Influence of Mouth Rinsing a Carbohydrate Solution on 1-h Running Performance

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ABSTRACT

ROLLO, I., M. COLE, R. MILLER, and C. WILLIAMS. Influence of Mouth Rinsing a Carbohydrate Solution on 1-h Running Performance. Med. Sci. Sports Exerc., Vol. 42, No. 4, pp. 798–804, 2010. Purpose: The aim of this study was to investigate the influence of mouth rinsing a CHO-electrolyte (CHO–E) solution on 1-h running performance. A second study determined whether mouth rinsing a CHO–E solution altered the blood glucose and plasma insulin concentrations at rest. Methods: After a 13-h fast, 10 endurance-trained male runners completed two 1-h performance runs on an automated treadmill while mouth rinsing 25 mL of either a 6.4% CHO–E (C) or placebo (P) solution immediately before and at 15-min intervals during the 1-h run. An additional 10 healthy active males followed the same mouth rinsing procedure during a 1-h resting period. Finger prick blood samples were obtained for the determination of blood glucose and plasma insulin concentrations. Results: Runners covered 211 m (90% confidence intervals = 42–380 m, P = 0.048) further during the C trial (14,298 ± 685 m, mean ± SD) in comparison with the P trial (14,086 ± 732 m). There was no change in blood glucose concentrations during the 1-h run (P: pre = 4.3 ± 0.2 mmol⋅L⁻¹, post = 4.3 ± 0.3 mmol⋅L⁻¹; C: pre = 4.3 ± 0.4 mmol⋅L⁻¹, post = 4.3 ± 0.3 mmol⋅L⁻¹). At rest, there was no change in blood glucose (P: 4.3 ± 0.1 mmol⋅L⁻¹, C: 4.3 ± 0.2 mmol⋅L⁻¹) or plasma insulin (P: 6.2 ± 1.1 mU⋅L⁻¹, CHO: 5.9 ± 1.0 1.1 mU⋅L⁻¹) concentrations (P > 0.10). Conclusions: Mouth rinsing a 6.4% CHO–E solution was associated with increased distance covered during a 1-h performance run in comparison to mouth rinsing a placebo solution. Mouth rinsing a CHO–E was not associated with changes in blood glucose concentration during exercise or at rest. Key Words: TREADMILL, SPEEDS, ENDURANCE, DISTANCE

T he benefits of ingesting CHO-electrolyte (CHO–E) solutions during prolonged exercise, i.e., cycling and running, on endurance capacity have been established in well-controlled laboratory studies. The development of fatigue during prolonged exercise is closely associated with the depletion of muscle glycogen stores (7). Thus, nutritional studies, directed at improving preexercise CHO concentrations as well as providing CHO during exercise, have shown improvements in endurance capacity by maintaining euglycemia late in exercise and under certain circumstances, delaying the depletion of muscle glycogen stores (for reviews, see [13,14,38]).

Although there are a large number of studies investigating the influence of CHO ingestion on endurance capacity (time to fatigue), there are fewer studies on endurance performance. Endurance performance is assessed using tests that require the completion of a preset amount of external mechanical work (cycling) (40) or distance (cycling or running) (12,23) in as fast a time as possible or by asking athletes to complete as much work as possible in a specified time (36). Endurance performance tests are of interest because they are more representative of “real-life” sporting events. Laboratory-based studies typically use an exercise duration of 45 min to 1 h to assess endurance performance. During such exercise, endogenous glycogen stores are sufficient for the exercise task (19), and the provision of exogenous CHO contributes minimally to CHO oxidation in the muscle in comparison with the oxidation of endogenous muscle glycogen (35). Nevertheless, some studies (4,6,8,29) but not all (1,15,40) have reported a performance benefit as a result of ingesting CHO.

