studies have investigated the dose-response relationship between carbohydrate concentration and endurance performance. The first reported that 90 min running performance was improved with a 6% carbohydrate-electrolyte solution compared with a placebo with no further improvement when rinsing with a 12% solution (Wright & Davison, 2013). More recently, two studies have reported that increasing the concentration of maltodextrin in the rinsed solution has no effect on endurance cycling performance. Specifically, Ispoglou et al. (2015) reported that when seven trained male cyclists rinsed with 0, 4, 6, and 8% carbohydrate solutions, there were no performance differences between any trials for a 1 hr time trial performance. Similar findings were reported when nine recreationally active males mouth rinsed with a 0, 3, 6 and 12% carbohydrate solutions during a 20 km time trial (Kulaksiz et al., 2016). However, the use of untrained/ inexperienced cyclists (Kulaksiz et al., 2016; Wright & Davison, 2013), extremely large performance improvements (up to 18.6% improvement between trials; Wright & Davison, 2013) and short periods of fasting before the exercise test (only 3 hr post prandial; Ispoglou et al., 2015) are all limitations in study design for these investigations.

Therefore, the purpose of the current study was to investigate if a dose response relationship exists between the concentration of a carbohydrate mouth rinse solution and endurance cycling performance, in endurance trained cyclists. Our hypothesis was that greater carbohydrate concentrations in the rinsed solution would be associated with greater improvements in cycle time trial performance.

Methods

Subjects

After institutional ethical approval, 12 competitive male cyclists completed a health screen questionnaire and provided written consent, but the data from one subject was omitted as it later transpired he had not adequately controlled physical activity before trials. All subjects were cyclists accustomed to training and/or competitions lasting at least 1 hr. The physical characteristics (mean \pm SD) of the subjects were age: 40 ± 8 years; weight: 77.6 ± 7 kg; height: 1.79 ± 0.07 m; $\dot{V}O_{2peak}$: 58 ± 11 ml·kg⁻¹·min⁻¹.

Experimental Design

Subjects completed two preliminary trials, followed by three experimental trials that were administered in a randomized, double blinded study design. In all trials, exercise was completed on the same electrically braked cycle ergometer (Lode Excalibur, Groningen, Netherlands).

Preliminary Sessions

During the first visit, peak oxygen uptake ($\dot{V}O_{2peak}$) and peak power output (W_{peak}) were determined using an incremental exercise test. Workload was initially set at 95 W, and increased by 35 W every 3 min, until exhaustion. One minute expired air samples were collected into a Douglas bag at the end of each stage and at exhaustion. The preferred seat height and handle bar position for each subject was noted and was repeated in subsequent visits. During the second preliminary session, subjects completed the full time trial used in the experimental trials to habituate them to the protocol. During the familiarization trial, subjects rinsed their mouth with the placebo solution used in the experimental trials.

Experimental Trials

Experimental trials took place in the morning following an overnight fast at a time standardized for each subject. Trials were separated by at least one week. On the day preceding the first experimental trial, subjects recorded their dietary intake and any habitual low intensity physical activity in a diary, replicating these patterns of diet and activity before subsequent trials. Adherence to this was checked verbally before each trial. During this time, subjects abstained from alcohol intake and any strenuous exercise.

Upon arrival at the laboratory, subjects provided a urine sample, which was analyzed for osmolality using a handheld refractometer (Atago PAL-1, Japan) and attached a heart rate monitor (Polar, Kempele, Finland). Following a brief warm-up (5 min at 40% W_{peak} , 5 min at 60% W_{peak} and 3 min of self-selected stretching), subjects completed a simulated cycling time trial, during which they were required to complete a set amount of work (844 ± 63 kJ) as fast as possible. The total amount of work for completion was standardized for each subject and was equivalent to cycling for 1 hr at 75% W_{peak} . This was calculated according to the following formula (Carter et al., 2004):

$$\text{Total work} = 0.75 \times W_{peak} \times 3600 \text{ s}$$

The ergometer was set in linear mode so that 75% W_{max} was obtained when pedalling at the subject's preferred cadence, determined during the $\dot{V}O_{2peak}$ test. Subjects received no performance-related information (exercise time, heart rate or cadence) other than the accumulated work performed displayed on a computer screen and no encouragement was provided to subjects during trials. At the start and every 12.5% of the time trial thereafter, subjects rinsed and expectorated 25 ml of one of the three solutions. Solutions were a carbohydrate-free placebo solution (PLA) and two carbohydrate solutions made up using maltodextrin to provide a final weight/volume concentration of 7% (7% CHO) or 14% (14% CHO) maltodextrin. Solutions were taste-matched and made up using 200 ml/l single concentrate no-added sugar orange and pineapple flavor squash (Robinsons Soft Drinks Ltd,

