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Carbohydrate mouth rinse has no effects on behavioral or neuroelectric indices of cognition

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ABSTRACT

Rinsing the mouth with a carbohydrate solution has been suggested as a means to enhance aspects of both physical and cognitive performance. However, evidence in support of these assertions is relatively weak. The purpose of this study was to investigate the effects of a carbohydrate mouth rinse solution on motor speed, inhibition, and sustained attention as indexed by both behavioral and neuroelectric measures. Using a double-blind, placebo-controlled, within-subjects crossover design, 50 college-aged young adults performed a battery of cognitive tasks both before and after rinsing their mouth for 10 s with 20 mL of either a carbohydrate mouth rinse solution or a sensory-matched placebo control solution. A simple tapping task was used as a measure of motor speed, a modified Eriksen flanker task was used to index inhibition, and a rapid visual information processing task was used as a measure of sustained attention. Participants demonstrated longer reaction times in the Flanker task after rinsing their mouths with the carbohydrate mouth rinse, relative to pretest. No differences in reaction time were observed for the placebo control condition. P3 latency in the Flanker task as an index of attentional processing speed was shorter at posttest than at pretest in the placebo control – but not the carbohydrate mouth rinse – condition. These results suggest that despite claims of cognitive enhancement, carbohydrate mouth rinses do not appear to alter motor speed, inhibition, or sustained attention as compared to a placebo control in non-physically-fatigued college-aged adults.

1. Introduction

A growing number of companies are promoting carbohydrate-based mouth rinse products claiming to enhance aspects of both physical and cognitive performance. While the tenet that swishing a carbohydrate-based solution around the mouth for only 5 to 10 s without ingestion would have any effect on performance whatsoever appears dubious, such statements are not devoid of evidence. Indeed, a number of recent systematic reviews and meta-analyses have indicated that carbohydrate mouth rinse use is associated with increased skeletal muscle power output during exercise (Brietzke et al., 2019; De Ataide e Silva et al., 2014; Peart, 2017), and a position statement from the Academy of Nutrition and Dietetics Academy, Dietitians of Canada, and the American College of Sports Medicine (2016) indicates that carbohydrate mouth rinse use improves performance during sustained high-intensity exercise. However, support for the potential cognitive benefits of carbohydrate mouth rinse is relatively weak as a result of the poor methodological rigor of much of the literature in this area incorporating weak experimental designs, very small samples, lacking appropriate placebo controls, and selecting cognitive assessments that may have compromised construct validity with repeated administration. Accordingly, the aim of the present investigation was to determine the effect of carbohydrate mouth rinse use on aspects of cognition using a well-powered double-blind, placebo-controlled, within-subjects crossover design.

Changes in cognition induced through the use of carbohydrate mouth solutions (distinct from carbohydrate ingestion) are believed to result from the triggering of oral receptors, which activate aspects of the primary taste cortex and the orbitofrontal cortex projecting to the dorsolateral prefrontal cortex, anterior cingulate cortex, and ventral striatum (Chambers et al., 2009; O'Doherty et al., 2001). Indeed, in a seminal series of studies in this area, Chambers et al. (2009) demonstrated that 10 s of oral mouth rinsing of carbohydrate solutions containing either glucose, sodium saccharin, or maltodextrin increased BOLD fMRI activation of the insula/frontal operculum, medial orbitofrontal cortex, dorsolateral prefrontal cortex, anterior cingulate cortex, and the caudate relative to an artificial saliva control solution in a sample of 7 college-aged young adults in a rested state. Similarly,

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Turner et al. (2014) observed increased activation of the sensorimotor cortex following rinsing the mouth with maltodextrin solution, relative to an artificial saliva control solution and a placebo solution in a sample of 10 college-aged young adults in a rested state. The findings from these studies should be interpreted with caution, however, given the small sample sizes and the fact that these brain regions are involved in a wide array of cognitive processes such that increased brain activity may not necessarily result in enhanced cognition. That said, carbohydrate-induced stimulation of these oral receptors does appear to result in greater activation of a number of brain regions involved with high-level cognitive operations such as attention and cognitive control. As a result, a popular assertion within this body of literature is that the triggering of oral receptors through the use of carbohydrate mouth rinse solutions enhances — or at the very least moderates the depletion of — self-control (Hagger and Chatzisarantis, 2013; Molden et al., 2012; Sanders et al., 2012).

Self-control as it is measured in these investigations can ultimately be encompassed by the larger construct of cognitive control (often used synonymously with 'executive function'), which refers to a broad class of cognitive operations that facilitate goal-directed interactions with the environment (Meyer and Kieras, 1997; Norman and Shallice, 1986). Such cognitive operations encompass the ability to resist distraction or habits to maintain focus (i.e., inhibition); the ability to actively store, maintain, and manipulate information (i.e., working memory); and the ability to dynamically shift attention, select information, and alter response strategies (i.e., cognitive flexibility) (Barkley, 1997; Davidson et al., 2006; Kane and Engle, 2002; Postle, 2006). Of these domains, the vast majority of the literature observing the beneficial effects of carbohydrate mouth rinse use has focused upon inhibitory aspects of cognitive control. For instance, in two of the more methodologically rigorous studies in this literature (i.e., using larger sample sizes and taste-matched placebo control solutions), both Molden et al. (2012) and Sanders et al. (2012) examined the effect of swishing a carbohydrate solution orally for 5 s on inhibitory control as assessed using the Stroop task, relative to swishing non-carbohydrate control solutions. In both studies, carbohydrate mouth rinse use was associated with decreased reaction time for the Stroop task conditions with greater inhibitory control demands. More specifically, utilizing a between-subjects design with 51 college-aged adults, Sanders et al. (2012) observed shorter reaction time for incongruent trials of the Stroop task for those individuals who were orally swishing a carbohydrate solution relative to those using a non-carbohydrate sweetened solution (oral mouth rinse occurred during task completion). Similarly, using a between-subjects pretest-posttest design in a sample of 31 college-aged adults, Molden et al. (2012) had participants complete the Stroop task prior to and then again immediately after swishing a carbohydrate or control solution for 5 s, observing shorter reaction time at posttest for the incongruent trials of the Stroop task for those individuals who orally swished a carbohydrate solution. While the ubiquity and potential clinical utility of the Stroop task is clear, when deployed within strong experimental protocols appropriate for examining the effects of a particular intervention — such as carbohydrate mouth rinse solutions, the necessity for repeated assessments renders this task potentially problematic. As the Stroop task requires that participants suppress the dominant tendency to read and instead respond based upon the color of ink a word is printed in (i.e., 'RED' printed in blue ink), greater exposure to the task with repeated assessments increases the likelihood for individuals to adopt compensatory strategies, such as blurring of vision, which compromise the construct validity of the assessment (Pontifex et al., 2019). Thus, improvements in performance may come about not as a result of enhancements in inhibitory control, but rather as a function of other attentional and motor processes.