A key variable, affecting performance, seems to be the method by which CHO enters the circulation during exercise performance. Carter et al. (10) reported that infusing glucose into cyclists (60 g·h⁻¹) had no influence on their 1-h cycle time trial performance, yet mouth rinsing the CHO solution without ingestion resulted in significant improvements in their performance (9). These findings are also supported by Pottier et al. (31), who reported the benefit mouth rinsing a CHO solution on a 1-h cycle time trial performance in comparison with the ingestion of the same solution. These observations have led authors to speculate on possible link between CHO in the mouth and the brain during exercise, a relationship that has been recently explored by Chambers et al. (11).
The concept that mouth rinsing a CHO–E solution may exert a “central effect” is consistent with studies that have found runners experience more pleasure and report lower RPE while ingesting CHO–E during prolonged exercise (2,3). In a previous study, we reported that runners who mouth rinsed a CHO–E solution increased self-selected running speed during a 30-min run at a set RPE of 15. In addition, we found that increased self-selected speed corresponded with enhanced feelings of pleasure in comparison to mouth rinsing a placebo solution (32). Nevertheless, mouth rinsing a CHO solution has recently been shown not to have an influence on performance during a 1-h treadmill running test (39). However, the authors of this study acknowledged that a limitation to treadmill time trials is the runners’ inability to spontaneously alter running speed (26,36,39). Thus, these authors suggested that treadmill tests that require conscious alterations of running speed may not be sufficient to detect any potentially subconscious central effect of a CHO mouth rinse on performance (39).

To overcome this limitation, we have used a treadmill that allows the runner to change pace spontaneously without manually changing the treadmill speed. Using an automated treadmill, we developed a 1-h running performance test that required runners to complete the greatest distance in the set time (33). The performance test has a coefficient of variation (CV) of 1.4%, which is smaller than that in an earlier study (36). Hopkins and Hewson (22) reported that running tests require a CV of 1.5% or less to detect small changes in running performance. Taking advantage of this advancement in treadmill technology, we were well placed to extend the investigations into mouth rinsing CHO and running performance.

To this end, the aim of the present study was to investigate the influence of mouth rinsing a 6.4% CHO–E solution on self-selected running speed and distance covered in 1 h. To confirm that the mouth rinsing procedure did not lead to changes in blood glucose concentrations, we conducted an additional study that examined blood glucose and plasma insulin concentrations during a 1-h resting period.

METHODS

Participants. The physiological characteristics of the participants for both the performance and resting studies are reported in Table 1. Participants were healthy active men who gave their written consent before participating in this study approved by Loughborough University Ethical Advisory Committee. The number of participants was determined using a nomogram based on the ratio limits of agreement (30). All participants in the performance study were experienced runners accustomed to training and/or competitions lasting at least 1 h in duration.

Procedures. Participants fasted for 13–15 h overnight (no food, only water). After the overnight fast, they reported to the laboratory at the same time of day for each trial, which was separated by 7 d. For the performance study, runners were fully habituated with the testing procedures before the completion of two 1-h running trials. Runners were asked to refrain from heavy exercise and to consume a standardized diet 48 h before each trial; that is, they recorded their food intake in the 48 h before the first trial and replicated it before the next trial. There were no significant differences between trials in the average daily energy intake (14.4 ± 1.5 MJ) or quantities of CHO (6.5 ± 1.5 g·kg⁻¹·body mass (BM)), protein (2.0 ± 0.4 g·kg⁻¹·BM), or fat (1.5 ± 0.5 g·kg⁻¹·BM) consumed in the 48 h before each trial (dietary composition was analyzed by CompEat Pro 5.8.0, Nutrition Systems, Grantham, UK). For the resting study, participants sat quietly in a laboratory recovery room for 20 min before the start of the 1-h resting period.

One-hour running performance trials. Runners arrived at the laboratory and rested for 20 min before a 5-min resting expired air collection. They then sat at rest for a further 20 min before being allowed to empty their bladder; thereafter, BM was recorded. Before each trial, the runners were weighed and fitted with an HR monitor before completing a 5-min warm-up at 60% VOpeak RPE were recorded at 3 min into the 5-min warm-up. On completion of the warm-up, each runner was allowed 2 min to prepare for the run and, if required, empty his bladder again (on these occasions, urine was collected and accounted for in the calculation of BM changes). Expired air was collected by the Douglas bag method between 3.45 and 4.45 min during the warm-up and between 13.40 and 14.40 min, between 28.40 and 29.40 min, and between 43.40 and 44.40 min during the 1-h run. On completion of the 1-h run, the runners were towel-dried, and BM was again recorded. Sweat rates were calculated by subtracting the runners’ postrun BM from their BM immediately before the run.