UK). Each 25 ml was delivered via a plastic syringe and subjects rinsed the solution around their mouth for 5 s before expectorating into a preweighed plastic container. The syringe and plastic container were weighed before and after each mouth rinse using an electronic balance (Argos, Stafford, UK) to determine the volume of fluid rinsed and expectorated, to determine whether any fluid was unintentionally ingested. The temperature of the rinse solution was measured at the start of each trial using a mercury in glass thermometer. Heart rate was recorded every 12.5% of the time trial, while RPE and GI comfort were determined every 25% of the time trial. RPE was determined using the 6–20 point Borg scale (Borg, 1982), and GI comfort was assessed using a 12-point scale, with anchors provided at 0 *neutral*, 4 *uncomfortable*, 8 *very uncomfortable*, and 12 *painful*. Time to complete each 12.5%, as well as time to complete the entire time trial was recorded.

On completion of the final trial, subjects were asked if they had been able to distinguish between the solutions rinsed during each trial; if so, they were asked to identify which solution they thought was which.

Statistical Analyses

Data are reported as mean and standard deviation (mean \pm SD), unless otherwise stated. All data were analyzed using SPSS software package (version 21.0; SPSS Inc, Chicago, IL, USA). A Shapiro-Wilk test was used to test for normality of distribution. Overall time trial performance, trial order effect, body mass, urine osmolality, environmental conditions, a solution temperature and expectorated volume were all analyzed using a one way repeated measures analysis of variance (ANOVA). A two-way repeated-measures ANOVA (trial \times time) was used to examine performance for each 12.5% of the time trial, heart rate, RPE and GI comfort. Post hoc paired *t* tests or Wilcoxon Signed Rank tests were used as appropriate and the Holm-Bonferroni adjustment was used to control the family-wise error rate. Statistical significance was accepted when $p < .05$.

Results

Time Trial

There was no trial order effect for time to complete the time trial, with performance times of 58.1 ± 4.5 min, 57.8 ± 4.4 min and 58.2 ± 5.0 min on the first, second and third trials, respectively ($p = .761$). The mouth rinse protocol influenced the time to complete the time trial (Figure 1; $p < .001$), with subjects completing the time trial faster during 7% CHO (57.3 ± 4.5 min; $p = .004$) and 14% CHO (57.4 ± 4.1 min; $p = .007$), compared with PLA (59.5 ± 4.9 min), with no difference between the two CHO trials ($p = .737$). While there were main effects of time ($P < 0.001$) and trial ($P < 0.001$) for time to complete each 12.5% of the time trial, there was no interaction effect ($p = .221$), indicating similar pacing

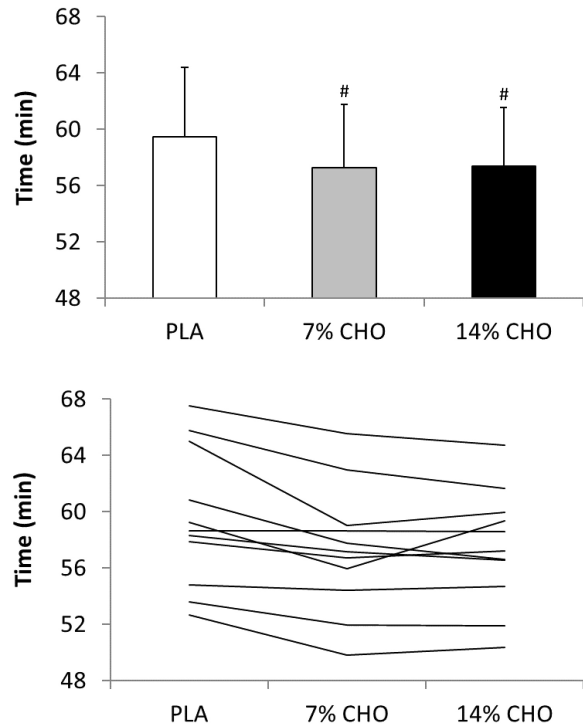


Figure 1 — Time to complete the time trial during PLA, 7% CHO and 14% CHO. Top panel displays mean \pm SD values. Bottom panel displays individual subject data. # denotes a significant difference from PLA trial.

between trials (Figure 2). There was no difference between trials for environmental temperature ($p = .550$) or relative humidity ($p = .345$), and across all trials these variables were 21.6 ± 1.1 °C and $50.3 \pm 4.4\%$, respectively.

