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To cite this article: Mickey Wai-Kit Suen, Fenghua Sun, Ajmol Ali & Eric Tsz-Chun Poon (2025) Effects of carbohydrate, caffeine, and combined mouth rinses on physiological and perceptual responses during high-intensity interval exercise following a pre-exercise meal: a double-blinded, placebo-controlled, randomized crossover trial, Journal of the International Society of Sports Nutrition, 22:1, 2562977, DOI: [10.1080/15502783.2025.2562977](https://doi.org/10.1080/15502783.2025.2562977)

To link to this article: <https://doi.org/10.1080/15502783.2025.2562977>



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Published online: 18 Sep 2025.



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Effects of carbohydrate, caffeine, and combined mouth rinses on physiological and perceptual responses during high-intensity interval exercise following a pre-exercise meal: a double-blinded, placebo-controlled, randomized crossover trial

Mickey Wai-Kit Suen ^{a,b}, Fenghua Sun ^c, Ajmol Ali ^d and Eric Tsz-Chun Poon ^e

^aThe University of Hong Kong, Department of Paediatrics and Adolescent Medicine, Hong Kong; ^bHKU School of Professional and Continuing Education, College of Life Sciences and Technology, Hong Kong; ^cThe Education University of Hong Kong, Department of Health and Physical Education, Taipo, Hong Kong; ^dMassey University, School of Sport, Exercise and Nutrition, Auckland, New Zealand; ^eThe Chinese University of Hong Kong, Department of Sports Science and Physical Education, Hong Kong

ABSTRACT

Background: Mouth rinsing with carbohydrate (CHO), caffeine (CAF), and their combined (CHO+CAF) solutions has been shown to enhance exercise performance. However, most previous studies were conducted under fasted conditions, which may not accurately reflect the typical practices of athletes who generally consume food before intense exercise or competition. This study examined the effects of CHO, CAF, and CHO+CAF mouth rinses on physiological and perceptual responses during high-intensity interval exercise (HIIE) following a pre-exercise meal.

Methods: Twelve recreationally active males (age: 23.4 ± 3.2 years) completed four HIIE trials involving 8 bouts of 1-min cycling at 85% of peak power output (PPO), separated by 1-min active recovery at 20% of PPO. Using a double-blinded randomized crossover design, participants rinsed with either 10% maltodextrin (CHO), 1.2% caffeine (CAF), 10% maltodextrin + 1.2% caffeine (CHO+CAF), or water (PLA) twice in each trial (after warm-up and interval 4). All solutions were taste-matched using the artificial sweetener sucralose. A standardized CHO-rich ($1 \text{ g}\cdot\text{kg}^{-1}$ body weight) breakfast was provided an hour before testing.

Results: Ratings of perceived exertion were significantly different between conditions after interval 4 (CHO: 12.3 ± 1.6 ; CAF: 13.5 ± 2.2 ; CHO+CAF: 12.7 ± 1.7 ; PLA: 13.7 ± 2.4 ; $p = 0.049$, $\eta_p^2 = 0.21$), but no significant effects of the mouth rinse conditions were observed on heart rate, blood glucose, blood lactate, affective valence, perceived activation, or affective responses (pleasure, arousal, and dominance) (all $p > 0.05$).

Conclusion: These findings suggest a limited ergogenic benefit of CHO and/or CAF mouth rinse through physiological and perceptual responses following sufficient food intake.

ARTICLE HISTORY

Received 28 November 2024
Accepted 3 September 2025


KEYWORDS

Oral rinsing; ergogenic aid; taste receptor; cycling; sport nutrition

1. Introduction

Mouth rinsing and expectorating solutions with carbohydrate (CHO) or caffeine (CAF) have been shown to independently improve various aspects of exercise performance. For instance, CHO mouth rinses have been associated with improvement in both endurance [1] and sprint performance [2], whereas CAF mouth rinses have been suggested to enhance sprint performance [3], interval exercise performance [4], and cognitive performance [5]. When CHO is rinsed, it stimulates oral cavity receptors regardless of sweetness and subsequently activates brain regions related to reward processing and motor control, including the cingulate cortex, orbitofrontal cortex, and corpus striatum [6,7]. This approach offers an ergogenic alternative to CHO ingestion that may cause gastrointestinal distress during intense exercise [8]. Similarly, CAF mouth rinsing is thought to antagonize oral adenosine receptors and stimulate oral bitter taste receptors without entering circulation. This strategy may help mitigate common side effects associated with traditional CAF ingestion, such as insomnia and headache [9], and results in the activation of the dorsolateral prefrontal cortex – an

CONTACT Eric Tsz-Chun Poon  eric.poon@cuhk.edu.hk  Kwok Sports Building, Department of Sports and Physical Education, The Chinese University of Hong Kong, Shatin, N.T. Hong Kong

 Supplemental data for this article can be accessed online at <https://doi.org/10.1080/15502783.2025.2562977>

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effect not observed when mouth rinsing CHO solutions [7]. As such, combining CHO and CAF in a mouth rinse solution (CHO+CAF) has also been hypothesized to induce an additive activation of distinct taste receptors via simultaneous stimulation of different neural pathways, potentially leading to further enhancements in cognitive performance during exercise [10].

Despite these proposed mechanisms, the ergogenic effects of various mouth rinse were not universally observed in the literature [10,11]. One reason cited for the discrepancies in studies reporting positive or no effects of mouth rinses on exercise performance is the influence of pre-exercise meals. For example, a previous systematic review revealed inconsistent results regarding the impact of CHO mouth rinses on exercise performance, potentially influenced by endogenous glycogen availability and variations in study designs [11]. Of note, many studies reporting an ergogenic effect of mouth rinses were conducted under fasted conditions [6,12] or at least 4 hours post-absorption [1], which may not accurately reflect the typical practices of athletes who generally consume food before intense exercise or competition.

To further elucidate the ergogenic potential of various mouth rinse strategies in a practical context, the current study aimed to examine the effects of combined or separated CHO and CAF mouth rinses on physiological and perceptual responses during high-intensity interval exercise (HIIE) following a pre-exercise meal. HIIE was chosen as the exercise modality for this study due to its interval nature that closely resembles the competition demands of intermittent sports that involve fluctuation in exercise intensity and efforts (e.g. soccer, rugby, and basketball), as well as its time efficiency in enhancing cardiovascular fitness compared to traditional continuous exercise [13]. Notably, limited literature exists regarding mouth rinsing in HIIE that incorporates pre-exercise CHO intake [14], which is commonly practiced by athletes before competition. We hypothesized that the combined or separated CHO and CAF mouth rinses would elicit more positive physiological and perceptual responses during HIIE compared to the placebo mouth rinse condition following a pre-exercise meal.