All performance trials were performed in a laboratory (21°C ± 2°C and 45% relative humidity) containing the treadmill and fan positioned 1 m in front of the runner to provide cooling. Runners were monitored throughout exercise via closed-circuit television by an investigator in an adjacent room. The treadmill display panel and the HR monitor were covered so that feedback to the runner was limited to a clock displaying the time remaining throughout the 1-h run. Runners began the trial by standing in front of the treadmill (1% gradient) and received the following instruction from the same investigator: “This is a running

| TABLE 1. The physiological characteristics of participants in the resting and performance studies. |
|---------------------------------------------|---------------------------------------------|
| n                                          | Resting                                    |
| Age (yr)                                   | 26 ± 3                                     |
| Training volume: approximate miles per week | 41 ± 4 (3–6)                               |
| Training frequency per week                | 6 ± 2 (3–10)                               |
| Training volume: approximate miles per week | 43 ± 13 (30–70)                            |
| V̇Opeak (L·min⁻¹)                          | 4.7 ± 0.3                                  |
| V̇Opeak (mL·min⁻¹·kg⁻¹)                    | 63.9 ± 43                                  |
| Running experience (yr)                    | 6 ± 2 (3–10)                               |
| Training frequency per week                | 41 ± 4 (3–6)                               |
| Training volume: approximate miles per week | 43 ± 13 (30–70)                            |
| Running experience of the 10 runners in the performance study has been reported as mean ± SD (range). |
All trials were carried out on a motorized treadmill that allowed spontaneous changes in speed without manual input (33). Runners received no feedback about their performance, i.e., distance covered, running speed, and HR until the completion of the whole study.

**Treadmill.** All trials were carried out on a motorized treadmill (Runner MT2000; Bianchini & Draghetti, Cavezzo, Italy) that has an ultrasonic feedback-controlled radar modulator that spontaneously regulates treadmill belt velocity corresponding to the changing position of the runner on the treadmill belt (28). Thus, the treadmill velocity increases or decreases as the runner moves to the front or the back of the treadmill belt, respectively. Therefore, changes in velocity are achieved without the need for manual input or visual feedback from the runner. More specifically, when the runner moves to the front section of the treadmill (<36 cm from treadmill console), the speed increases (0.8 m s⁻¹). If the runner stays in the middle of the treadmill (between 36 and 65 cm from treadmill console), the speed remains constant. When the runner moves to the rear of the treadmill (>65 cm from treadmill console), the speed decreases (1.1 m s⁻¹). Consequently, the runner will always be brought back to the center of the treadmill belt (33). Speeds from the treadmill console were recorded on a computer at 15-s intervals throughout the 1-h run. The distance covered during 15 s was calculated and totaled for 1 h to determine the overall distance achieved.

**Solution and rinse procedure.** The solutions used in this study were a commercially available 6.4% CHO–E beverage (C) (Lucozade Sport, Brentford, England) and a color- and taste-matched placebo (P) solution. The P solution was matched in formulation to the CHO–E solution except that it contained no CHO. Both the exercise and resting studies used double-blind random crossover design. In both studies, participants mouth rinsed the solutions immediately before and at 15, 30, and 45 min during the 1-h run. Each 25 mL of solution was delivered in a plastic volumetric syringe (Kendall monosaic) a total of four times, equating to a total volume of 100 mL of solution rinsed and expectorated during the trial. In the resting study, participants were asked to swallow twice to clear the oral cavity of saliva before each rinse. The solution was mouth rinsed for 5 s before being expectorated into a preweighed plastic container. The syringe and plastic container were weighed before and after each rinse using an electronic balance (Mettler, Toledo AB54-s, Switzerland) to determine the volume of rinsed solution and expectorate, respectively. The volume of expectorate was subtracted from the known volume of solution rinsed to determine whether any solution had been ingested or remained in the oral cavity. On completion of the studies, participants were asked if they could distinguish between the solutions that they had mouth rinsed during the two trials.