Pretrial Measures

There was no difference for pretrial body mass (PLA: 78.6 ± 6.2 kg; 7% CHO: 78.6 ± 6.4 kg; 14% CHO: 78.7 ± 6.2 kg; $p = .783$), urine osmolality (PLA: 339 ± 187 mOsm·kg⁻¹; 7% CHO: 329 ± 186 mOsm·kg⁻¹; 14% CHO: 365 ± 206 mOsm·kg⁻¹; $p = .788$) or resting heart rate (PLA: 67 ± 7 beat·min⁻¹; 7% CHO: 66 ± 7 beat·min⁻¹; 14% CHO: 66 ± 6 beat·min⁻¹; $p = .830$).

Heart Rate, RPE and GI Comfort

There was a main effect of time ($P < 0.001$), but no main trial ($p = .107$) or interaction effect ($p = .391$) for heart rate (Table 1). There was also a main effect of time ($p < .001$) but no main trial ($p = .849$) or interaction effect ($p = .787$) for RPE (Table 1). There was no time ($p = .123$), trial ($p = .422$) or interaction ($p = .864$) effect for GI comfort. Scores for GI comfort ranged from 0–2 during trials, indicating very little GI discomfort was present during exercise (Table 1).

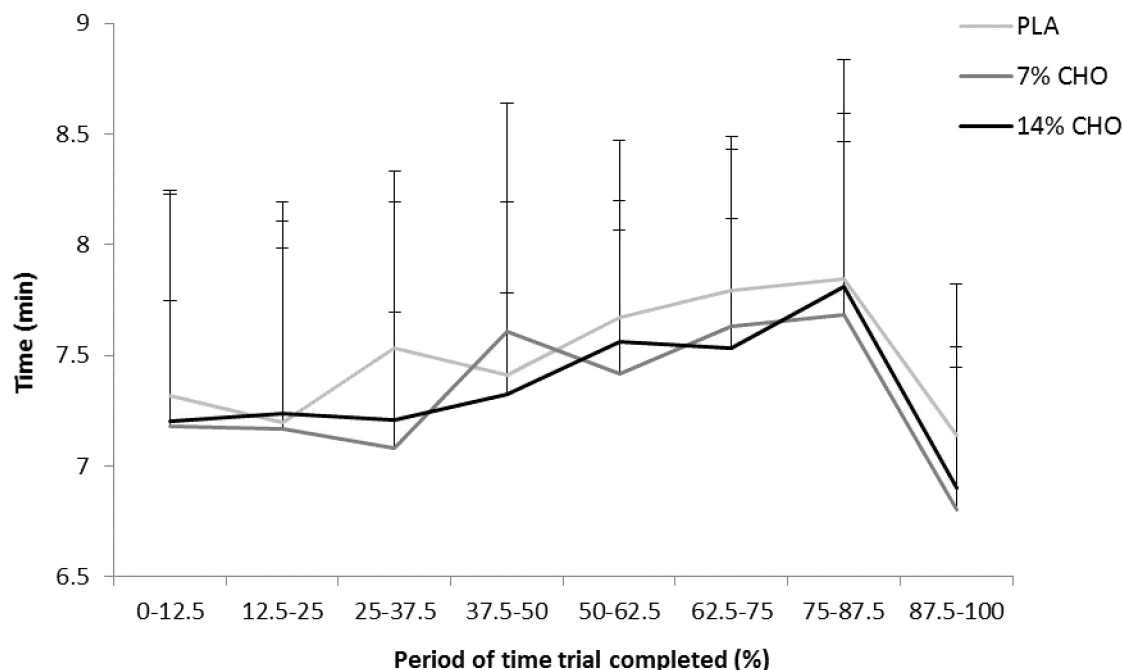


Figure 2 — Time to complete each 12.5% segment of the time trial in the PLA, 7% CHO and 14% CHO trials. Data are expressed as mean \pm SD. There was a main effect of time ($p < .001$) and trial ($p < .001$), but no interaction effect.