Beyond the assessment of overt behavioral performance, however, event-related brain potentials (ERPs) — which refer to a class of electroencephalographic activity that occurs in response to, or in preparation for, an event — provide a means of gaining insight into the subset of processes that occur between stimulus encoding and response production. In particular, ERP components such as the P3 (also known as the P3b and P300) and the error related negativity (ERN) would appear to be of particular interest for understanding the effects of carbohydrate mouth rinse on cognitive operations given frequent claims regarding facilitations in attention and self-regulation (Hagger and Chatzisarantis, 2013; Molden et al., 2012; Sanders et al., 2012). The P3 ERP component is one of the most widely-studied ERP components as it provides a neural index of attentional allocation — with larger amplitude reflecting greater attentional resource allocation and shorter latency reflecting superior cognitive processing speed (Polich, 2007). In the context of understanding the effects of carbohydrate mouth rinse, assessment of the P3 ERP component thus enables interrogation of the extent to which the allocation of attentional resources and cognitive processing speed are induced through carbohydrate mouth rinse use. Another ERP component of particular interest to the present investigation is the Error-Related Negativity (ERN). The ERN serves to index self-regulatory processes — with larger amplitude reflecting the activation of action monitoring processes in response to erroneous behaviors — and is generated in the dorsal portion of the anterior cingulate cortex (Carter et al., 1998; Miltner et al., 2003; Van Veen and Carter, 2002). Because rinsing with carbohydrate solutions has been purported to enhance self-regulation and has been demonstrated to increase activation of the anterior cingulate cortex, carbohydrate mouth rinse use should alter the activation of action monitoring processes as indexed by the ERN ERP component. At present, however, little research investigating the effects of carbohydrate mouth rinse on cognition has utilized such neural markers. Promisingly however, enhancements in cognitive processing speed (as indexed by shorter P3 latency) have been observed 10 min following ingestion of a carbohydrate drink relative to ingesting a placebo drink in a sample of 86 preadolescent children in a between-subjects pretest-posttest design (Walk et al., 2017). While it is important to note that enhancements in cognition induced by carbohydrate ingestion may differ from those induced through the use of carbohydrate mouth rinses, such enhancements in neural indices of processing speed were observed during a period that could conceivably be attributed to activation of oral receptors rather than metabolic processes.

Accordingly, given claims regarding the cognitive benefits of carbohydrate mouth rinse use despite the paucity of high-quality research in this area, the present investigation sought to utilize behavioral and neuroelectric measures of cognition to characterize those changes induced through the use of a commercially-available carbohydrate mouth rinse through a double-blind, within-subjects randomized crossover experimental design incorporating both pre- and post-test assessments. Rather than utilize small numbers of elite athletes who may have a high degree of familiarity with carbohydrate mouth rinse — both in terms of use and marketing — which presents potential confounds in regards to expectancy bias in addition to statistical power (Boot et al., 2013), we utilized a robust sample of college-aged adults and specifically assessed for any expectancy effects across a variety of physical and cognitive domains. In other words, it is likely that athletes who themselves choose to use these products to enhance their performance would have a high degree of expectancy about its effectiveness. In a study conducted by Green et al. (2001), participants who were told they were receiving a glucose drink that would enhance their performance on a battery of cognitive tasks did, in fact, perform better than those who were not informed about its effectiveness – thus making the measurement of expectancy in the present investigation of considerable importance (Green et al., 2001). Additionally, to better characterize the effects of carbohydrate mouth rinse use, a battery of cognitive tasks was utilized to assess motor speed, inhibition, and sustained attention as well as neuroelectric indices of attention (i.e., the P3 ERP) and action monitoring (i.e., the ERN ERP). Given the preliminary evidence to date, it was hypothesized that the use of a carbohydrate mouth rinse solution would manifest with enhancements (i.e., shorter reaction time and P3

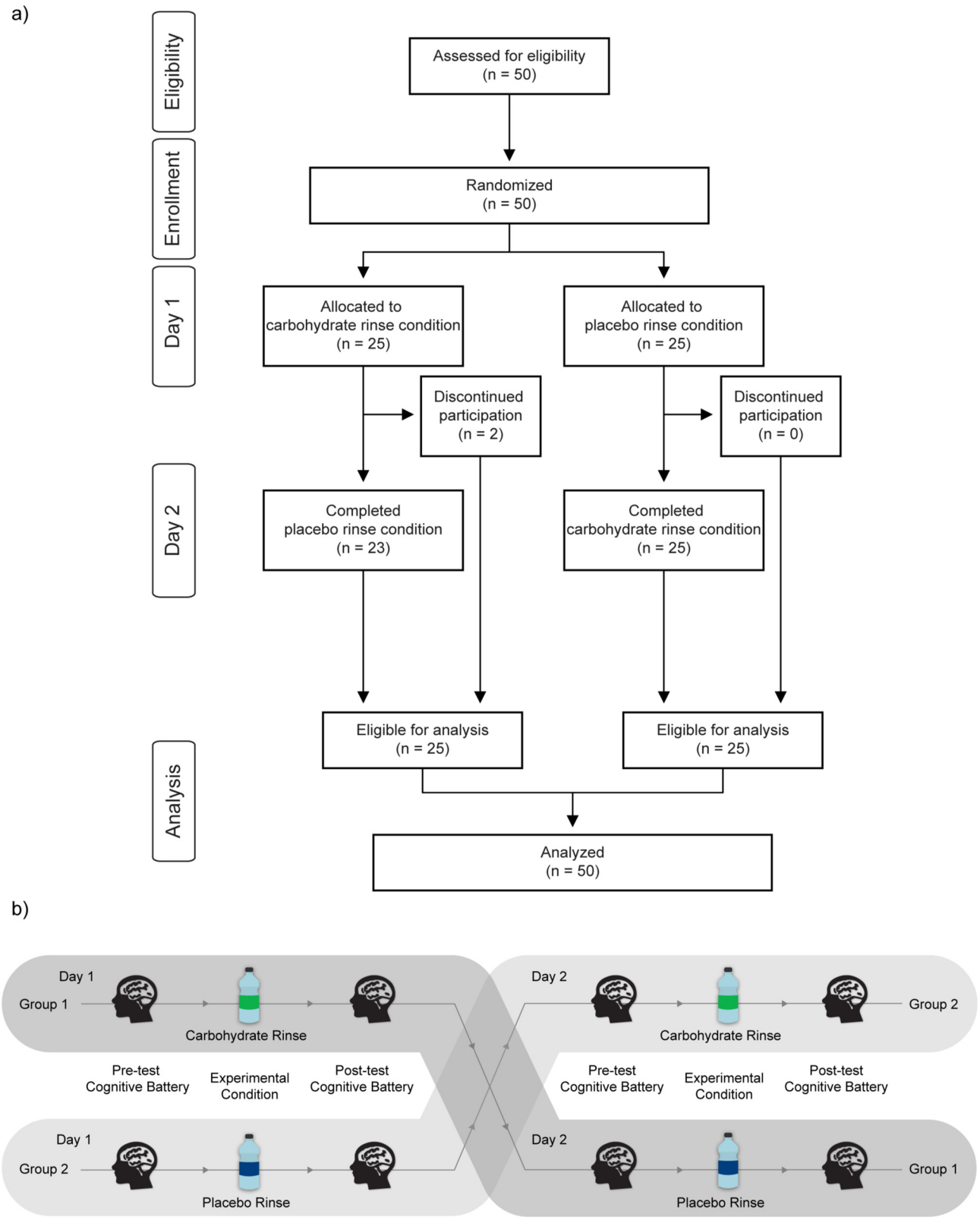

Fig. 1. a) CONSORT diagram showing enrollment and retention of participants throughout the study; b) Schematic of the double-blind crossover experimental design.

latency; increases in response accuracy and P3 amplitude; reductions in ERN amplitude) across each of these various domains.