**Psychological scales.** For the performance trials, the Feeling Scale (FS) (18) was used to assess the feelings of the runners, i.e., the affective dimension of pleasure–displeasure. This FS scale is an 11-point single-item bipolar rating scale that ranges from −5 to +5. Anchors are provided at the “0” point (“neutral”) and at all odd integers, ranging from “very good” (+5) to “very bad” (−5) (16). The perceived activation scale (FAS) (37) is a six-point, single-item measure of perceived activation/arousal (energized). The scale ranges from 1 to 6, with anchors at 1 (“low arousal”) and 6 (“high arousal”), and has been used in previous exercise studies (2,3,17). Both the FS and FAS have the advantage of most other self-report scales of being easily administered during exercise. Gastrointestinal (GI) comfort was rated using a 12-point scale with anchors provided at 0= “neutral,” 4= “uncomfortable,” 8= “very uncomfortable,” and 12= “painful.” The FS and FAS, together with the GI scale, were administered at rest, immediately before, and at 15, 30, 45, and 60 min during the 1-h run. The RPE was collected from the runner during the warm-up and at 15, 30, and 45 min during the 1-h run. During the resting trial, a one-dimensional bipolar hedonic scale with numeric anchors ranging from −4 (extremely unpleasant) through 0 (neither pleasant nor unpleasant) to +4 (extremely pleasant) was used to assess the hedonic response to the rinsed solution. This scale has been used previously to assess the hedonic tone of a taste stimulus at rest (25).

**Blood analysis.** In the performance and resting trials, all blood samples (20 μL) were taken in duplicate, deproteinized, frozen, and later analyzed for the concentrations of glucose (27). For the performance trials, finger prick blood samples were collected at rest and immediately after the 1-h run. In the resting study, fingertip blood samples were collected in 300-μL microtubes (Microvette, CB 300; Sarstedt Ltd., UK) at rest, immediately before the first rinse, and at 2, 4, 10, 15, 30, 45, and 60 min. After the collection of 2 × 20 μL, the remainder of the blood was centrifuged, and plasma was collected for the determination of plasma insulin concentrations using an ELISA kit (Mercodia; Insulin ELISA, Uppsalsa, Sweden) and plate reader (Expert Plus; ASYS Atlantis, Eugendorf, Austria).

**Statistical analysis.** All data were analyzed using SPSS (version 16.0, IBM, Chicago, IL). The mean differences in performance (total distance covered and trial order) were detected using a paired-samples t-test. The quantitative approach to likelihoods of benefit, triviality, and harm to running performance was further enriched by dividing the range of substantial values into more finely graded magnitudes. Using the spreadsheet by Hopkins (21), the P value was converted into 90% confidence intervals (CI) for, and inferences about, the true value of the effect statistic. It has been previously reported that distance runners and sports professionals need to be concerned about changes in performance of between ~0.5% and ~1.0% (22). Thus, the set threshold value for possible benefit or harm to performance was set at 1% of the mean distance covered during the two trials. Mean differences in self-selected running speed (analyzed in 5-min blocks during the 1-h run) and
psychological scores were detected using a repeated-measures factorial ANOVA (trial × time). Significant main effects for individual time points were further analyzed using paired t-tests and the Bonferroni adjustment for the number of pairwise comparisons used. For the second part of the study, blood glucose and plasma insulin concentrations were analyzed using a repeated-measures factorial ANOVA (trial × time) with significant main effects for individual time points further analyzed using paired t-tests and Bonferroni adjustment. All data are presented as mean ± SD; the CI was set at P ≤ 0.10 a priori (20).

RESULTS

Performance study. The runners completed a greater distance during the C trial (14,298 ± 685 m) than during the P trial (14,086 ± 732 m). Runners completed 211 m (90% CI of difference = 42–380 m, P = 0.048) more during the C trial than during the P trial, representing 1.5% of the total distance covered. The threshold value was set at 142 m; thus, the chance that the true value of the effect is beneficial, negligible, or harmful to running performance is 76.3%, 23.5%, and 0.2%, respectively. Individual running performances for the P and C trials are shown in Figure 1; there was no trial order effect on distance covered (P = 0.527). The change in distance covered ± the 90% confidence limit (169 m) is shown Figure 2.