Table 1 Heart Rate (beats·min⁻¹), Rating of Perceived Exertion (6–20) and Gastrointestinal Comfort (0–12) every 25% of Time Trial

	25%	50%	75%	100%
Heart rate (beats·min ⁻¹)				
PLA	139 \pm 14	144 \pm 15	147 \pm 18	157 \pm 18
7% CHO	140 \pm 15	146 \pm 16	148 \pm 16	159 \pm 17
14% CHO	136 \pm 14	141 \pm 16	146 \pm 17	157 \pm 18
RPE (6–20)				
PLA	14 \pm 2	16 \pm 1	16 \pm 2	18 \pm 2
7% CHO	13 \pm 2	15 \pm 1	16 \pm 1	18 \pm 2
14% CHO	14 \pm 1	16 \pm 1	16 \pm 2	18 \pm 2
Gastrointestinal comfort (0–12)				
PLA	0 \pm 0	0 \pm 1	1 \pm 1	1 \pm 1
7% CHO	0 \pm 1	0 \pm 1	1 \pm 1	1 \pm 1
14% CHO	1 \pm 1	1 \pm 1	1 \pm 1	1 \pm 1

Note. Data are Expressed as Mean \pm SD.

Rinse Solution Temperature, Expectorate Volume and Solution Detection

There was no difference between trials in the temperature of the rinse solution (PLA: 13.4 \pm 4.2 °C; 7%: 12.2 \pm 2.3 °C; 14%: 13.7 \pm 2.8 °C; $p = .625$) or the volume of rinse solution expectorated (PLA: 24.5 \pm 1.1 ml; 7%: 24.9 \pm 1.4 ml; 14%: 24.9 \pm 1.3 ml; $p = .627$). Seven of the eleven subjects failed to distinguish between the rinse solutions. The

remaining four correctly differentiated the placebo from the two carbohydrate solutions, but only one correctly distinguished between the 7% and 14% concentrations.

Discussion

The main finding of this study was that no further improvement in ~1 hr cycle time trial performance was observed when

the carbohydrate concentration of the rinsed solution was increased from 7% to 14%, compared with a taste-matched placebo. Thus, we reject our hypothesis that there would be a dose response effect of carbohydrate concentration on endurance performance.

The findings of this study support those of Wright and Davison (2013), who showed that there was no additional performance benefit of mouth rinsing a 12% carbohydrate solution over that observed between a 6% solution and a placebo. Wright and Davison (2013) recruited 7 males who were instructed to cover as much distance as possible in a 90 min treadmill test, rinsing their mouth at 0, 15, 30 and 45 min of the protocol. However, the participants only covered relatively short distances (Placebo 13.9 ± 1.7 km; 6% CHO 14.6 ± 1.7 km; 12% CHO 14.9 ± 1.6 km), suggesting the population were not well trained, despite being reported to be in competitive sports teams. Furthermore, extremely large performance improvements seen in some trials (up to 18.6%) far exceed the typical improvements seen in performance studies, calling into question either the standardization of pretrial conditions or the variability of the protocol employed. The present study used the same cycling time trial protocol as the original mouth rinse studies (Carter et al., 2004; Chambers et al., 2009), which has a reported variability of 3.35% in trained cyclists (Jeukendrup et al., 1996). As such, we have confidence that the observed differences between performance trials in the current study were a consequence of the carbohydrate rinse intervention.

In contrast to the current study and that of Wright and Davison (2013), two other dose-response studies have reported no effect of carbohydrate mouth rinse on endurance performance. Ispoglou et al. (2015) used the same performance time trial and rinse regimen as the current study and showed no effect of mouth rinsing with 4, 6, or 8% carbohydrate (89% sucrose; 11% glucose) solutions compared with a 0% placebo. However, the cyclists had ingested a meal 3 hr before exercise and were therefore not in a fasted state during the trials (Ispoglou et al., 2015). Although Lane et al. (2013) reported that mouth rinsing a 10% maltodextrin solution for 10 s improved 60 min cycle time trial performance in both fed and fasted conditions, the magnitude of improvement was greater in the fasted condition. Furthermore, Beelen and colleagues (2009) have shown that 1 hr cycling time trial performance is not influenced by mouth rinsing a 6.4% maltodextrin solution compared with water when cyclists ingest ~ 2.5 g carbohydrate·kgBM⁻¹ two hours before the test. Indeed, imaging studies have shown that the central activation of reward centers in the brain in response to carbohydrate feedings are diminished under conditions of satiety in comparison with hunger (Haase et al., 2009). Thus, although providing a carbohydrate rich meal before exercise may have some ecological validity, it is not favorable to detecting small performance benefits that carbohydrate mouth rinse may provide (Rollo et al., 2010).

