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Carbohydrate ingestion but not mouth rinse maintains sustained attention when fasted

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HIGHLIGHTS

- We compared ingestion versus mouth rinse of isocaloric carbohydrate on attention.
- Ingesting only 1.5 g carbohydrate provided cognitive benefits in a fasted state
- Mouth rinsing isocaloric carbohydrate did not provide similar benefits as ingestion
- Prevention of mental fatigue with low carbohydrate was not related to blood glucose

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ABSTRACT

Carbohydrate (CHO) receptors in the mouth signal brain areas involved in cognitive tasks relying upon motivation and task persistence; however, the minimal CHO dose that improves mental activity is unclear.

Purpose: To determine if CHO (via ingestion or oral rinse) influences sustained attention without eliciting glycemic responses when in a fasted state.

Methods: Study A: Six healthy adults completed five treatment trials, ingesting 0–6% CHO solutions to evaluate glycemic response. Peak blood glucose for 6% and 1.5% CHO was greater ($p < 0.05$) than 0% and 0.4% CHO; thus, the low 0.4% CHO was evaluated further. Study B: Following an overnight fast, ten healthy adults completed three trials in a crossover design: 1) 400 ml 0.4% CHO ingested serially via 25 ml boluses, 2) 375 ml 0% CHO control (CON) ingested followed by one 25 ml 6% CHO isocaloric (1.5 g CHO) mouth rinse, and 3) CON ingest followed by CON rinse. Following treatments, a 20 min Continuous Performance Task (CPT) was performed to assess accuracy and precision.

Results: Accuracy and precision were not different during the first 5 min of CPT. However, accuracy was maintained with CHO ingest ($p = 1.0$) but decreased over 20 min ($p < 0.05$) with both CHO and CON rinse treatments. Precision tended to decline over 20 min CPT with CON ($p = 0.06$) and CHO rinse ($p = 0.05$) but were maintained with CHO ingest ($p = 1.0$). No differences in glycemic responses were observed between treatments.

Conclusions: Compared to mouth rinsing CON or CHO (1.5 g in 6% CHO), ingestion of an isocaloric low-CHO drink maintained sustained attention over a mentally fatiguing task and appears effective after fasting without eliciting a glycemic response.

1. Introduction

Commonly ingested carbohydrate (CHO) drinks (i.e. sports drinks, juices, and energy drinks) contain sugar and calories (i.e. 6–12 g CHO or 24–48 kcal in 100 ml) and may have health-related consequences (i.e. dental caries, obesity, insulin resistance, diabetes) [1–3]. Thus, recommendations are to limit daily sugar intake to 30–45 g/d [4]. Due to these health concerns, low-CHO drinks have become increasingly popular particularly under sedentary conditions; however, research to support the potential efficacy for them is lacking. Aside from being an effective aid for physical performance, CHO may also benefit cognition, particularly during mentally fatiguing tasks [5–8].

Carbohydrate is essential for brain function although performance of mental tasks may not be dependent on CHO metabolism or related to blood glucose levels [7,9]. Whether the glycemic index of meal ingestion influences post-prandial cognitive function also remains inconclusive [10]. Moreover, prolonged mental work requiring sustaining attention over time does not consistently elicit glycemic changes [11]; and, measures of systemic blood glucose are not necessarily reflective of cerebral blood glucose during mental tasks [12–14]. Yet, provision of glucose may improve mental performance [14] by eliciting a sensory signal to the central nervous system (CNS) triggered by taste receptors and

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possibly oral receptors responsive to caloric properties of carbohydrate [15,16]. Glucose in the mouth is evidenced to activate brain areas involved in cognitive behavior related to decision making, attentional processing, allocation of neural resources, and motivation and reward [15], thus providing support for a central mechanism by which CHO may help to sustain effort during a mental or physical task [13,14,17].

Evidence that CHO can act as an acute signal to influence task performance independent of glycemic fluctuation and insulin response [15, 18] is provided in studies by either ingesting [14] or administering a CHO bolus swirled in the mouth for a short duration (5–10 s), then expectorated rather than ingested immediately prior to a task [19,20]. The simple presence of as little as 1.5 g CHO (25 ml of solution of 6% CHO) in the mouth versus artificially-sweetened placebo benefits mental task performance requiring self-control [19–22] when performed after >3 h of fasting [19]. Even though taste and ingestion of artificially-sweetened beverages may be pleasurable and stimulate brain reward centers, the same behavioral effects may not be observed as with CHO energy-containing drinks [14,23]. During a fatiguing task, individuals must continuously evaluate cost versus benefit of continuing to allocate effort and attention to the task [13]. Participants maintain better self-control (e.g. attention, impulsivity, cognitive processing) through a proposed mechanism triggered by stimulation of oral receptors by CHO [15, 24]. Brain imaging studies using fMRI [15,25] suggest sensory input from CHO in the mouth activates the brain's reward systems and influence persistence during performance tasks which require maintaining attention to a goal [7,9,26].