2. Methods

2.1. Participants

Twelve recreationally active young males with diverse sports background voluntarily participated in this study and completed all trials (Table 1). Participants were recruited through online advertisements in the university and via social media. A CONSORT flowchart is shown in Figure 1. Inclusion criteria included (1) ages 18–30 years and (2) physically active (at least 150 min of moderate or 75 min of vigorous intensity exercise per week), as evaluated by the International Physical Activity Questionnaire [15]. Exclusion criteria included (a) history of smoking; (b) diagnosis of diabetes, hypertension, cardiovascular diseases, or metabolic disorders; or (c) use of medication that would affect exercise performance and metabolic responses. Usual caffeine intake was measured by a previously published questionnaire [16]. All participants received information of the experimental procedures and provided their written informed consent. The study protocol was conducted in accordance with the Declaration of Helsinki regarding the use of human participants and was approved by the Research Ethics Committee of the University of Hong Kong School of Professional and Continuing Education. Due to a lack of direct comparisons between various mouth rinse approaches and their physiological responses following food ingestion in previous

Table 1. Characteristics of the participants ($n = 12$).

Age (years)	23.4	±	3.2
Height (cm)	172.7	±	6.5
Body weight (kg)	63.4	±	10.4
BMI (kg/m^2)	21.2	±	3.1
Body fat (%)	11.4	±	4.2
PPO (W)	241.2	±	44.1
CHO intake ($\text{g}/\text{kg}/\text{day}$)	4.4	±	1.9
Caffeine intake ($\text{mg}/\text{kg}/\text{day}$)	0.4	±	0.5

Data are presented as mean \pm SD. BMI, body mass index; CHO, carbohydrate; PPO, peak power output.

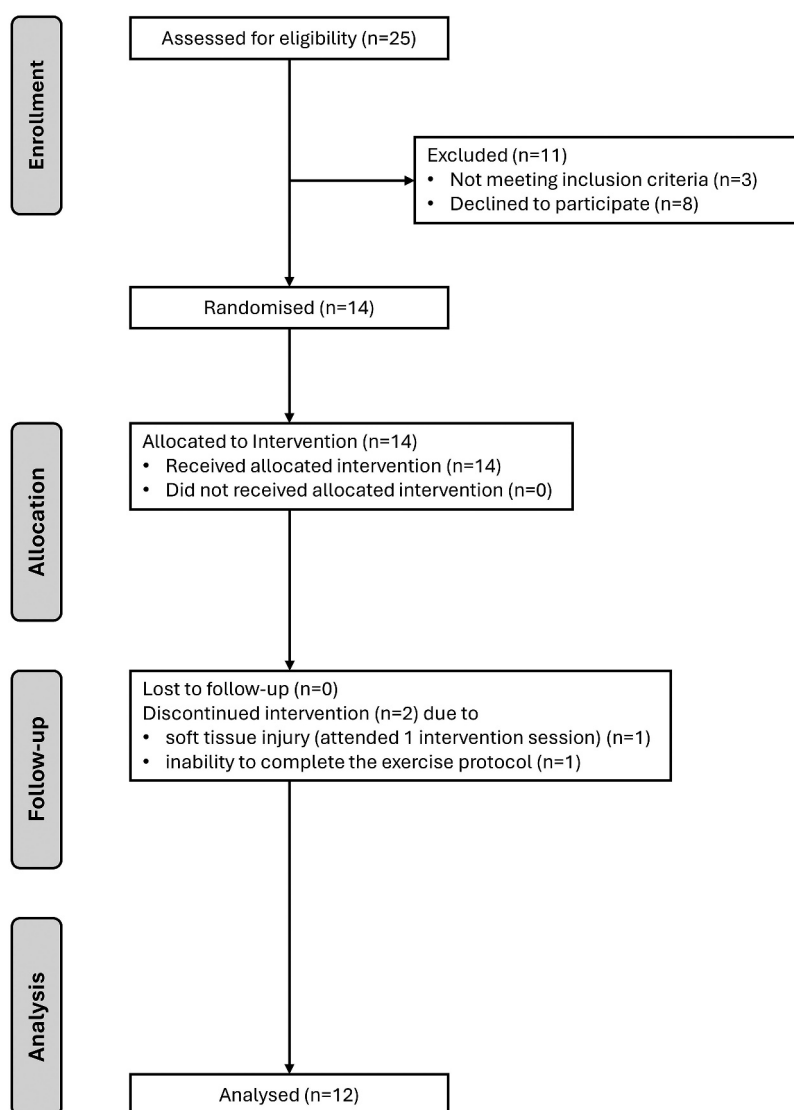


Figure 1. CONSORT flowchart.

studies, our current sample size ($n = 12$) was determined based on a review of existing literature on CHO+CAF mouth rinse [3,14,17]. This decision also considered the practical constraints of recruiting and retaining participants for an extensive exercise study with four crossover trials. Post-hoc sample size analysis is provided in the Discussion section.

2.2. Experimental design

A double-blinded, placebo-controlled, randomized crossover design was adopted. Each participant visited the Exercise Physiology Laboratory at the Chinese University of Hong Kong a total of five times at a similar time in the morning (± 2 h). Visit 1 was a preliminary test comprised of anthropometric measurement, a peak power output (PPO) test, and a familiarization session. The subsequent four visits (Visit 2–5) were main experimental trials with 5–7 days apart, with four different mouth rinse solutions. This washout period was chosen to accommodate individuals who might not be accustomed to the vigorous nature HIIE, ensuring complete recovery. This approach aligns with previous acute studies on mouth rinsing that utilized similar HIIE or repeated sprint protocols [17–19]. Figure 2 shows the schematic overview of the study design.