More recently Kulaksiz et al. (2016) reported that 20 km cycle time trial performance was not influenced by mouth rinsing either 3%, 6% or 12% maltodextrin solu-

tions compared with a 0% placebo. Direct comparisons to the current study are difficult due to differences in protocol used and training status of the participants. Kulaksiz et al. (2016) recognized that the $\dot{V}O_{2\max}$ values of their participants were lower (~ 21 – 42%) than those recruited to previous mouth rinse studies (Carter et al., 2004; Chambers et al., 2009; Lane et al., 2013). Although Kulaksiz et al. (2016) used a validated protocol (Zavorsky et al., 2007), it has been shown that top performers (i.e., those cyclists that maintained a higher average power output over 20 km) had a coefficient of variation that was four times lower compared with the bottom performers (1.2% and 4.8%, respectively; Zavorsky et al., 2007). The mean power output in the study by Kulaksiz et al. (2016) was lower (~ 200 Watts) than the bottom cyclists in the validation study (~ 260 Watts), suggesting that the population recruited may not have been appropriate for the test used.

A limitation of the current study was that a no-rinse control trial was not included in the study design and Gam et al. (2013) have suggested that mouth rinsing *per se* during exercise maybe detrimental to performance (Gam et al., 2013). Nevertheless, the results of the current study are consistent with previous cycling studies reporting that routinely mouth rinsing and expectorating a carbohydrate solution during exercise increases self-selected power outputs during cycling time trials of approximately 1 hr in duration (Carter et al., 2004; Chambers et al., 2009; Lane et al., 2013; Pottier et al., 2008). Indeed, Pottier et al. (2008) showed that mouth rinsing and expectorating a carbohydrate solution had a greater performance benefit compared with ingesting (14 ml·kgBM·h⁻¹) the same solution without rinsing (3.7% vs 1.4%, respectively). Despite the oral cavity being exposed to carbohydrate in both trials, the discrepancy in performance was attributed to the short oral transit time when the carbohydrate-electrolyte solution was ingested (Pottier et al., 2008). To support this hypothesis, Sinclair et al. (2014) reported that 30 min cycle time-trial performance was improved by doubling the duration (5 s to 10 s) that a 6.4% maltodextrin solution was rinsed in the mouth. Whether an increased duration of rinse would have influenced the results in the current study is unknown, however prolonged rinsing may interfere with participants breathing patterns during high intensity exercise and therefore potentially become a confounding factor (Gam et al., 2013). Regardless, while there may be a dose response when doubling the duration of carbohydrate exposure to the oral cavity (Sinclair et al., 2014), the results of the current study suggest that this dose response does not extend to doubling the concentration of carbohydrate in the rinsed solution (Figure 1).

The mechanism(s) by which endurance performance is improved by mouth rinsing and expectorating carbohydrate solutions remain unknown. Previous studies have speculated that the presence of carbohydrate exerts a central response during exercise and manifests as improved performance (Carter et al., 2004; Chambers et al., 2009). Observations from imaging studies at rest have reported that regions in the brain, specifically the insula/frontal

operculum, orbitofrontal cortex and striatum, are activated when carbohydrate enters the oral cavity, independent of sweetness (Chambers et al., 2009). These regions of the brain activated by carbohydrate in the oral cavity are believed to be associated with reward and sensory perception (Turner et al., 2014) which may influence behavioral responses (Kringelbach et al., 2004). Receptors (T1R2 and T1R3) within the mouth are likely to signal that carbohydrates are rewarding due to both palatability and caloric value (Berthoud 2003; Smeets et al., 2005; van Rijn et al., 2015). Thus, speculatively, mouth rinsing a carbohydrate solution provides the promise of exogenous energy to the brain when liver and muscle glycogen stores are depleted. However, increasing the energy content of the carbohydrate rinse solution that the oral cavity is exposed to (i.e., from 7% to 14% in the current study) had no measurable impact on performance or perception of effort (Figure 1; Table 1).