2. Method

2.1. Participants

Analyses were conducted on a sample of 50 college-aged adults (M_{age} = 20.7 ± 0.8 years, 34 females, 26% nonwhite) recruited from Michigan State University. Of the 50 participants, 18% identified as nonwhite (N = 4 Asian, N = 5 Black of African American, N = 1 unknown or not reported). All participants provided written informed consent in accordance with the Michigan State University Institutional Review Board. Further, all participants completed a health history and demographics questionnaire; reported being free of any neurological diseases, physical disabilities, or allergies to any of the ingredients in the carbohydrate mouth rinse; and indicated normal or corrected-to-normal vision. See Fig. 1a for a CONSORT flow diagram of enrollment.

2.2. Procedure

Using a double-blind placebo controlled, within-subjects randomized crossover experimental design, participants visited the laboratory on two separate days (see Fig. 1b for a schematic diagram of the research design and Table 1 for experimental session characteristics). During the first visit, participants completed an informed consent, a demographics questionnaire, and then were randomized into one of two counterbalanced session orders (Day 1: carbohydrate rinse, Day 2: placebo rinse or Day 1: placebo rinse, Day 2: carbohydrate rinse) to ensure that any observed effects were unrelated to the specific order in which participants received the experimental conditions and on separate days to ensure no carryover effects could result from the potential ingestion of solution. For each session, participants were outfitted with an EEG cap and seated in a comfortable chair in front of a computer monitor in a sound-attenuating testing chamber. Participants were then administered practice trials prior to the start of each cognitive assessment.

Immediately following completion of the pretest cognitive assessments, participants were given 20 mL of either a carbohydrate or placebo control solution and asked to swish the solution around in their mouth for 10 s before expectorating. The carbohydrate solution was a commercially-available carbohydrate mouth rinse product ("UnitRinse") containing water, organic tapioca maltodextrin, lactic acid, organic flavor and natural flavor. The placebo solution contained an identical set of ingredients with the omission of organic tapioca maltodextrin. Both the carbohydrate and placebo control solutions were matched for sensory properties (e.g., color, "Mixed Berry" flavor, and viscosity) and were provided by Unit Nutrition (Unit Nutrition, LLC, New York, NY). The composition of both mouth rinse solutions was verified through an independent third-party laboratory using colorimetric enzyme assays to determine glucose concentration levels. The carbohydrate solution contained 43.8 mg/dL of glucose whereas the placebo solution contained 0 mg/dL of glucose. Consistent with the extant literature, sixty seconds following expectoration of the solution, participants began the post-test cognitive assessments (De Pauw et al., 2015; Hagger and Chatzisarantis, 2013; Molden et al., 2012).

Table 1
Participant demographic and experimental session characteristics (mean ± SD).

Measure	All participants	[Range]
N	50 (34 female)	
Age (years)	20.7 ± 0.8	[19–23]
Nonwhite (%)	18%	
Days between sessions	8.7 ± 9.4	[1–37]
Difference between session times (hours)	2.4 ± 2.4	[0–10]
Pretest duration (minutes)	27.5 ± 1.7	[24.5–31.5]
Posttest duration (minutes)	21.5 ± 0.9	[20–24]

2.3. Perceptions and expectancy of the carbohydrate and placebo solutions

Given the double-blind experimental procedure, neither the experimenter nor the participant was aware of whether the solution administered on each particular day was the carbohydrate rinse or the placebo control. To quantify the extent to which the carbohydrate and placebo control solutions were similar with regard to their sensory properties, participants were asked to rate the mouth rinse solutions based on pleasantness, bitterness, and sweetness (De Pauw et al., 2015; O'Doherty et al., 2000) following completion of the cognitive assessments on each day of testing. At the end of the second day of testing, participants were asked to rate how similar they believed the solutions administered during each testing session to be to one another as well as to complete an expectancy questionnaire that asked them: (1) to rate their familiarity with carbohydrate mouth rinse solutions; (2) to indicate if they had ever used these solutions prior to the study; and (3) to indicate their expectancy regarding the effectiveness of these solutions for altering (a) sports performance, (b) motor skills, (c) cognition, (d) well-being, and (e) metabolism. Finally, to quantify changes in fatigue induced by the experimental protocol, on each day of testing participants were asked to rate their level of fatigue on a scale of 0 ("Not fatigued at all") to 100 ("Extremely fatigued") at three time points: 1) at the beginning of the session before any cognitive testing, 2) after the first cognitive battery, just prior to the mouth rinse, and 3) at the very end of the session, following the second cognitive battery.

2.4. Cognitive assessments

Participants completed a cognitive assessment battery in a fixed order assessing the domains of fine motor speed, inhibition, and sustained attention a total of 4 separate times (pre- and post- administration of the mouth rinse solution on day 1; pre- and post- administration of the mouth rinse solution on day 2). Task order was the same for each participant to ensure consistency across conditions and sessions – and thus, to eliminate post-rinse task administration time as a potential experimental confound. For the inhibition and sustained attention domains, in addition to behavioral indices of performance, a Neuroscan SynampRT amplifier (Compumedics, Inc., Charlotte, NC) was used to acquire event-related brain potentials (ERPs) using established protocols for data acquisition and processing (McGowan et al., 2019; Pontifex et al., 2011, 2015). Specifically, the P3 was assessed in response to both the inhibition and sustained attention tasks; while the ERN was assessed in response to errors of commission only during the inhibition task — errors on the sustained attention task were predominantly comprised of errors of omission which do not allow for the assessment of the ERN. The total duration of the cognitive battery was approximately 20 min including practice trials and transition time between each task.

2.4.1. Motor speed

The finger tapping task was used as a measure of fine motor speed. Using the "Tapping Test" mobile application (Sybu Data (Pty) Ltd., Cape Town, South Africa), participants were asked to tap the index finger of their dominant hand against an iPad screen as many times as possible in 10 s, keeping their palm and all four other fingers as flat as possible against the iPad screen as they did so. Participants were provided with one practice period of 10 s before the test periods (six test periods of 10 s each: three at the beginning of the cognitive assessment battery and three at the end) were administered. Fine motor speed was quantified as the mean number of taps across the test periods.