The mean running speed in the P trial was 14.1 ± 0.7 km h⁻¹, and in the C trial, it was 14.3 ± 0.7 km h⁻¹ (P = 0.054). The mean difference in running speed was 0.2 km h⁻¹ (CI = 0.04–0.4 km h⁻¹). Pacing strategy was similar between runners and consistent between trials. Mean self-selected running speed during the 1-h run is shown in Figure 3. Calculated sweat rate was 1.5 ± 0.2 L h⁻¹ for the P trial and 1.6 ± 0.2 L h⁻¹ for the C trial (P = 0.531), equivalent to a loss of 1.1% mean BM.

At rest, there was no significant difference in perceived activation (FAS: P = 3.1 ± 1.0, C = 3.1 ± 0.1), runners’ pleasure-displeasure (FS: P = 1.5 ± 1.9, C = 1.2 ± 2.0), GI comfort (P = 0.8 ± 1.0, C = 0.5 ± 1.1), or oxygen uptake values (P = 3.8 ± 0.5 mL min⁻¹ kg⁻¹, C = 3.7 ± 0.4 mL min⁻¹ kg⁻¹). The 5-min warm-up speed was 11.7 ± 1.1 km h⁻¹, and \( \dot{VO}_2 \) was 38 ± 3 mL min⁻¹ kg⁻¹ equivalent to 60% \( \dot{VO}_{2peak} \) for both trials.

RPE for the warm-up was 9 ± 2 for the P trial and 10 ± 1 for the C trial. The mean volume of expectorate for the P trial (25.5 ± 1.0 mL) and the C trial (26.2 ± 1.0 mL) was greater than the mean volume of solution rinsed (25.1 ± 0.1 mL) in both trials (P < 0.05). The mean physiological responses and psychological scores during the C and P trials are reported in Table 2. None of the 10 runners was able to distinguish between the solutions they had mouth rinsed in the two trials.

Resting study. There was no change in blood glucose concentrations during the 1 h in the C trial or in the P trial (P = 0.277). The mean blood glucose concentrations were 4.3 ± 0.1 mmol L⁻¹ for the P trial and 4.3 ± 0.2 mmol L⁻¹ for the C trial (P = 0.619). There were also no differences in plasma insulin concentrations during the 1-h resting period (P = 0.302, n = 6) or between trials (P = 6.2 ± 1.1 mU L⁻¹, CHO = 5.9 ± 1.0 mU L⁻¹).

The mean volume of fluid rinsed during the P trial was 26.0 ± 0.3 mL, and the mean volume of expectorate was 25.7 ± 0.7 mL (P = 0.004). Thus, the mean difference between the rinse and expectorate was 0.3 mL. The mean volume of solution rinsed during the C trial was 26.6 ± 0.9 mL, and the mean volume of expectorate was 26.5 ± 0.9 mL (P = 0.394). The mean scores for the hedonic scale
at rest were 1.6 ± 1.6 for the P trial and 2.1 ± 1.2 for the C trial (P = 0.339).

**DISCUSSION**

The main finding of the present study was that runners who mouth rinsed a 6.4% CHO–E solution covered a greater distance during a 1-h running performance test than when they mouth rinsed a color- and taste-matched placebo.