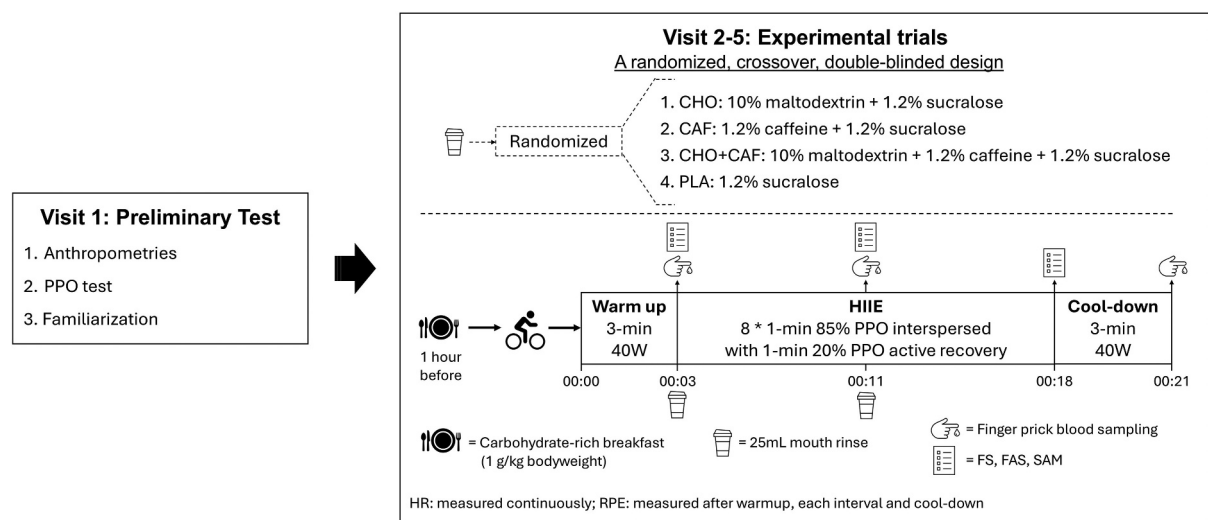


Figure 2. A schematic overview of the experimental design. CHO = carbohydrate mouth rinse; CAF = caffeine mouth rinse; CHO+CAF = combined carbohydrate and caffeine mouth rinse; PLA = placebo mouth rinse. FAS, felt arousal scale; FS, feeling scale; HR, heart rate; PPO, peak power output; RPE, rating of perceived exertion; SAM, self-assessment manikin.

2.3. Preliminary testing

All participants attended the preliminary test at least 7 days before commencing their first experimental trial. Upon arrival, participants' height and weight were measured (Seca, Leicester; MC-780 MA, Tanita, Japan, respectively) while wearing light clothing and barefoot after being asked to void their bladders. Then, an incremental cycling test was performed on an ergometer (LC7, Monark Exercise AB, Sweden) at a fixed, self-chosen pace (60–80 rpm) to determine PPO, as adapted from a previously published protocol [20]. The same ergometer was used throughout the study. Seat height and handlebar setting were adjusted to an appropriate position and duplicated in all subsequent trials for each participant. The cycling test started at 40 W for 3 min as a warm-up. Then, the workload was increased by 30 W per min. The test stopped when reaching volitional exhaustion, defined as a pedal cadence lower than 55 rpm. Encouragement was given to the participants to exert maximal effort throughout the test. The determination of PPO was based on the following formula [21]:

$$\text{PPO} = W_{\text{completed}} + (t/60 \times 30)$$

where $W_{\text{completed}}$ is the workload of the last completed workout and t is the time (seconds) of the duration of the uncompleted workout. After a sufficient rest period, as perceived by the participants (i.e. at least 15 min following the PPO tests), they were introduced to the testing procedures of the subsequent main trials and were allowed to test the intensity of the HIIE protocol and other experimental setting, which served as a familiarization session.

2.4. Experimental trials

Each participants attended four main experimental trials (Visit 2–5) after an overnight fasting. Upon arrival at the laboratory in the morning, they were provided with a CHO-rich standardized breakfast (1 g·kg⁻¹ body weight of CHO; 53.2 ± 2.7% CHO; 16.3 ± 0.3% protein; 25.5 ± 2.4% fat) composed of cereal (Weetabix, England) and milk (lactose-free, Pauls), 1 hour before the interval exercise was performed. This nutrient provision was aligned with current pre-exercise fueling guidelines, which suggest that athletes should consume 1–4 g·kg⁻¹ body weight of CHO 1–4 hours before exercise, ensuring practicality for their needs [22]. During the interim period, the participants stayed in the laboratory and only plain water was allowed for consumption. The exercise protocol consisted of a 3-min cycling warm-up at 40 W, 8 bouts of 1-min high-intensity cycling at 85% PPO separated by 1-min low-intensity recovery at 20% PPO, and a 3-min cycling cool-down at 40 W. This exercise protocol is adapted from previous studies [23,24] and has been supported for developing both aerobic and anaerobic capacities in athletes during specific periods of a periodization program [25].

2.5. Mouth rinse protocols

During each experimental trial, participants were given two boluses in 25 mL of either 10% (2.5 g) maltodextrin (MyProtein, UK) (CHO), 1.2% caffeine (300 mg) (Nutricost, USA) (CAF), 10% maltodextrin + 1.2% caffeine (CHO+CAF) or water as a placebo (PLA). The ergogenic effects of 10% CHO and 1.2% CAF mouth rinsing have been reported previously [26,27]. All solutions were flavored with 1.2% (300 mg) sucralose (BULKSUPPLEMENTS.com, USA) for taste-matching. Participants rinsed the solution within the buccal cavity for 10 s after warm-up and interval 4 (before physiological and perceptual measurements were taken). The investigators monitored the process to ensure participants' compliance. None of the participants correctly determined the order of mouth rinse solutions received.

2.6. Dietary and exercise control

Participants were asked to abstain from any intense exercise, alcohol, and caffeine the day before all testing sessions. They were informed to report their diet the day before their first experimental trials and replicate a similar diet 24 h before all subsequent sessions. Dietary intake was calculated based on a local government nutritional database (Center for Food Safety, HKSAR).

2.7. Physiological responses

Heart rate (HR) was continuously monitored by telemetry (H10 Sensor, Polar Electro, Finland). Approximately 20 μ L of whole blood was collected through finger prick sampling at three-time points: before interval 1, before interval 5, and upon completion. Portable analyzers (Contour Plus, Bayer HealthCare LLC, Diabetes Care, Tarrytown, NY, USA; Lactate Plus, Nova Biomedical, Waltham, MA, USA) were used to measure blood glucose and blood lactate concentrations.

2.8. Psychological responses

Participants indicated their responses regarding the rating of perceived exertion (RPE) after warm-up, each interval, and cool-down, using the revised 6-to-20-point scale [28]. The feeling scale (FS) [29] and the felt arousal scale (FAS) [30] were used to assess affective valence and perceived activation respectively. Affective responses were assessed by the self-assessment manikin (SAM) which comprised of three aspects: pleasure, arousal, and dominance, shown as pictorial scales [31]. FS, FAS, and SAM were measured after warm-up, after interval 4, and after interval 8. All scales were printed and visually available during the exercise protocol.