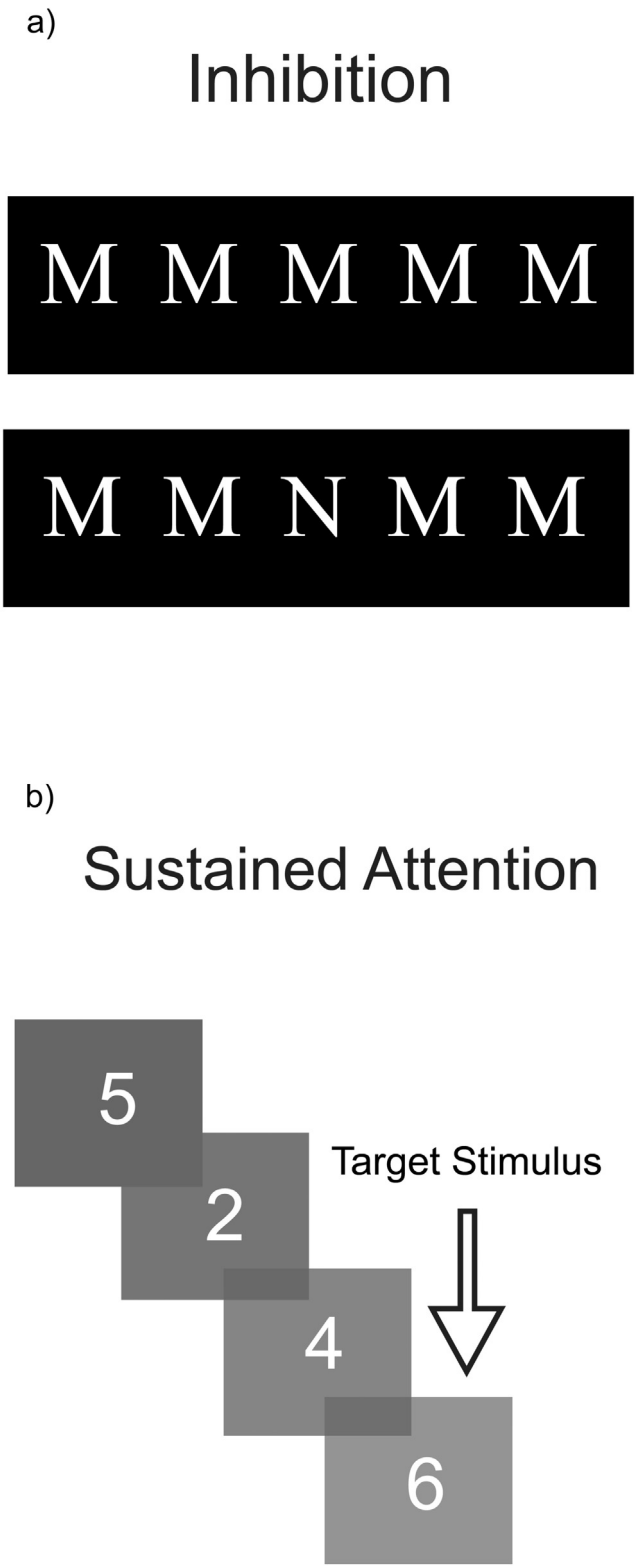

Fig. 2. Depiction of a) the Flanker task (wherein the top panel reflects a *congruent* trial and the bottom panel reflects an *incongruent* trial) and b) the Rapid Visual Information Processing (RVIP) task used in this experiment.

2.4.2. Inhibition

A flanker task (Eriksen and Eriksen, 1974) was used to measure inhibitory control (see Fig. 2a). Participants were instructed to attend to and to respond as accurately as possible to a centrally presented letter nested among a lateral array of letters that were either congruent (e.g., "M M M M M" or "N N N N N") or incongruent (e.g., "M M N M M" or "N N M N N") with the centrally presented letter. Participants completed 80 practice trials followed by 240 trials grouped into three blocks of 80 trials, each consisting of equiprobable congruency and directionality. For each block of trials, participants were presented with perceptually similar letter pairs (e.g., pretest block 1: M – N, pretest block 2: E – F, pretest block 3: O – Q; posttest block 1: I – T, posttest block 2: U – V, posttest block 3: P – R) and were instructed to respond by pressing the button assigned to the centrally presented target stimulus. To ensure a high degree of task difficulty, response compatibility was manipulated at the midpoint of each block by switching the stimulus-response mapping for each set of letters (e.g., left button press for "M" through the first 40 trials of block 1, then right button press for "M" through the last 40 trials of block 1). Participants were given explicit instruction about this switch to ensure continued successful performance of the task. Flanking letters were presented 55 ms prior to target letter onset, and all five letters remained on the screen for a subsequent 100 ms (for a total stimulus duration of 155 ms) with a response window of 1000 ms and a variable inter-trial interval of 2300, 2400, 2500, 2600, or 2700 ms using PsychoPy, 1.85.2 (Peirce, 2009). Inhibition was quantified using the mean reaction time to correctly responding following the onset of the stimulus and the proportion of correct responses relative to the number of trials administered — within both congruent and incongruent trials separately.

2.4.3. Sustained attention

The rapid visual information processing (RVIP) task (Neale et al., 2015; Smit and Rogers, 2000) was used to index sustained attention (see Fig. 2b). Participants were presented with a series of single digits (1–9) in a box in the center of the screen at a rate of 100 digits/min and were instructed to make a button response with their right thumb as soon as they detected any of the three target sequences: '2-4-6,' '3-5-7,' or '4-6-8.' To minimize working memory load, the three target sequences were presented on the bottom of the screen throughout the duration of the task. Participants were provided with a 1 min practice period prior to beginning the test trials. Sustained attention was quantified as the mean reaction time to correctly respond to target sequences and the proportion of responses that correctly coincided with the 64 target sequences presented.

2.5. ERP approach

EEG activity was recorded from 64 electrode sites (Fpz, Fz, FCz, Cz, CPz, Pz, POz, Oz, Fp1/2, F7/5/3/1/2/4/6/8, FT7/8, FC3/1/2/4, T7/8, C5/3/1/2/4/6, M1/2, TP7/8, CB1/2, P7/5/3/1/2/4/6/8, O1/2) arranged in an extended montage based on the International 10-10 system (Chatrian et al., 1985) using a Neuroscan Quik-Cap (Compumedics, Inc., Charlotte, NC). Recordings were referenced to averaged mastoids (M1, M2), with AFz serving as the ground electrode. Additional electrodes were placed above and below the left orbit and on the outer canthus of both eyes to monitor electrooculographic (EOG) activity with a bipolar recording. Continuous data were digitized at a sampling rate of 1000 Hz and amplified 500 times with a DC to 70 Hz filter using a Neuroscan SynAmps RT Amplifier. The EEG data was then imported into EEGLAB (Delorme and Makeig, 2004) and prepared for temporal ICA decomposition. Data > 2 s prior to the first event marker and 2 s after the final event marker were removed to restrict computation of ICA components to task-related activity. The continuous data was filtered using a 0.05 Hz high-pass 2nd order Butterworth IIR filter to remove slow drifts (Pontifex et al., 2017a), and the mastoids electrodes were removed prior to ICA decomposition. ICA decomposition was performed using the extended infomax algorithm to extract sub-Gaussian components using the default settings called in the MATLAB implementation of this function in EEGLAB with the block size heuristic (floor[sqrt(EEG.pnts/3)]) drawn from MNE-Python (Gramfort et al., 2013). Following the ICA decomposition, the eyeblink artifact