Carbohydrate mouth rinse has been reported to increase the activation of cortico-motor pathways and voluntary force production in both fresh and fatigued muscle involved in elbow flexion (Gant et al., 2010). Consistent with endurance performance studies, the neuromuscular response to mouth rinsing carbohydrate has been reported to be more sensitive when participants have lower endogenous carbohydrate stores (Ataide-Silva et al., 2016). Furthermore, mouth rinsing a 6.4% maltodextrin solution was shown to maintain electromyographic activity and enhance whole body, moderate intensity exercise performance (Bastos-Silva et al., 2016). To this end, the mechanism by which carbohydrate mouth rinse influences exercise performance may not be solely a consequence of promised exogenous energy delivery to the brain, but may also be directly evoking central motor responses.

In conclusion, mouth rinsing and expectorating a 7% maltodextrin solution, for 5 s routinely during exercise was associated with improved ~1 hr cycling time trial performance. No dose-response relationship was observed. Therefore, the practical implications of this study suggest that, under fasting conditions, mouth rinsing a 7% carbohydrate solution may offer a performance benefit to athletes in cycling time trial performances of approximately 1h. There is no further benefit from rinsing a more concentrated carbohydrate solution.

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References

Anantaraman, R., Carmines, A.A., Gaesser, G.A., & Weltman, A. (1995). Effects of carbohydrate supplementation on

performance during 1 hour of high-intensity exercise. *International Journal of Sports Medicine*, 16(7), 461–465. PubMed doi:10.1055/s-2007-973038

Ataide-Silva, T., Ghiarone, T., Bertuzzi, R., Stathis, C.G., Leandro, C.G., & Lima-Silva, A.E. (2016). Carbohydrate Mouth Rinse Ameliorates Neuromuscular Response with Lower Endogenous Carbohydrate Stores. *Medicine and Science in Sports and Exercise*, [Epub ahead of print]. doi:10.1249/MSS.0000000000000973

Bastos-Silva, V.J., Melo Ade, A., Lima-Silva, A.E., Moura, F.A., Bertuzzi, R., & de Araujo, G.G. (2016). Carbohydrate Mouth Rinse Maintains Muscle Electromyographic Activity and Increases Time to Exhaustion during Moderate but not High-Intensity Cycling Exercise. *Nutrients*, 8(3). PubMed doi:10.3390/nu8030049

Beelen, M., Berghuis, J., Bonaparte, B., Ballak, S., Jeukendrup, A.E., & van Loon, L.J.C. (2009). Carbohydrate mouth rinsing in the fed state does not enhance time trial performance. *International Journal of Sport Nutrition and Exercise Metabolism*, 19(4), 400–409. PubMed doi:10.1123/ijsnem.19.4.400

Below, P.R., Mora-Rodriguez, R., Gonzalez-Alonso, J., & Coyle, E.F. (1995). Fluid and carbohydrate ingestion independently improve performance during 1 h of intense exercise. *Medicine and Science in Sports and Exercise*, 27(2), 200–210. PubMed doi:10.1249/00005768-199502000-00009

Berthoud, H.R. (2003). Neural systems controlling food intake and energy balance in the modern world. *Current Opinion in Clinical Nutrition and Metabolic Care*, 6(6), 615–620. PubMed doi:10.1097/00075197-200311000-00002

Borg, G.A.V. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, 14, 377–381. PubMed doi:10.1249/00005768-198205000-00012

Carter, J., Jeukendrup, A.E., Mundel, T., & Jones, D.A. (2003). Carbohydrate supplementation improves moderate and high-intensity exercise in the heat. *Pflügers Archiv*, 446(2), 211–219. PubMed doi:10.1007/s00424-003-1020-4

Carter, J.M., Jeukendrup, A.E., & Jones, D.A. (2004). The effect of carbohydrate mouth rinse on 1-h cycle time trial performance. *Medicine and Science in Sports and Exercise*, 36(12), 2107–2111. PubMed doi:10.1249/01.MSS.0000147585.65709.6F

Chambers, E.S., Bridge, M.W., & Jones, D.A. (2009). Carbohydrate sensing in the human mouth: effects on exercise performance and brain activity. *The Journal of Physiology*, 578(8), 1779–1794. PubMed doi:10.1113/jphysiol.2008.164285