2.9. Statistical analysis

Data were analyzed using IBM SPSS software package (version 28.0; Chicago, IL, USA). Shapiro-Wilk statistics was used to confirm the normality of data. Mauchly's test of sphericity was performed with Huynh-Feldt correction for violated sphericity. A two-way repeated-measures ANOVA, with time and mouth rinse treatments as factors (i.e. independent variables), was used to examine the main and interaction effects on the outcome measures, following the approach used in previous relevant studies [16,32]. An additional one-way ANOVA was conducted at individual time points for isolating the effects of mouth rinse treatments during HIIE. This approach can provide more detailed insights into how each treatment performs at different stages of the exercise protocol and help identify if there are significant effects that might be masked in the two-way ANOVA due to interaction effects. When statistical significance was observed, post hoc tests were performed with Bonferroni adjustment to reduce the likelihood of false positive findings under multiple comparisons. The effect size was expressed as partial eta squared (η_p^2) with 0.01 as small, 0.06 as moderate, and > 0.14 as large [33]. All data are reported as mean \pm SD unless otherwise specified. The significance was set at $p \leq 0.05$.

3. Results

The physiological and perceptual responses across different mouth rinse conditions at each individual time point are shown in [Table 2](#).

3.1. Physiological responses

HR significantly changed over time during interval exercise ($p < 0.001$) but no main effect by treatment ($p = 0.966$, $\eta_p^2 = 0.008$) or Treatment \times Time interaction ($F_{22,069, 242.761} = 0.618$, $p = 0.910$, $\eta_p^2 = 0.053$) was observed. Blood glucose and blood lactate significantly increased over time ($p < 0.001$). There was no main effect by treatment ($p = 0.899$, $\eta_p^2 = 0.017$) or Treatment \times Time interactions ($F_{3,548, 39.028} = 1.312$, $p = 0.284$, $\eta_p^2 = 0.107$) on blood glucose. Similarly, no main effects of treatment ($p = 0.173$, $\eta_p^2 = 0.138$) or Treatment \times Time interactions ($F_{3,33} = 0.622$, $p = 0.712$, $\eta_p^2 = 0.054$) were observed for blood lactate.

3.2. Perceptual responses

RPE significantly increased over time during interval exercise ($p < 0.001$) and there was no significant main effect by treatments ($p = 0.436$, $\eta_p^2 = 0.078$). As shown in [Table 2](#), however, differences in RPE between treatment conditions approached significance after interval 4 ($p = 0.049$, $\eta_p^2 = 0.210$), with large effect sizes. The lowest RPE was observed for CHO mouth rinse after warm-up and interval 4. However, post hoc tests showed no significant results among all paired conditions ($p > 0.05$, Supplementary Table S1).

There were no main effects by treatment ($p = 0.494$, $\eta_p^2 = 0.069$) and by time ($p = 0.331$), and no Treatment \times Time interaction ($F_{3, 33} = 0.315$, $p = 0.927$, $\eta_p^2 = 0.028$) for FS. FAS significantly changed over time but no main effect by treatment ($p = 0.451$, $\eta_p^2 = 0.072$) or Treatment \times Time interaction ($F_{3, 33} = 0.902$, $p = 0.499$, $\eta_p^2 = 0.076$) was observed.

For SAM, there was a main effect by time on arousal ($p < 0.001$) but not pleasure ($p = 0.103$) and dominance ($p = 0.718$). Pleasure ($p = 0.482$, $\eta_p^2 = 0.071$), arousal ($p = 0.531$, $\eta_p^2 = 0.064$) and dominance ($p = 0.500$, $\eta_p^2 = 0.068$) were not significantly different between treatment conditions. Also, no Treatment \times Time interactions were observed in pleasure ($F_{3, 33} = 0.630$, $p = 0.705$, $\eta_p^2 = 0.054$), arousal ($F_{3, 33} = 0.657$, $p = 0.685$, $\eta_p^2 = 0.056$) and dominance ($F_{3, 33} = 0.719$, $p = 0.635$, $\eta_p^2 = 0.061$).

4. Discussion

The primary findings of our study indicated that neither combined nor separated mouth rinse of CHO and CAF improved overall physiological (HR, blood glucose, and blood lactate) and perceptual (RPE, FS, FAS, and SAM) responses during a 21-min interval cycling protocol, which contradicts our hypothesis. However, trends of a significant effect of mouth rinsing over time on RPE, particularly by CHO solution, were observed after warm-up and interval 4, when mouth rinsing was performed.

In line with previous studies that examined the ergogenic effects of combined mouth rinse on HIIE postprandially [14,34], our results suggest a limited benefit after a standardized CHO intake. Gough et al. [14] examined the effects of CHO+CAF mouth rinse on repeated sprint test performance (at 75th min) during a 90-min simulated soccer match. The authors reported no significant improvement in power output and physiological and perceptual responses by CHO and/or CAF mouth rinse during the sprint test, after participants consumed a high CHO ($2 \text{ g}\cdot\text{kg}^{-1}$) meal 2 hours before each trial. Similarly, after only 3 hours of fasting, Devenney et al. [34] reported no differences in exercise capacity, HR, blood lactate, and RPE between CHO mouth rinse and placebo during HIIE. Notably, caffeine ingestion augmented CHO mouth rinse and increased distances to exhaustion compared to sole CHO mouth rinse and placebo, implying a smaller effect of mouth rinsing compared to traditional ergogenic aid. Indeed, the limitation of gustatory stimulation following food ingestion has been reported with neuroimaging evidence. Haase et al. [35] reported that taste stimuli by sucrose and caffeine elicited greater activation of brain regions relating to sensory reception when fasted and lower activation of regions relating to emotional and motivational responses when fed. These

Table 2. Physiological and perceptual responses across different mouth rinse conditions at each time point ($n = 12$).