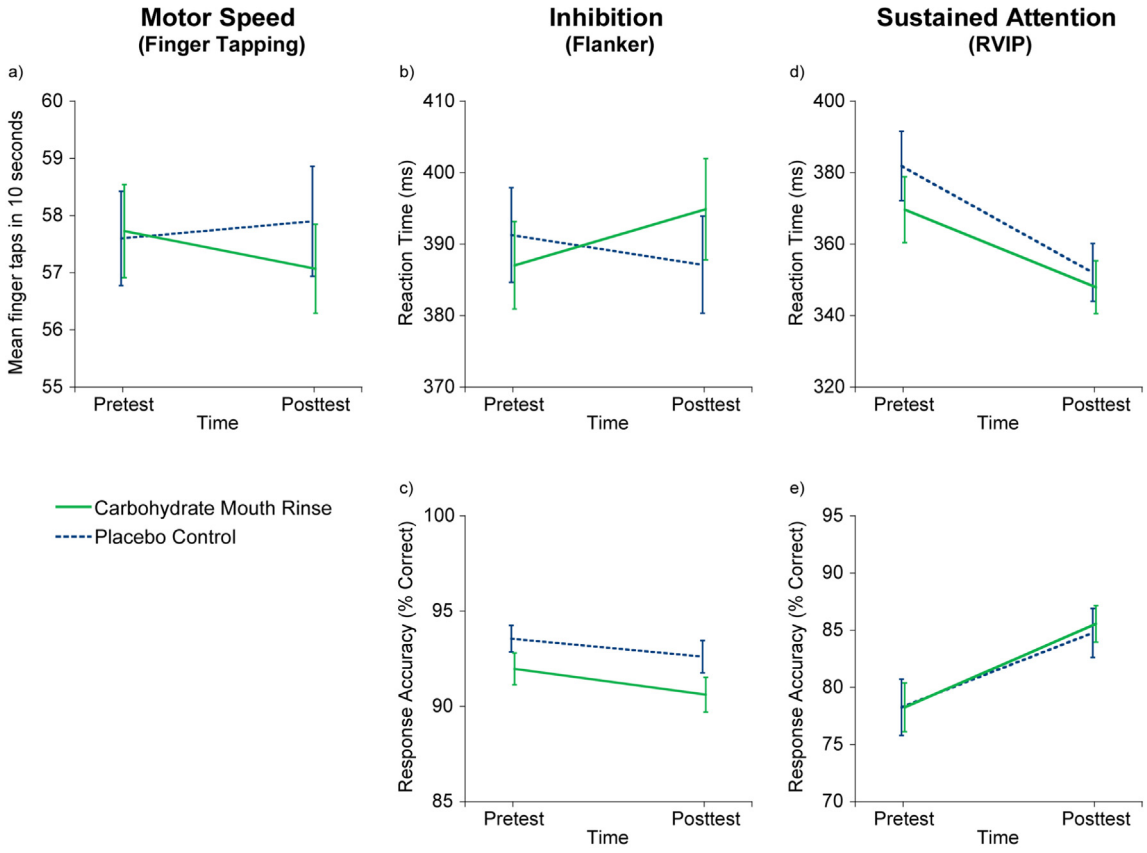

Fig. 3. Mean (± SE) behavioral performance on each of the tasks. a) Number of finger taps in 10 s. b) Reaction time on the flanker. c) Response accuracy on the flanker task. d) Reaction time on the RVIP task. e) Response accuracy on the RVIP task.

components were identified using the icablinkmetrics function (Pontifex et al., 2017b) and the EEG data was reconstructed without the eyeblink artifact.

Following removal of the eye blink components, stimulus-locked epochs were created for correct trials from −500 to 1500 ms around the stimulus, baseline corrected using the −100 to 0 ms pre-stimulus period, and filtered using a zero phase shift low-pass filter at 30 Hz. Trials with artifact exceeding ± 100 μV were rejected. To ensure the integrity of the signal, stimulus-locked epochs were visually inspected blind to the experimental condition, time point, and congruency prior to computing mean waveforms. Following visual inspection, the mean number of trials included in the waveforms was 145.1 ± 32.6 trials stimulus-locked to the congruent and incongruent trials (separately) of the Flanker task and 36.6 ± 7.7 trials stimulus-locked to the final stimulus of the target sequences of the RVIP task. Attentional engagement (as indexed by the P3 ERP component) was evaluated as the mean amplitude within a 50 ms interval surrounding the largest positive going peak within a 275 to 700 ms latency window following stimulus onset for the flanker task, and a 275 to 600 ms window for the RVIP task (McGowan et al., 2019; Pontifex et al., 2015). ERP latency was quantified as the time at which maximum peak amplitude occurred.

Response-locked epochs were also created for errors of commission from −1000 to 1500 ms around the response, baseline corrected using the −100 to 0 ms pre-response period, and filtered using a zero-phase shift band-pass filter at 12 Hz. Trials with artifact exceeding ± 100 μV were rejected. To ensure the integrity of the signal, response-locked epochs were visually inspected blind to the experimental condition, time point, and congruency prior to computing mean waveforms. Following visual inspection, the mean number of trials included in the waveforms was 16.0 ± 8.6 trials (range: 6–43 trials) response-locked to errors of commission during the Flanker task. Data from participants who committed fewer than six errors were excluded from analysis of response-locked errors of commission. See the Supplementary Appendix for information about the number of participants included in each condition. Action monitoring (as indexed by the ERN ERP component) was evaluated as the mean amplitude within a 50 ms interval surrounding the largest negative going peak within a − 20 to 150 ms latency window following response onset (Hajcak et al., 2005; Moser et al., 2012; Schroder et al., 2012). Given the well-established nature of these ERP components elicited in response to these tasks, analyses were conducted using a nine channel region-of-interest approach centering around the topographic maxima of the P3 (i.e., the CP1/Z/2, P1/Z/2, PO3/Z/4 electrodes) and ERN (i.e., the F1/Z/2, FC1/Z/2 electrodes) ERP components (McGowan et al., 2019; Moser et al., 2012).

2.6. Statistical analysis

Analyses of all dependent variables were conducted while the data was still in a blinded state using a 2 (Solution: Carbohydrate Mouth Rinse, Placebo Control) × 2 (Time: Pretest, Posttest) univariate multilevel model including the random intercept for each Participant, Participant × Solution, and Participant × Time interactions. For the inhibition task, analysis included an additional fixed level for Congruency (Congruent, Incongruent) and an additional random intercept for Participant × Congruency. Use of a multi-level model allowed for the retention of participants with incomplete data, offered a robust way to account for several sources of variability (Goldstein, 2011; Volpert-Esmond et al., 2018), and is preferable for repeated measures designs (Quené and Van den Bergh, 2004). All analyses were performed using the lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), and emmeans (Lenth et al., 2017) packages in R version 3.6.1 (R Core Team, 2013) with Kenward-Roger degrees of freedom