Our findings are in agreement with several studies that have shown the benefit of mouth rinsing CHO solutions on time trial performance during cycling (9,11,31). Carter et al. (9) were the first to report that compared with mouth rinsing with water, mouth rinsing a 6.4% maltodextrin solution improved 1-h cycling performance by 2.9%. The findings of the present study provide evidence that participants are able to mouth rinse a solution during exercise without ingestion. However, it is important to note that salivary secretions during the mouth rinse procedure would have contributed to the volume of expectorate. Nevertheless, despite not being able to ascertain absolutely whether any solution was ingested, the results of the present study confirm assumptions made by Carter et al. (9) that mouth rinsing a CHO–E solution has no influence on blood glucose concentrations. Pottier et al. (31) have also reported that mouth rinsing a 6% (sucrose = 5.4 g 100 mL⁻¹, glucose = 0.46 g 100 mL⁻¹) CHO–E solution improves time trial performance during cycling. However, they also reported that mouth rinsing had a greater performance benefit (3.7%) than when their cyclists ingested (14 mL·kg⁻¹·h⁻¹) the same solution. Despite the mouth being exposed to CHO in both trials, the discrepancy in performance was attributed to the short oral transit time when ingesting the CHO–E solution (31). In two separate investigations, Chambers et al. (11) reported that mouth rinsing both a sweet 6.4% glucose solutions and nonsweet 6.4% maltodextrin solution improved 1-h cycling performance by approximately 2% and 3%, respectively. Each cycling study used the same performance test in which cyclists were required to complete a set amount of external mechanical work as quickly as possible (approximately 1 h in duration). This performance test has a reported CV of 3.35% (24). Consequently, only Pottier et al. (31) reported an improvement in performance greater than that of the known variation of performing the cycling time trial, i.e., 3.7%. In the present study, the difference in distance covered between the C and P trials was greater than 1.4% (CV), i.e., the day-to-day variation of the testing procedure (33).

Analysis of the true value of the effect statistic revealed that mouth rinsing a CHO–E solution is likely (76%) to have a substantially positive effect on 1-h running performance (5). In Figure 1, it is clear that 2 of the 10 runners (nos. 7 and 8) increased their performance substantially on the C trial. Interview with these runners revealed that they did not habitually ingest sports drinks during training or competition. Therefore, an interesting question would be to discover whether such individuals are more sensitive to CHO interventions, i.e., responders and nonresponders. However, it is important to note that caution should be taken when interpreting data with low participant numbers. When runners 7 and 8 were removed from the analysis, it revealed that the C trial is likely to have a 77.8% negligible effect and 21.9% positive effect. Nevertheless, it is important to note that in both analysis of 8 and 10 runners, mouth rinsing a CHO–E had a 0.3% and 0.2% chance having a substantial negative effect on performance, respectively. The results of the present study contribute to the evidence reported by four of five studies that mouth rinsing a CHO solution is associated with improvements in performance. Therefore, athletes who experience GI discomfort when ingesting CHO–E while running may want to consider the mouth rinsing strategy because there are no adverse effects and it may lead to an improvement in performance.

In the studies that used cycling time trials, each reports that the mean power output during the time trial was increased when mouth rinsing a CHO solution (9,11,31). However, only Carter et al. (9) reports significant changes in power output during the time trial, i.e., during the first three-quarters (approximately 45 min) of the performance test. In the present study, running speed reached statistical significance between 25 and 30 min and between 35 and 40 min (Fig. 3). An explanation as to why mouth rinsing CHO influenced performance at different time points between the present study and previous cycling studies is hard to establish given the two different modes of exercise. However, it is most likely a consequence of the different pacing strategies adopted by runners and cyclists in time trials. Runners typically maintain their self-selected running speed for the majority of the test and tend to sprint toward the end of the time trial (33). In cycle studies, power output gradually declines during the first three-quarters of the time trial before being increased to the completion of the set amount.
of external work (9,11,23,31). These observations suggest that care must be taken when making comparisons between cycling and running protocols. Thus, the distinct difference between the present study and those performed in cycling is that mouth rinsing a CHO solution improved performance by increasing self-selected running speed, whereas in cycling, the benefit to performance seems to be achieved by reducing the decline in power output during the time trial.