	CHO	CAF	CHO+CAF	PLA	<i>p</i>
HR (beats/min)					
Baseline	84 ± 11	83 ± 9	86 ± 6	87 ± 7	0.490
Post warm-up	114 ± 10	112 ± 10	113 ± 13	115 ± 15	0.850
Work interval 1	137 ± 10	136 ± 8	137 ± 9	136 ± 10	0.823
Recovery interval 1	124 ± 8	124 ± 6	124 ± 7	125 ± 10	0.959
Work interval 2	146 ± 9	145 ± 9	146 ± 8	147 ± 11	0.787
Recovery interval 2	129 ± 8	132 ± 8	131 ± 8	130 ± 11	0.726
Work interval 3	152 ± 8	153 ± 7	153 ± 7	154 ± 12	0.876
Recovery interval 3	136 ± 8	136 ± 7	136 ± 8	135 ± 11	0.975
Work interval 4	156 ± 8	158 ± 8	157 ± 8	158 ± 11	0.800
Recovery interval 4	144 ± 9	144 ± 10	143 ± 7	143 ± 10	0.921
Work interval 5	160 ± 7	159 ± 8	160 ± 8	161 ± 11	0.580
Recovery interval 5	142 ± 8	143 ± 8	143 ± 8	143 ± 12	0.917
Work interval 6	162 ± 7	164 ± 7	163 ± 7	163 ± 11	0.856
Recovery interval 6	146 ± 8	145 ± 10	145 ± 9	146 ± 13	0.953
Work interval 7	165 ± 7	165 ± 7	165 ± 7	166 ± 11	0.938
Recovery interval 7	146 ± 9	145 ± 10	148 ± 10	148 ± 11	0.546
Work interval 8	167 ± 7	166 ± 8	168 ± 8	167 ± 11	0.413
Post cool-down	125 ± 11	125 ± 10	122 ± 10	123 ± 12	0.594
RPE					
Post warm-up	7.3 ± 1.2	8.3 ± 1.5	8.4 ± 1.9	8.3 ± 2.1	0.088
Interval 1	9.1 ± 1.4	10.1 ± 2.1	9.6 ± 1.6	9.7 ± 1.3	0.298
Interval 2	10.8 ± 1.4	11.3 ± 1.8	10.5 ± 1.6	10.6 ± 1.4	0.457
Interval 3	11.9 ± 1.2	12.3 ± 1.4	11.6 ± 1.6	12.0 ± 2.2	0.688
Interval 4	12.3 ± 1.6	13.5 ± 2.2	12.7 ± 1.7	13.7 ± 2.4	0.049
Interval 5	12.9 ± 1.9	13.7 ± 1.9	13.5 ± 2.1	13.8 ± 2.7	0.422
Interval 6	13.8 ± 2.3	14.5 ± 2.4	14.3 ± 2.6	14.7 ± 2.7	0.473
Interval 7	14.4 ± 3.0	14.9 ± 2.5	15.1 ± 3.0	15.5 ± 2.7	0.419
Interval 8	15.5 ± 2.9	16.1 ± 3.0	16.0 ± 2.6	16.5 ± 2.4	0.583
Post cool-down	11.1 ± 2.4	10.1 ± 2.0	11.3 ± 2.7	11.3 ± 2.8	0.227
Blood Glucose (mmol/L)					
Post warm-up	5.2 ± 0.9	5.5 ± 1.6	5.5 ± 1.0	5.3 ± 0.8	0.482
Interval 4	4.4 ± 0.7	4.3 ± 0.9	4.5 ± 0.7	4.4 ± 0.5	0.767
Post cool-down	4.7 ± 1.1	4.3 ± 0.6	4.5 ± 0.4	4.7 ± 1.3	0.543
Blood Lactate (mmol/L)					
Post warm-up	2.1 ± 0.4	2.3 ± 0.8	2.4 ± 1.0	2.7 ± 1.7	0.436
Interval 4	6.7 ± 1.1	6.7 ± 0.8	7.0 ± 0.9	6.6 ± 1.1	0.479
Post cool-down	7.6 ± 1.9	7.7 ± 1.8	8.3 ± 1.5	8.1 ± 1.9	0.338
F5					
Post warm-up	2.3 ± 2.1	1.8 ± 1.8	1.8 ± 1.9	1.7 ± 2.1	0.546
Interval 4	1.5 ± 1.8	1.2 ± 1.9	0.8 ± 2.5	1.0 ± 2.1	0.673
Interval 8	1.5 ± 2.7	1.3 ± 2.6	1.2 ± 2.5	0.8 ± 3.0	0.562
FAS					
Post warm-up	2.4 ± 1.3	2.9 ± 0.8	2.8 ± 1.1	2.9 ± 1.2	0.384
Interval 4	3.8 ± 1.1	3.7 ± 0.9	3.8 ± 1.2	4.1 ± 1.1	0.386
Interval 8	4.4 ± 1.2	4.8 ± 0.9	4.6 ± 0.8	4.7 ± 1.1	0.621
SAM – Pleasure					
Post warm-up	2.2 ± 0.9	2.3 ± 0.9	2.2 ± 0.9	2.3 ± 1.2	0.782
Interval 4	2.4 ± 0.8	2.8 ± 0.7	2.6 ± 1.1	2.9 ± 1.0	0.174
Interval 8	2.8 ± 1.1	2.7 ± 1.2	2.6 ± 1.0	2.8 ± 1.1	0.820
SAM – Arousal					
Post warm-up	3.3 ± 1.5	3.5 ± 1.1	3.6 ± 1.1	3.3 ± 0.9	0.774
Interval 4	2.3 ± 0.8	2.7 ± 0.8	2.5 ± 0.7	2.8 ± 1.1	0.189
Interval 8	2.3 ± 1.1	2.5 ± 1.1	2.1 ± 0.9	2.3 ± 0.8	0.559
SAM – Dominance					
Post warm-up	3.4 ± 1.1	3.1 ± 1.1	3.2 ± 1.4	2.9 ± 0.9	0.569
Interval 4	3.1 ± 0.8	3.1 ± 0.7	2.8 ± 1.1	3.2 ± 0.6	0.466
Interval 8	3.3 ± 1.0	3.0 ± 1.3	2.8 ± 1.2	3.0 ± 1.1	0.510

Data are presented as mean ± SD. *p* -values shown were obtained from one-way repeated measures ANOVA. CHO = carbohydrate mouth rinse; CAF = caffeine mouth rinse; CHO+CAF = combined carbohydrate and caffeine mouth rinse; PLA = placebo. HR, heart rate; FAS, felt arousal scale; FS, feeling scale; RPE, rating of perceived exertion; SAM, self-assessment manikin.

differences in neuronal activation have further consolidated the findings by Fares and Kayser [36] and Lane et al. [37]. Both studies observed a lower performance-enhancing effect of CHO mouth rinse in following food ingestion comparing a fasted state. Although the moderation effect of acute dietary status on CAF mouth rinse has not been explicitly studied, it is plausible that the oral CAF represents similar restrictions. Washif et al. [38] reported increased arousal by CHO+CAF mouth rinse compared to no mouth rinse in repeated sprints (3 × 15 s sprint by 2 min active recovery). This ergogenic effect might be explained by

overnight fasting during Ramadan in this study. Conversely, Taheri Karami et al. [4] suggested an ergogenic effect of mouth rinsing regardless of exercising in a fed state. CAF mouth rinse improved shuttle running capacity after consuming a standardized breakfast (~60 g CHO). However, CAF mouth rinse in this study was performed using mixture of caffeinated and decaffeinated coffee to achieve targeted concentrations of caffeine. Other chemicals in coffee such as tannin also contribute to its bitter taste and may lead to a stronger neuronal activation through bitter taste stimulation [39].