Coggan, A.R., & Coyle, E.F. (1987). Reversal of fatigue during prolonged exercise by carbohydrate infusion or ingestion. *Journal of Applied Physiology (Bethesda, Md.)*, 63(6), 2388–2395. PubMed

Coyle, E.F., Coggan, A.R., Hemmert, M.K., & Ivy, J.L. (1986). Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. *Journal of Applied Physiology (Bethesda, Md.)*, 61(1), 165–172. PubMed

Desbrow, B., Anderson, S., Barrett, J., Rao, E., & Hargreaves, M. (2004). Carbohydrate-electrolyte feedings and 1 h time trial cycling performance. *International Journal of Sport Nutrition and Exercise Metabolism*, 14(5), 541–549. PubMed doi:10.1123/ijsnem.14.5.541

- Gam, S., Guelfi, K.J., & Fournier, P.A. (2013). Opposition of carbohydrate in a mouth-rinse solution to the detrimental effect of mouth rinsing during cycling time trials. *International Journal of Sport Nutrition and Exercise Metabolism*, 23(1), 48–56. [PubMed doi:10.1123/ijsnem.23.1.48](#)
- Gant, N., Stinear, C.M., & Byblow, W.D. (2010). Carbohydrate in the mouth immediately facilitates motor output. *Brain Research*, 1350, 151–158. [PubMed doi:10.1016/j.brainres.2010.04.004](#)
- Haase, L., Cerf-Ducastel, B., & Murphy, C. (2009). Cortical activation in response to pure taste stimuli during the physiological states of hunger and satiety. *NeuroImage*, 44(3), 1008–1021. [PubMed doi:10.1016/j.neuroimage.2008.09.044](#)
- Ispoglou, T., O'Kelly, D., Angelopoulou, A., Bargh, M., O'Hara, J.P., & Duckworth, L.C. (2015). Mouth Rinsing With Carbohydrate Solutions at the Postprandial State Fail to Improve Performance During Simulated Cycling Time Trials. *Journal of Strength and Conditioning Research*, 29(8), 2316–2325. [PubMed doi:10.1519/JSC.0000000000000882](#)
- Jeukendrup, A., Brouns, F., Wagenmakers, A.J., & Saris, W.H. (1997). Carbohydrate-electrolyte feedings improve 1 h time trial cycling performance. *International Journal of Sports Medicine*, 18(2), 125–129. [PubMed doi:10.1055/s-2007-972607](#)
- Jeukendrup, A., Saris, W.H., Brouns, F., & Kester, A.D. (1996). A new validated endurance performance test. *Medicine and Science in Sports and Exercise*, 28(2), 266–270. [PubMed doi:10.1097/00005768-199602000-00017](#)
- Jeukendrup, A.E. (2004). Carbohydrate intake during exercise and performance. *Nutrition (Burbank, Los Angeles County, Calif.)*, 20(7-8), 669–677. [PubMed doi:10.1016/j.nut.2004.04.017](#)
- Jeukendrup, A. E., J. M. Carter & I. Rollo (2013). **Carbohydrate mouth rinse: performance effects and mechanisms.** *Sports Science Exchange* #118 26(118): 1-8.
- Kringelbach, M.L., de Araujo, I.E., & Rolls, E.T. (2004). Taste-related activity in the human dorsolateral prefrontal cortex. *NeuroImage*, 21(2), 781–788. [PubMed doi:10.1016/j.neuroimage.2003.09.063](#)
- Kulaksiz, T.N., Kosar, S.N., Bulut, S., Guzel, Y., Willems, M.E., Hazir, T., & Turnagol, H.H. (2016). Mouth Rinsing with Maltodextrin Solutions Fails to Improve Time Trial Endurance Cycling Performance in Recreational Athletes. *Nutrients*, 8(5). [PubMed doi:10.3390/nu8050269](#)
- Lane, S.C., Bird, S.R., Burke, L.M., & Hawley, J.A. (2013). Effect of a carbohydrate mouth rinse on simulated cycling time-trial performance commenced in a fed or fasted state. *Applied Physiology, Nutrition, and Metabolism*, 38(2), 134–139. [PubMed doi:10.1139/apnm-2012-0300](#)
- Neufer, P.D., Costill, D.L., Flynn, M.G., Kirwan, J.P., Mitchell, J.B., & Houmard, J. (1987). Improvements in exercise performance: effects of carbohydrate feedings and diet. *Journal of Applied Physiology (Bethesda, Md.)*, 62(3), 983–988. [PubMed](#)