In contrast to the results of the present study, Whitham and McKinney (39) reported that the distance covered during 45 min of treadmill running was not improved when runners mouth rinsed a 6% maltodextrin or flavor-matched placebo solution at 6-min intervals. Runners completed a 15-min warm-up run at 65% \( \dot{V}O_2 \) before being asked to run as far as possible in 45 min. Unlike the present study, Whitham and McKinney (39) found no differences in mean running speed at any time point during the 45-min run. Nevertheless, the study confirmed previous observations that runners are able to accurately replicate their running performance when asked to cover as much distance as possible in a given time (33). That Whitham and McKinney (39) observed no difference in running speed with a CHO mouth rinse is possibly a consequence of two key aspects of their treadmill running procedure. The first difference is that, although runners had complete control of the treadmill speed, they had to make changes manually. Therefore, when the runners felt like changing their running speed, they had to engage in the process of manually altering the treadmill speed (39). Whitham and McKinney (39) recognized that using a performance test that required a manual control of pace may not be optimal for detecting a potentially subconscious central effect of CHO mouth rinse (39). This may explain why differences in speed were observed in the present study, which used an automated treadmill system that allowed spontaneous changes in speed without manual input (33). Thus, the automated treadmill may be more sensitive in detecting the small effect size that mouth rinsing a CHO–E may induce. Second, an aspect that seems a key in determining endurance performance is the preexercise CHO status of the individual. Observations from cycling studies suggest that CHO supplementation has little ergogenic effect when endogenous glycogen stores are sufficient to maintain exercise intensity during the exercise period (15,40). In support of this observation, we have recently found no benefit of CHO ingestion on the 1-h running performance when a preexercise meal was consumed 3 h before exercise (Rollo and Williams, unpublished observations). Therefore, the 4-h postprandial period may not have been long enough to reduce endogenous CHO stores to show the benefit of the mouth rinsing procedure. Nevertheless, it is important to note that both Carter et al. (9) and Pottier et al. (31), who imposed a 4- and 3-h fast, respectively, did find significant performance benefits from mouth rinsing a CHO solution. However, the amount and composition of the preexercise meals were not reported.

The mechanism(s) by which mouth rinsing with a CHO–E solution increased self-selected running speed in the present study are, as yet, unknown. Previous authors have speculated that mouth rinsing CHO may trigger reward centers in the brain (9) or suppress fatigue signals to the brain from working muscles (31). Chambers et al. (11) recently used functional magnetic resonance imaging to explore the influence of oral exposure to glucose and maltodextrin on the brain. Their study reports that both glucose and maltodextrin in the mouth activate regions in the brain associated with reward, such as the insula/frontal operculum, orbitofrontal cortex, and striatum (11). These regions of the brain are believed to mediate behavioral responses to rewarding stimuli, such as taste (34). In support of these findings, we have previously shown that increases in self-selected running speeds during a 30-min run at an RPE of 15 corresponded to runners experiencing enhanced feeling of pleasure when mouth rinsing CHO (32). With respect to performance, mouth rinsing CHO during exercise may activate these brain regions and result in altered behavior, i.e., increase in self-selected running speed. However, it is important to note that the glucose and maltodextrin solutions used for the functional magnetic resonance imaging scans were far more concentrated (18%) than those used during exercise (6%–6.4%) (9,11,31). In the present study, blood glucose and plasma insulin concentrations were unchanged during the 1-h resting period in response to mouth rinsing CHO. In a study by Just et al. (25), which reported a release of insulin in response to glucose in the mouth, participants held the solution in the mouth for a much longer duration (45 s) compared with rinse times in the present and previous exercise studies (5 s). Thus, just as with the question of the influences of solution concentration, the duration that CHO is in the mouth may also have an influence on a centrally governed feed forward mechanism.

**FUTURE RESEARCH**

Future research is needed to establish whether the same central activation, reported by Chambers et al. (11), can be achieved when mouth rinsing CHO solutions with similar concentrations to those that have been shown to influence exercise performance. In addition, of interest would be to discover what overall contribution a centrally governed “feed forward” response makes when performance benefits are observed after the ingestion of CHO–E solutions.

In conclusion, mouth rinsing a 6.4% CHO–E solution was associated with increased self-selected running speed and distance covered during a 1-h performance run. Mouth rinsing with a 6.4% CHO–E solution did not alter blood glucose or plasma insulin concentrations at rest. These findings suggest that mechanisms independent of glucose delivery to the systemic circulation may be responsible for the improved 1-h running performance.

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