Although there was no significant treatment effect over time by mouth rinsing CHO and/or CAF solution in the present study, we observed trends of between-condition differences in perceived exertion immediately after mouth rinsing (after warm-up and interval 4). Beaven et al. [3] reported increased mean power of sprint 1 by either CHO or CAF mouth rinse compared to placebo in repeated sprints (5 × 6 s sprint by 24 s active recovery). Increased peak power of sprint 1 and mean power of sprint 5 by CHO+CAF mouth rinse compared to CHO mouth rinse were observed as well, despite being non-statistically significant with moderate-large effect size (Cohen's $d = 0.66$ – 0.81). Collectively, these findings suggest that mouth rinsing may offer benefits in shorter-duration protocols that involve multiple rinses and/or frequent measurements. The previous work by Gough et al. [14] found no differences in performance between the first repeated sprint test (0th min) and the second repeated sprint test (75th min) while mouth rinsing was performed once only (immediately before 75th min). Although Devenney et al. [34] applied multiple mouth rinsing (5 s mouth rinse every second interval [4 min]) and found no effects of sole CHO mouth rinse on HIIE postprandially, measurements were taken every 5–10 min. Most studies [3,38] and the current study employed multiple mouth rinsing with outcome measurements on every interval/sprint (6 s–2 min) found between-condition differences in specific time points but not continuously. This suggests that the benefit of mouth rinsing tends to be acute and small and less likely to be sustained over time. Especially during HIIE, a ceiling effect of physiological or psychological measurement upon exertion of high intensity effort has been hypothesized [3]. As the high exercise load has elicited submaximal responses, changes in these outcome variables might become less sensitive to interventions, hence limiting the observation of potential benefits.

Our study has several strengths, including the use of a double-blinded, placebo-controlled design and randomized cross-over design, which enhances the robustness of the methodology. Conducting HIIE protocols following a pre-exercise breakfast also provides high external validity and practical relevance, as it closely mimics the typical practices of athletes before exercise in the morning. However, this study presented several limitations. First, due to the lack of relevant pilot data, an a priori sample size calculation was not conducted. While our current sample size ($n = 12$) may result in insufficient statistical power to detect difference in certain outcomes, we performed post-hoc effect size analyses based on the significant result observed for the RPE, which is our primary outcome variable. Using the partial eta-squared ($\eta_p^2 = 0.21$) from the ANOVA results, we calculated Cohen's f effect size as 0.52. With a significance level (α) of 0.05 and power ($1 - \beta$) of 0.80, the post-hoc power analysis indicated that a sample size of at least 10 participants would be sufficient to detect the observed effect after adjusting for nonsphericity. Our study included 12 participants, which falls within this range and achieves an actual power of ~88%, suggesting that our study was adequately powered to detect differences in RPE between conditions. These findings provide valuable preliminary evidence, and we acknowledge that future studies with larger sample sizes and a priori sample size calculations are warranted to confirm these results. Secondly, our results were limited to recreationally active individuals, and elite athletes may experience even small ergogenic benefits from mouth rinsing. Future studies should investigate this application in individuals with higher fitness levels. Additionally, the exclusive inclusion of male participants restricts the generalizability of our findings. Future research should incorporate female participants and examine variations throughout the entire menstrual cycle, as hormonal variations may affect metabolic and exercise responses to mouth rinses [40]. Furthermore, our study utilized a 10 × 1-minute sprint protocol to address the demands of team-based intermittent sports. While shorter intervals may better simulate high-intensity bursts, our focus on longer intervals aimed to enhance both aerobic and anaerobic capacities, reflecting practices in some periodization programs [25]. Future research should explore shorter interval protocols to further evaluate their effectiveness in training athletes for intermittent sports, thereby providing a more comprehensive understanding of optimal training strategies. Lastly, the exercise intensity of our HIIE protocol was controlled and pre-determined at 85% PPO, limiting our ability to assess changes in performance variables such as mean power and peak power. Nonetheless, this approach mitigates pacing challenges, as participants might have overexerted themselves in the initial

sprints if allowed to reach their highest power output within our relatively 'endurance-based' protocol. This could introduce confounding factors related to pacing strategies and potential learning effects across trial conditions, ultimately compromising the robustness of our results. Conversely, our current methodological approach enables a fair comparison of physiological and perceptual responses while exercising at a consistent intensity across different treatment conditions. This provides valuable insights for exercise professionals, particularly regarding how mouth rinse strategies may influence training load, perceived exertion, and emotional arousal during endurance capacity training.

In conclusion, our results suggest limited benefits of mouth rinsing CHO and/or CAF solutions during HIIE following a pre-exercise meal. However, CHO and/or CAF mouth rinsing presents minimal side effects. The feasibility of performing mouth rinsing during the recovery period of HIIE retains practical significance, particularly in scenarios where food or supplementation intake is discouraged during competition. As a greater impact of mouth rinsing is expected under the absence of pre-exercise meals, athletes who often train in a fasted condition (e.g. those in weight category sports for weight control or those specifically training under a low carbohydrate availability for specific metabolic [41]) may be able to mitigate declines in training quality under these circumstances. Further investigation on the determinants of the ergogenic effects of mouth rinse, such as the mouth rinse protocol, ideal dosage and types of exercise, would benefit the development of practical guidelines to coaches and athletes.

Acknowledgments

we would like to thank all the participants in this study. We also thank the laboratory staffs for conducting the blinding for the solutions and randomization for the crossover order.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Chinese University of Hong Kong under Direct Grant for Research.

ORCID

Mickey Wai-Kit Suen  <http://orcid.org/0009-0004-3321-0298>

Fenghua Sun  <http://orcid.org/0000-0001-5251-4087>

Ajmol Ali  <http://orcid.org/0000-0002-6093-1435>

Eric Tsz-Chun Poon  <http://orcid.org/0000-0002-0842-1323>

Authorship

MS and EP conceptualized the study design. MS collected the data, performed the data analysis and prepared the first draft. FS, AA, and EP revised the manuscript. EP supervised this study.