- Pottier, A., Bouckaert, J., Gilis, W., Roels, T., & Derave, W. (2008). Mouth rinse but not ingestion of a carbohydrate solution improves 1-h cycle time trial performance. *Scandinavian Journal of Medicine & Science in Sports*, 20(1), 105–111. [PubMed doi:10.1111/j.1600-0838.2008.00868.x](#)
- Rollo, I., Cole, M., Miller, R., & Williams, C. (2010). Influence of mouth rinsing a carbohydrate solution on 1-h running performance. *Medicine and Science in Sports and Exercise*, 42(4), 798–804. [PubMed doi:10.1249/MSS.0b013e3181bac6e4](#)
- Rollo, I., & Williams, C. (2009). Influence of Ingesting a Carbohydrate-Electrolyte Solution Before and During a 1-hr Running Performance Test. *International Journal of Sport Nutrition and Exercise Metabolism*, 19(6), 645–658. [PubMed doi:10.1123/ijsnem.19.6.645](#)
- Rollo, I., & Williams, C. (2011). Effect of mouth-rinsing carbohydrate solutions on endurance performance. *Sports Medicine (Auckland, N.Z.)*, 41(6), 449–461. [PubMed doi:10.2165/11588730-000000000-00000](#)
- Rolls, E.T. (2007). Sensory processing in the brain related to the control of food intake. *The Proceedings of the Nutrition Society*, 66(1), 96–112. [PubMed doi:10.1017/S0029665107005332](#)
- Sinclair, J., Bottoms, L., Flynn, C., Bradley, E., Alexander, G., McCullagh, S., . . . Hurst, H.T. (2014). The effect of different durations of carbohydrate mouth rinse on cycling performance. *European Journal of Sport Science*, 14(3), 259–264. [PubMed doi:10.1080/17461391.2013.785599](#)
- Smeets, P.A., de Graaf, C., Stafleu, A., van Osch, M.J., & van der Grond, J. (2005). Functional MRI of human hypothalamic responses following glucose ingestion. *NeuroImage*, 24(2), 363–368. [PubMed doi:10.1016/j.neuroimage.2004.07.073](#)
- Tsintzas, K., & Williams, C. (1998). Human muscle glycogen metabolism during exercise. Effect of carbohydrate supplementation. *Sports Medicine (Auckland, N.Z.)*, 25(1), 7–23. [PubMed doi:10.2165/00007256-199825010-00002](#)
- Tsintzas, O.K., Williams, C., Boobis, L., & Greenhaff, P. (1996). Carbohydrate ingestion and single muscle fiber glycogen metabolism during prolonged running in men. *Journal of Applied Physiology (Bethesda, Md.)*, 81, 801–809. [PubMed](#)
- Turner, C.E., Byblow, W.D., Stinear, C.M., & Gant, N. (2014). Carbohydrate in the mouth enhances activation of brain circuitry involved in motor performance and sensory perception. *Appetite*, 80, 212–219. [PubMed doi:10.1016/j.appet.2014.05.020](#)
- van Rijn, I., Griffioen-Roose, S., de Graaf, C., & Smeets, P.A. (2015). Neural Processing of Calories in Brain Reward Areas Can be Modulated by Reward Sensitivity. *Frontiers in Behavioral Neuroscience*, 9, 371. [PubMed](#)
- Widrick, J.J., Costill, D.L., Fink, W.J., Hickey, M.S., McConell, G.K., & Tanaka, H. (1993). Carbohydrate feedings and exercise performance: effect of initial muscle glycogen concentration. *Journal of Applied Physiology (Bethesda, Md.)*, 74, 2998–3005. [PubMed](#)
- Wright, B.F., & Davison, G. (2013). Carbohydrate mouth rinse improves 1.5 h run performance: is there a dose-effect? *International Journal of Exercise Science*, 6, 328–340. [PubMed](#)
- Zavorsky, G.S., Murias, J.M., Gow, J., Kim, D.J., Poulin-Harnois, C., Kubow, S., & Lands, L.C. (2007). Laboratory 20-km cycle time trial reproducibility. *International Journal of Sports Medicine*, 28, 743–748. [PubMed doi:10.1055/s-2007-964969](#)

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