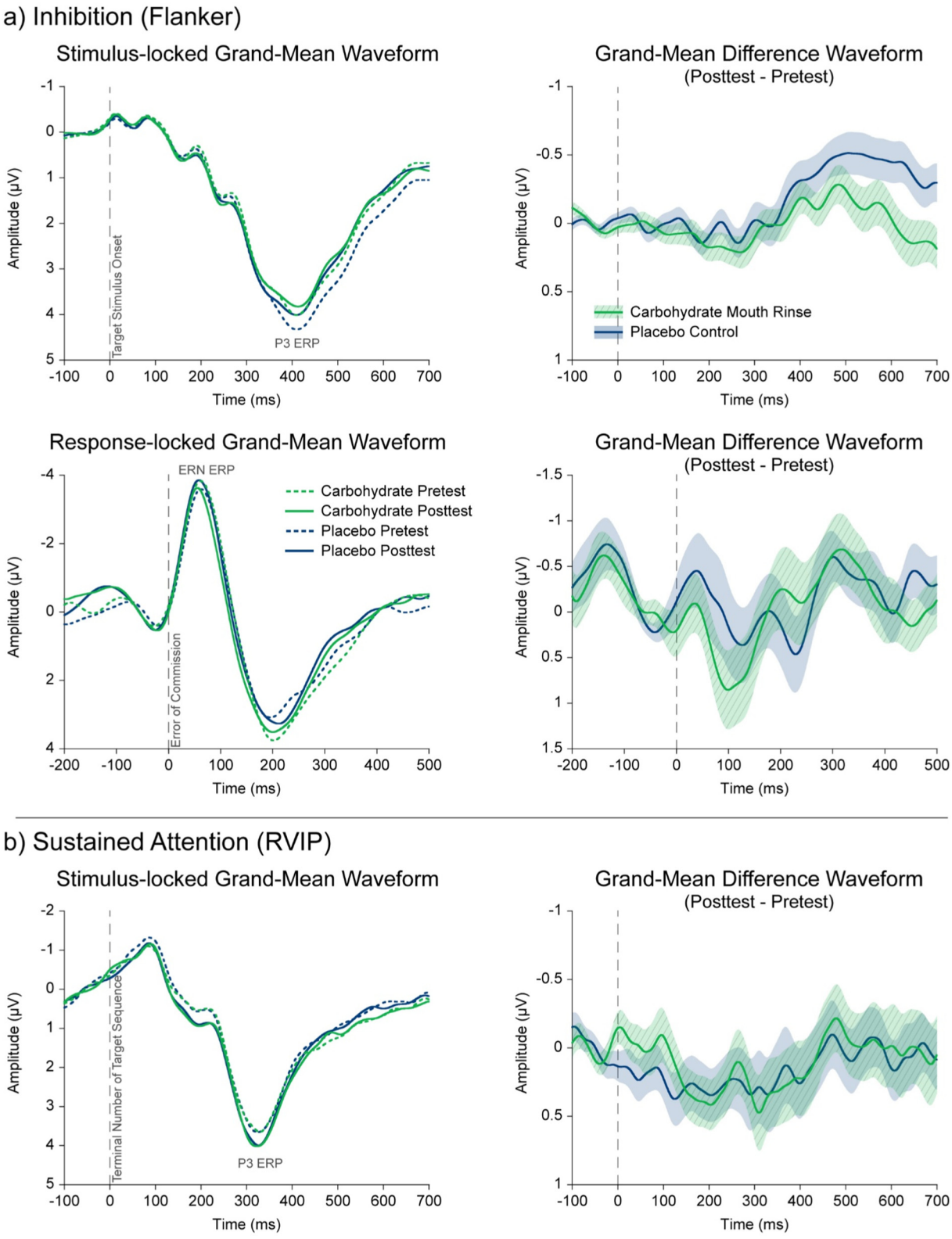

Fig. 4. a) Illustration of the neuroelectric activity elicited in response to the Flanker task. The top graphs represent the grand mean stimulus-locked waveforms collapsed across congruency and the CP1/Z/2, P1/Z/2, PO3/Z/4 electrode sites. The middle graphs represent the grand mean response-locked waveforms elicited in response to error of commission trials in the Flanker task collapsed across the F1/Z/2, FC1/Z/2 electrodes sites. b) Illustrations of the grand mean stimulus-locked waveforms elicited in response to the RVIP task target trials collapsed across the CP1/Z/2, P1/Z/2, PO3/Z/4 electrode sites.

approximations. Analyses were conducted with $\alpha = 0.05$ and Benjamini-Hochberg false discovery rate control = 0.05 for post-hoc decompositions. For each inferential finding, Cohen's f^2 and d with 95% confidence intervals were computed as standardized measures of effect size, using appropriate variance corrections for within-subject (d_{rm}) comparisons (Lakens, 2013). Given a sample size of 50 participants and a beta of 0.20 (i.e., 80% power), the present research design theoretically had sufficient sensitivity to detect differences exceeding $d_{rm} = 0.4$ (with a two-sided alpha) as computed using G*Power 3.1.2 (Faul et al., 2007).

3. Results

The findings presented below are abridged for the sake of clarity to highlight relevant findings involving interactions of Solution × Time. See Fig. 3 for behavioral results and Fig. 4 for neuroelectric results. A more complete reporting of observed effects can be found within the Supplementary Appendix.

3.1. Perceptions and expectancy of the carbohydrate and placebo solutions

Five participants rated the solutions as "Extremely Similar," 8 participants rated the solutions as "Very Similar," 14 participants rated the solutions as "Moderately Similar," 21 participants rated the solutions as "Slightly Similar," and no participants rated the solutions as "Not Similar at All." Further, no statistically significant differences between the perceptions of the carbohydrate and placebo control solutions were observed in terms of pleasantness, bitterness, or sweetness ($p's \geq 0.10$).

Participants reported a low level of familiarity and previous use of carbohydrate mouth rinse solutions: only 2% of participants reported having ever used the solutions, and over 95% of participants reported being either "not familiar at all" or only "slightly familiar" with them. Participants also had low expectations regarding the effectiveness of carbohydrate mouth rinse solutions, suggesting minimal potential expectancy bias (Boot et al., 2013). In particular for each domain (i.e., sports performance, motor skill, cognition, well-being, and metabolism), more than half of participants reported believing that the solutions would be either "not at all effective" or only "slightly effective."

Analysis of participant fatigue during the course of the experiment revealed a main effect of Time, $F(2, 98) = 36.5$, $p < 0.001$, $f^2 = 1.87$ [95% CI: 1.06 to 3.71]. Post hoc comparisons revealed increasing levels of fatigue over the duration of the experiment such that the start of pretest was associated with the lowest levels of fatigue, and the end of the posttest cognitive assessment battery was associated with the greatest levels of fatigue, $t's(98) \geq 2.8$, $p's \leq 0.007$, $d_{rm}'s \geq 0.13$ [95% CI: 0.03 to 0.83].

3.2. Fine motor speed

No interaction of Solution × Time was observed for finger tapping, $F(1, 48) = 2.5$, $p = 0.1$, $f^2 = 0.65$ [95% CI: 0.26 to 1.37].

3.3. Inhibition

3.3.1. Behavior

For the carbohydrate mouth rinse condition, Flanker reaction time was longer at posttest (394.9 ± 50.1 ms) relative to pretest (387.0 ± 43.3 ms), $t(81) = 2.7$, $p = 0.008$, $d_{rm} = 0.22$ [95% CI: 0.06 to 0.39], see Fig. 2. No such effect was observed in response to the placebo control condition, $t(84) = 1.4$, $p = 0.2$, $d_{rm} = 0.11$ [95% CI: −0.04 to 0.39], and no interactions involving Solution × Time were observed for response accuracy, $F(1, 193) = 0.8$, $p = 0.4$, $f^2 = 0.01$ [95% CI: 0.00 to 0.05].