References

1. Carter JM, Jeukendrup AE, Jones DA. The effect of carbohydrate mouth rinse on 1-h cycle time trial performance. *Med Sci Sports Exerc.* 2004 Dec;36(12):2107–2111. doi: [10.1249/01.MSS.0000147585.65709.6F](https://doi.org/10.1249/01.MSS.0000147585.65709.6F)
2. Shirai A, Wadazumi T, Hirata Y, et al. Carbohydrate mouth rinse and spray improve prolonged exercise performance in recreationally trained male college students. *Sports (Basel).* 2022 Mar 29;10(4):51. doi: [10.3390/sports10040051](https://doi.org/10.3390/sports10040051)
3. Beaven CM, Maulder P, Pooley A, et al. Effects of caffeine and carbohydrate mouth rinses on repeated sprint performance. *Appl Physiol Nutr Metab.* 2013 Jun;38(6):633–637. doi: [10.1139/apnm-2012-0333](https://doi.org/10.1139/apnm-2012-0333)
4. Taheri Karami G, Hemmatinavar M, Koushkie Jahromi M, et al. Repeated mouth rinsing of coffee improves the specific-endurance performance and jump performance of young male futsal players. *J Int Soc Sports Nutr.* 2023 Dec;20(1):2214108. doi: [10.1080/15502783.2023.2214108](https://doi.org/10.1080/15502783.2023.2214108)

5. Pomportes L, Brisswalter J, Casini L, et al. Cognitive performance enhancement induced by caffeine, carbohydrate and guarana mouth rinsing during submaximal exercise. *Nutrients*. 2017 Jun 9;9(6):589. doi: [10.3390/nu9060589](https://doi.org/10.3390/nu9060589)
6. Chambers ES, Bridge MW, Jones DA. Carbohydrate sensing in the human mouth: effects on exercise performance and brain activity. *J Physiol*. 2009 Apr 15;587(Pt 8):1779–1794. doi: [10.1113/jphysiol.2008.164285](https://doi.org/10.1113/jphysiol.2008.164285)
7. De Pauw K, Roelands B, Knaepen K, et al. Effects of caffeine and maltodextrin mouth rinsing on P300, brain imaging, and cognitive performance. *J Appl Physiol* (1985). 2015 Mar 15;118(6):776–782. doi: [10.1152/jappphysiol.01050.2014](https://doi.org/10.1152/jappphysiol.01050.2014)
8. de Oliveira EP, Burini RC. Carbohydrate-dependent, exercise-induced gastrointestinal distress. *Nutrients*. 2014 Oct 13;6(10):4191–4199. doi: [10.3390/nu6104191](https://doi.org/10.3390/nu6104191)
9. de Souza JG, Del Coso J, Fonseca FS, et al. Risk or benefit? Side effects of caffeine supplementation in sport: a systematic review. *Eur J Nutr*. 2022 Dec;61(8):3823–3834. doi: [10.1007/s00394-022-02874-3](https://doi.org/10.1007/s00394-022-02874-3)
10. Poon ETC, Tsang JH, Sun F, et al. Exploring the ergogenic potential of carbohydrate-caffeine combined mouth rinse on exercise and cognitive performance: a systematic review. *Appl Physiol Nutr Metab*. 2024 Aug 21;49(12):1611–1621. doi: [10.1139/apnm-2024-0228](https://doi.org/10.1139/apnm-2024-0228)
11. de Ataíde e Silva T, Di Cavalcanti Alves de Souza ME, de Amorim JF, et al. Can carbohydrate mouth rinse improve performance during exercise? A systematic review. *Nutrients*. 2013 Dec 19;6(1):1–10. doi: [10.3390/nu6010001](https://doi.org/10.3390/nu6010001)
12. Rollo I, Cole M, Miller R, et al. Influence of mouth rinsing a carbohydrate solution on 1-h running performance. *Med Sci Sports exerc*. 2010 Apr;42(4):798–804. doi: [10.1249/MSS.0b013e3181bac6e4](https://doi.org/10.1249/MSS.0b013e3181bac6e4)
13. Poon ET, Li HY, Gibala MJ, et al. High-intensity interval training and cardiorespiratory fitness in adults: an umbrella review of systematic reviews and meta-analyses. *Scand J Med Sci Sports*. 2024 May;34(5):e14652. doi: [10.1111/sms.14652](https://doi.org/10.1111/sms.14652)
14. Gough LA, Faghy M, Clarke N, et al. No independent or synergistic effects of carbohydrate-caffeine mouth rinse on repeated sprint performance during simulated soccer match play in male recreational soccer players. *Sci Med Footb*. 2022 Nov;6(4):519–527. doi: [10.1080/24733938.2021.2021277](https://doi.org/10.1080/24733938.2021.2021277)
15. Craig CL, Marshall AL, Sjostrom M, et al. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc*. 2003 Aug;35(8):1381–1395. doi: [10.1249/01.MSS.0000078924.61453.FB](https://doi.org/10.1249/01.MSS.0000078924.61453.FB)
16. Karayigit R, Ali A, Rezaei S, et al. Effects of carbohydrate and caffeine mouth rinsing on strength, muscular endurance and cognitive performance. *J Int Soc Sports Nutr*. 2021 Sep 26;18(1):63. doi: [10.1186/s12970-021-00462-0](https://doi.org/10.1186/s12970-021-00462-0)
17. Dolan P, Witherbee KE, Peterson KM, et al. Effect of carbohydrate, caffeine, and carbohydrate + caffeine mouth rinsing on intermittent running performance in collegiate male lacrosse athletes. *J Strength Cond Res*. 2017 Sep;31(9):2473–2479. doi: [10.1519/JSC.0000000000001819](https://doi.org/10.1519/JSC.0000000000001819)
18. Krings BM, Peterson TJ, Shepherd BD, et al. Effects of carbohydrate ingestion and carbohydrate mouth rinse on repeat sprint performance. *Int J Sport Nutr Exerc Metab*. 2017 Jun;27(3):204–212. doi: [10.1123/ijsnem.2016-0321](https://doi.org/10.1123/ijsnem.2016-0321)
19. Kizzi J, Sum A, Houston FE, et al. Influence of a caffeine mouth rinse on sprint cycling following glycogen depletion. *Eur J Sport Sci*. 2016 Nov;16(8):1087–1094. doi: [10.1080/17461391.2016.1165739](https://doi.org/10.1080/17461391.2016.1165739)
20. Lee DCW, Sheridan S, Ali A, et al. Wearing compression tights post-exercise enhances recovery hemodynamics and subsequent cycling performance. *Eur J Appl Physiol*. 2021 Jul;121(7):2091–2100. doi: [10.1007/s00421-021-04661-0](https://doi.org/10.1007/s00421-021-04661-0)
21. Luttkohl H, McNaughton LR, Midgley AW, et al. A prediction model for peak power output from different incremental exercise tests. *Int J Sports Physiol Perform*. 2006 Jun;1(2):122–136. doi: [10.1123/ijssp.1.2.122](https://doi.org/10.1123/ijssp.1.2.122)
22. Thomas DT, Erdman KA, Burke LM. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: nutrition and athletic performance. *J Acad Nutr Diet*. 2016 Mar;116(3):501–528. doi: [10.1016/j.jand.2015.12.006](https://doi.org/10.1016/j.jand.2015.12.006)
23. Saner NJ, Lee MJ, Kuang J, et al. Exercise mitigates sleep-loss-induced changes in glucose tolerance, mitochondrial function, sarcoplasmic protein synthesis, and diurnal rhythms. *Mol Metab*. 2021 Jan;43:101110. doi: [10.1016/j.molmet.2020.101110](https://doi.org/10.1016/j.molmet.2020.101110)
24. Jiaqi Z, Zihan D, Heung-Sang Wong S, et al. Acute effects of various doses of nitrate-rich beetroot juice on high-intensity interval exercise responses in women: a randomized, double-blinded, placebo-controlled, crossover trial. *J Int Soc Sports Nutr*. 2024 Dec;21(1):2334680. doi: [10.1080/15502783.2024.2334680](https://doi.org/10.1080/15502783.2024.2334680)
25. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: part I: cardiopulmonary emphasis. *Sports Med*. 2013 May;43(5):313–338. doi: [10.1007/s40279-013-0029-x](https://doi.org/10.1007/s40279-013-0029-x)
26. da Silva WF, Lopes-Silva JP, Camati Felipe LJ, et al. Is caffeine mouth rinsing an effective strategy to improve physical and cognitive performance? A systematic review. *Crit Rev Food Sci Nutr*. 2023;63(3):438–446. doi: [10.1080/10408398.2021.1949576](https://doi.org/10.1080/10408398.2021.1949576)
27. Hartley C, Carr A, Bowe SJ, et al. Maltodextrin-based carbohydrate oral rinsing and exercise performance: systematic review and meta-analysis. *Sports Med*. 2022 Aug;52(8):1833–1862. doi: [10.1007/s40279-022-01658-3](https://doi.org/10.1007/s40279-022-01658-3)
28. Borg G. Borg's perceived exertion and pain scales. Champaign (IL): Human Kinetics; 1998.
29. Hardy CJ, Rejeski WJ. Not what, but how one feels: the measurement of affect during exercise. *J Sport Exerc Psychol*. 1989;11(3):304–317. doi: [10.1123/jsep.11.3.304](https://doi.org/10.1123/jsep.11.3.304)
30. Svebak S, Murgatroyd S. Metamotivational dominance - a multimethod validation of reversal theory constructs. *J Pers Soc Psychol*. 1985;48(1):107–116. doi: [10.1037/0022-3514.48.1.107](https://doi.org/10.1037/0022-3514.48.1.107)