While CHO mouth rinse triggers a CNS-response, CHO ingestion may also influence task performance through central *and* peripheral mechanisms. Therefore, studies should compare rinse and ingest conditions in parallel to partition the effects on cognitive behavior [19]. The dose and type of CHO ingested that may enhance cognition is unclear [14]. In animals, doses as low as 10 mg/kg glucose can improve memory; [27] whereas, in humans, the dose appears to be ~300 mg/kg (~20 g), and with greater effect during more difficult tasks or when attention is divided between multiple tasks [14,28].

Further research on the dose–response relationship of glucose to behavior is warranted in humans with additional consideration to the method of administration (i.e. ingest versus rinse) [14,19,28]. The minimum amount of CHO ingested that elicits a cognitive benefit without a glycemic effect is unknown. Thus, the aim of the present study was twofold. In Study A, we determined the amount of CHO that, when ingested, would not significantly elevate blood glucose; and, in Study B we determined the “central” effects of two methods of CHO administration (ingestion of a low dose CHO versus isocaloric CHO mouth rinse previously established as effective) on a cognitive task requiring sustained attention. Based on evidence that “low calorie beverages” do not alter blood glucose [29], we hypothesized that a low-CHO (<1%) drink could be identified that, when ingested, would not elicit a glycemic response different from placebo and compare favorably to a CHO mouth rinse in maintaining sustained attention during a mentally fatiguing task.

2. Methods

2.1. Study A

2.1.1. Participants

Six healthy males (n = 3) and females (n = 3) with mean (±SD) age of 25.2 ± 5.7 y and BMI 26.6 ± 3.7 kg/m^2 volunteered to participate in Study A. Participants completed a health-history screening questionnaire to ensure they met all inclusion criteria. Participants were excluded if: diabetic, pregnant, on a restrictive or weight loss diet, lost or gained significant body weight in the last 3 months, sensitive to artificial sweeteners such as aspartame, saccharin, or sucralose; or, used prescription medications that affect appetite, mood, energy level or blood sugar. Participants provided written informed consent as approved by the University Institutional Review Board.

2.1.2. Research design and experimental protocol

Each participant served as his or her own control performing all five tests. Treatment order began with an equal number of subjects completing the 0% and 6% CHO treatment in counterbalanced order. The next three trials were completed in order of increasing CHO concentration for all subjects. Each visit was separated by a minimum of 3 d and scheduled at the same time of morning following an overnight fast. Before each visit, participants refrained from exercise for 24 h and caffeine for 12 h. Upon arrival to the lab, 24 h diet recall and history questionnaire were completed. After the first visit, the 24 h diet recall was copied and returned to the participant to use as a guide for replicating 24 h dietary intake before the subsequent visits.

All treatments were mixed using varying proportions of fruit punch flavored Powerade ® (The Coca Cola Company, Atlanta, GA) and Powerade Zero ® (The Coca Cola Company, Atlanta, GA) to provide 400 ml of taste matched CHO drinks of the following concentrations: 0.4% CHO, 0.75% CHO, 1.5% CHO along with the 6% CHO drink (Powerade ®) and 0% CHO (Powerade Zero ®).

Participants remained seated for 10 min prior to obtaining a resting blood sample to confirm fasting blood glucose (<100 mg/dl). The sample was drawn by lancing a warmed fingertip into a heparinized capillary tube (Microvette® CB300, Sarstedt AG&Co., Numbrecht, Germany) for whole blood analysis of blood glucose (YSI Life Sciences, Inc. Yellow Springs, OH). Each participant was then given 5 min to consume 400 ml of the treatment beverage. Blood samples were obtained at 7.5, 15, 30, 45, and 60 min following ingestion. Glucose area under the curve (AUC) was calculated using the linear trapezoidal rule between 0 and 60 min and peak blood glucose was determined by the highest glucose reading obtained after ingestion of each treatment, independent of time point.

2.1.3. Statistical analyses

Data were reported as mean ± standard deviation (SD) and analyzed using SPSS 17.0 (Chicago, IL). Two-way (treatment × time) repeated measures ANOVA (treatment as within-subjects factor with repeated measures over time) was used to examine differences in blood glucose between treatments. The Greenhouse–Geisser correction was used if the sphericity assumption of equal variances across groups was violated. If a significant F ratio was obtained, the Bonferroni post hoc test was used to detect significant differences in pairwise comparisons between time points or treatments. Within-factor (treatment) repeated measures ANOVA with Bonferroni post hoc was used to detect significant differences between treatments for peak blood glucose and glucose AUC.

2.2. Study B

2.2.1. Participants

Ten healthy males (n = 4) and females (n = 6) age 28.3 ± 6.7 y and BMI 24.5 ± 2.6 kg/m^2 volunteered to participate in Study B with three of the subjects also participating in Study A. Participants again gave written informed consent as approved by the University Institutional Review Board.

2.2.2. Research design and experimental protocol

The experiment used a double-blind, within-subject, cross-over design with each subject serving as their own control under three treatments: placebo control and two isocaloric carbohydrate treatments, each presenting 1.5 g of CHO to the mouth by either ingestion (serially over 15 min) or mouth rinsing via a single dose. All treatments were ingested or rinsed prior to beginning a mentally fatiguing task. However, to assess subsequent recovery following mental fatigue, the CHO ingestion and CHO rinse treatments were again matched (1.5 g) using a