3.3.2. Attentional engagement

For the placebo control condition, P3 latency in response to the Flanker task was shorter at posttest (413.1 ± 45.3 ms) relative to pretest (426.4 ± 45.2 ms), $t(94) = 2.6$, $p = 0.01$, $d_{rm} = 0.23$ [95% CI: 0.06 to 0.41]. Neither differences in P3 latency between pretest and posttest were observed in the carbohydrate mouth rinse condition, $t(92) = 0.4$, $p = 0.7$, $d_{rm} = 0.05$ [95% CI: −0.21 to 0.31] nor a Solution × Time interaction for P3 amplitude were observed, $F(1, 192) = 0.5$, $p = 0.5$, $f^2 = 0.02$ [95% CI: 0.0 to 0.09].

3.3.3. Action monitoring

No interaction of Solution × Time was observed for ERN amplitude in response to the Flanker task, $F(1, 44) = 2.5$, $p = 0.1$, $f^2 = 0.48$ [95% CI: 0.16 to 1.05].

3.4. Sustained attention

3.4.1. Behavior

No interactions of Solution × Time were observed for RVIP behavioral task performance, $F's(1, 48) \leq 0.7$, $p \geq 0.4$, $f^2 \leq 0.02$ [95% CI: 0.0 to 0.10].

3.4.2. Attentional engagement

No interaction of Solution × Time was observed for either P3 amplitude or latency to the RVIP task, $F's(1, 48) < 0.1$, $p's \geq 0.8$, $f^2 < 0.01$ [95% CI: 0.0 to 0.06].

4. Discussion

The aim of the present investigation was to determine — using a rigorous double-blind, within-subjects randomized crossover experimental design — the effect of carbohydrate mouth rinse use on both behavioral and neuroelectric indices of cognition. Contrary to our a priori hypotheses, the use of a carbohydrate mouth rinse solution had neither beneficial effects on behavioral metrics of motor speed, inhibition, or sustained attention nor induced positive changes in neuroelectric indices of attentional engagement or action monitoring. Specifically, the only findings observed within the present investigation were that participants demonstrated longer reaction times in response to the inhibitory control task after rinsing their mouth with the carbohydrate mouth rinse relative to pretest and that use of the placebo mouth rinse induced faster attentional processing speed (as indexed by shorter P3 latency) during the inhibitory control task relative to pretest. While no effects of carbohydrate mouth rinse on cognition were observed, some caution is warranted in interpreting the effects of the placebo control solution given the lack of theoretical justification for such a solution to induce cognitive enhancements — suggesting these findings may reflect spurious statistical anomalies.

Despite the lack of any observed beneficial effect of carbohydrate mouth rinse within the present investigation, it is important to highlight that this investigation does not necessarily preclude the possibility that carbohydrate mouth rinse use might have a positive effect on cognition. Indeed, while the present findings for the P3 ERP component replicate those of a small ($N = 10$) pilot investigation (De Pauw et al., 2015), the statistical concept of a Type II error (the probability of finding no difference between conditions when a difference is present) dictates that the sensitivity of an investigation is inherently a function of the sample size and the magnitude of the effect. As the present investigation was appropriately powered for detecting moderate or larger effects (i.e., $d_{rm} \geq 0.4$), the magnitude of the effects of carbohydrate mouth rinse may simply be below this threshold and thus require substantially larger investigations to observe. Similarly, it is unclear what the relative half-life of the effect of carbohydrate mouth rinses are relative to their effect upon cognition. While the present investigation utilized a similar administration and assessment timing as the extant literature, further research is necessary to better examine how long it takes following utilization of carbohydrate mouth rinses to observe the onset of cognitive enhancements and how long such enhancements

persist. It is also important to acknowledge that while the repeated measures crossover design represents a strength of the present investigation to control for learning effects, such an approach may have overwhelmed the possibility of detecting an effect of carbohydrate mouth rinses since these effects are sufficiently small and thus may only be readily apparent in less-robust experimental designs.

Additionally, it has been posited that the effects of carbohydrate mouth rinses may only manifest in response to a depleted state (Hagger and Chatzisarantis, 2013). Indeed, in a series of investigations Hagger and Chatzisarantis (2013) observed that performance on a handgrip-based assessment of self-control was only different following rinsing the mouth with a glucose solution, relative to a placebo solution, when participants had first completed a cognitively fatiguing block of trials of the Stroop task in a sample of 48 high-school students using a between-subjects design. In this context then, the use of a pretest assessment battery within the current investigation is conceptually similar to such means of placing the participants in a cognitively "depleted" state and consistent with such an interpretation, as participants reported increasing levels of fatigue throughout the experimental session. Thus, the pretest assessment should have been sufficiently taxing for the carbohydrate mouth rinse to manifest with a beneficial effect, lending doubt to such interpretations. However, such claims regarding a depleted state could be more broadly extended to apply to physiological strain (i.e., depleted skeletal muscle glycogen). Indeed, a limitation of the present investigation is that participants were not required to be in a fasted state prior to the experimental sessions, nor was information regarding participants' food consumption prior to participating assessed. Given the target market of these carbohydrate mouth rinse products, further research is therefore necessary to better understand the extent to which such physiological states may moderate the beneficial effects of carbohydrate mouth rinse products such that their beneficial influence only manifests under particular physiological conditions.

Collectively, findings from the present investigation cast a shadow across claims of cognitive benefits following the use of carbohydrate mouth rinse products. While it is important to note that clearly more research is needed in this area to better examine the extent to which carbohydrate mouth rinse might induce changes in cognition in response to more nuanced circumstances. However, when using a rigorous experimental design to account for individual differences in responding (both methodologically through the use of a crossover design and statistically through the use of a multi-level model), utilizing a sensory-matched placebo control solution, and in a sample free of expectancy bias regarding the benefits of carbohydrate mouth rinse, the effect of carbohydrate mouth rinse appears negligible.

CRediT author statement

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Declaration of competing interest

No conflicting financial interests exist.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijpsycho.2020.02.012.

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Supplementary Appendix

This appendix has been provided by the authors to supplement the results provided within the manuscript.

Results

Perceptions of the carbohydrate and placebo solutions

Table S1.
Mean (± SD) values on a scale of 0 (Not at all) to 4 (Extremely) for participants' ratings of the solutions.

Variable	Carbohydrate Mouth Rinse	Placebo Control	*t*	d_{rm} [95% CI]	*p*
Bitterness	0.4 ± 0.6	0.4 ± 0.7	<0.1	0.01 [-0.4 to 0.4]	0.97
Pleasantness	2.0 ± 0.9	2.0 ± 1.0	0.1	0.02 [-0.4 to 0.4]	0.91
Sweetness	1.9 ± 0.9	1.6 ± 0.7	1.7	0.34 [-0.1 to 0.7]	0.10

Expectancy of the carbohydrate and placebo solutions

Table S2.
Mean counts of participants' perceptions of the effectiveness of carbohydrate mouth rinse in five domains.