31. Bradley MM, Lang PJ. Measuring emotion: the self-assessment manikin and the semantic differential. *J Behav Ther Exp Psychiatry*. 1994 Mar;25(1):49–59. doi: [10.1016/0005-7916\(94\)90063-9](https://doi.org/10.1016/0005-7916(94)90063-9)
32. Konishi K, Kimura T, Yuhaku A, et al. Mouth rinsing with a carbohydrate solution attenuates exercise-induced decline in executive function. *J Int Soc Sports Nutr*. 2017 11 22;14(1):45. doi: [10.1186/s12970-017-0200-0](https://doi.org/10.1186/s12970-017-0200-0)
33. Cohen J. *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale, N.J.: L. Erlbaum Associates; 1988.
34. Devenney S, Mangan S, Shortall M, et al. Effects of carbohydrate mouth rinse and caffeine on high-intensity interval running in a fed state. *Appl Physiol Nutr Metab*. 2018 May;43(5):517–521. doi: [10.1139/apnm-2017-0458](https://doi.org/10.1139/apnm-2017-0458)
35. Haase L, Cerf-Ducastel B, Murphy C. Cortical activation in response to pure taste stimuli during the physiological states of hunger and satiety. *Neuroimage*. 2009 Feb 1;44(3):1008–1021. doi: [10.1016/j.neuroimage.2008.09.044](https://doi.org/10.1016/j.neuroimage.2008.09.044)
36. Fares EJ, Kayser B. Carbohydrate mouth rinse effects on exercise capacity in pre- and postprandial states. *J Nutr Metab*. 2011;2011:1–6. doi: [10.1155/2011/385962](https://doi.org/10.1155/2011/385962)
37. Lane SC, Bird SR, Burke LM, et al. Effect of a carbohydrate mouth rinse on simulated cycling time-trial performance commenced in a fed or fasted state. *Appl Physiol Nutr Metab*. 2013 Feb;38(2):134–139. doi: [10.1139/apnm-2012-0300](https://doi.org/10.1139/apnm-2012-0300)
38. Washif JA, Hebert-Losier K, Chamari K, et al. Caffeine-carbohydrate mouth-rinsing counter-acts an observed negative effect of mouth-rinsing procedure during sprint-endurance training performance in fasted athletes: a pilot study. *Biol Sport*. 2022 Oct;39(4):865–873. doi: [10.5114/biolSport.2022.109959](https://doi.org/10.5114/biolSport.2022.109959)
39. Soares S, Brandão E, Guerreiro C, et al. Tannins in food: insights into the molecular perception of astringency and bitter taste. *Molecules*. 2020 Jun 2;25(11):2590. doi: [10.3390/molecules25112590](https://doi.org/10.3390/molecules25112590)
40. Helm MM, McGinnis GR, Basu A. Impact of nutrition-based interventions on athletic performance during menstrual cycle phases: a review. *Int J Environ Res Public Health*. 2021 Jun 10;18(12):6294. doi: [10.3390/ijerph18126294](https://doi.org/10.3390/ijerph18126294)
41. Bartlett JD, Hawley JA, Morton JP. Carbohydrate availability and exercise training adaptation: too much of a good thing? *Eur J Sport Sci*. 2015 01 02;15(1):3–12. doi: [10.1080/17461391.2014.920926](https://doi.org/10.1080/17461391.2014.920926)