Effectiveness Rating	Sport Performance	Motor Skill	Cognition	Well-Being	Metabolism
Not at all	18	9	10	18	19
Slightly	18	21	21	19	17
Moderately	9	12	12	9	10
Very	2	5	5	2	1
Extremely	0	1	0	0	0

Perceptions of fatigue

Analysis of perceptions of fatigue across the start of pretest, the end of the pretest, and the end of the posttest cognitive assessments revealed:

- No main effect of Solution (Carbohydrate Mouth Rinse vs Placebo Control), $F(1, 47) = 0.1$, $p = 0.7$, $f^2 < 0.01$ [95% CI: 0.00 to 0.03].
- A main effect of Time, $F(2, 98) = 36.5$, $p < 0.001$, $f^2 = 1.87$ [95% CI: 1.06 to 3.71]. Post hoc comparisons revealed increasing levels of fatigue over the duration of the experiment such that the start of pretest was associated with the lowest levels of fatigue, and the end of the posttest cognitive assessment battery was associated with the greatest levels of fatigue; *t's*(98) ≥ 2.8, *p's* ≤ 0.007, d_{rm}*'s* ≥ 0.13 [95% CI: 0.03 to 0.83].
- No interaction of Solution × Time, $F(2, 95) = 2.1$, $p = 0.1$, $f^2 = 0.11$ [95% CI: 0.00 to 0.30].

Table S3.
Mean (± SD) ratings for perceptions of fatigue on a 0 ("Not fatigued at all") to 100 ("Extremely fatigued") point scale for each experimental session.

Condition		Start of Pretest	End of Pretest	End of Posttest
Carbohydrate Mouth Rinse	Mouth	21.3 ± 19.7	30.0 ± 22.5	33.6 ± 23.5
Placebo Control		23.3 ± 21.3	29.6 ± 23.4	33.3 ± 24.3

Fine Motor Speed

The number of finger taps in ten seconds was used as an index of fine motor speed. Analysis revealed:

- No main effect of Solution (Carbohydrate Mouth Rinse vs Placebo Control), $F(1, 47) = 0.4$, $p = 0.5$, $f^2 = 0.11$ [95% CI: 0.00 to 0.30].
- No main effect of Time (Pretest vs Posttest), $F(1, 48) = 0.4$, $p = 0.5$, $f^2 = 0.10$ [95% CI: 0.00 to 0.28].
- No interaction of Solution × Time, $F(1, 48) = 2.5$, $p = 0.1$, $f^2 = 0.65$ [95% CI: 0.26 to 1.37].

Table S4.
Mean (± SD) values for the number of finger taps in ten seconds for each experimental session.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse	57.7 ± 5.8	57.1 ± 5.5
Placebo Control	57.6 ± 5.7	57.9 ± 6.7

Inhibition

A flanker task (Eriksen & Eriksen, 1974) was used to measure inhibitory control. Analysis revealed:

Flanker Task Reaction Time

- No main effect of Solution, $F(1, 47) = 0.5$, $p = 0.5$, $f^2 = 0.00$ [95% CI: 0.00 to 0.01].
- No main effect of Time, $F(1, 49) = 0.5$, $p = 0.5$, $f^2 = 0.00$ [95% CI: 0.00 to 0.02].
- A main effect of Congruency, $F(1, 49) = 524.4$, $p < 0.001$; such that participants responded slower to incongruent trials (410.1 ± 41.7 ms) relative to congruent trials (370.0 ± 42.5 ms), $d_{rm} = 1.08$ [95% CI: 0.85 to 1.32].
- A Solution × Time interaction, $F(1, 193) = 17.4$, $p < 0.001$, $f^2 = 0.03$ [95% CI: 0.00 to 0.13]. Post-hoc decomposition of the Solution × Time interaction was conducted by examining the effect of Time within each Solution condition. In the carbohydrate mouth rinse condition, reaction time was longer at posttest (394.9 ± 50.1 ms) relative to pretest (387.0 ± 43.3 ms), $t(81) = 2.7$, $p = 0.008$, $d_{rm} = 0.22$ [95% CI: 0.06 to 0.39]. No significant differences in reaction time were observed in the placebo control condition, $t(84) = 1.4$, $p = 0.2$, $d_{rm} = 0.11$ [95% CI: -0.04 to 0.39].
- No interaction of Solution × Congruency, $F(1, 194) < 0.1$, $p = 0.9$, $f^2 = 0.0$ [95% CI: 0.0 to 0.0].
- No interaction of Time × Congruency, $F(1, 190) < 0.1$, $p = 0.96$, $f^2 = 0.0$ [95% CI: 0.0 to 0.0].

No interaction of Solution × Time × Congruency, $F(1, 190) = 0.6$, $p = 0.4$, $f^2 = 0.0$ [95% CI: 0.0 to 0.02].

Table S5
Mean (± SD) values for Flanker task reaction time (ms) for each experimental session.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse		
Congruent Trials	367.5 ± 38.6	374.3 ± 45.5
Incongruent Trials	406.6 ± 38.9	415.5 ± 46.2
Placebo Control		
Congruent Trials	370.7 ± 41.9	367.7 ± 44.8
Incongruent Trials	411.9 ± 40.2	406.5 ± 41.4

Flanker Task Response Accuracy

A main effect of Solution, $F(1, 48) = 10.8$, $p = 0.002$; such that participants responded more accurately in the placebo control condition (93.1 ± 5.4%) than in the carbohydrate mouth rinse condition (91.3 ± 6.2%), $d_{rm} = 0.34$ [95% CI: 0.13 to 0.56].

A main effect of Time, $F(1, 49) = 8.2$, $p = 0.006$; such that participants responded more accurately at pretest (92.8 ± 5.4%) than at posttest (91.6 ± 6.2%), $d_{rm} = 0.23$ [95% CI: 0.06 to 0.39].

A main effect of Congruency, $F(1, 49) = 96.5$, $p < 0.001$; such that participants responded more accurately on congruent trials (93.8 ± 5.5%) than on incongruent trials (90.6 ± 5.8%), $d_{rm} = 0.65$ [95% CI: 0.47 to 0.83].

No interaction of Solution × Time, $F(1, 193) = 0.8$, $p = 0.4$, $f^2 = 0.01$ [95% CI: 0.00 to 0.05].

No interaction of Solution × Congruency, $F(1, 194) = 0.5$, $p = 0.5$, $f^2 = 0.0$ [95% CI: 0.0 to 0.04].

No interaction of Time × Congruency, $F(1, 190) = 0.2$, $p = 0.7$, $f^2 = 0.0$ [95% CI: 0.0 to 0.02].

No interaction of Solution × Time × Congruency, $F(1, 190) = 0.3$, $p = 0.6$, $f^2 = 0.0$ [95% CI: 0.0 to 0.03].

Table S6.
Mean (± SD) values for Flanker task response accuracy (% correct) for each experimental session.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse		
Congruent Trials	93.8 ± 5.6	92.2 ± 6.1
Incongruent Trials	90.2 ± 5.7	89 ± 6.6
Placebo Control		
Congruent Trials	95.1 ± 4.4	94.2 ± 5.4
Incongruent Trials	92.1 ± 4.8	91.1 ± 6.0

Flanker Task P3 Amplitude

No main effect of Solution, $F(1, 47) = 0.5$, $p = 0.5$, $f^2 = 0.02$ [95% CI: 0.00 to 0.09].

No main effect of Time, $F(1, 49) = 2.9$, $p = 0.1$, $f^2 = 0.11$ [95% CI: 0.00 to 0.31].

A main effect of Congruency, $F(1, 48) = 19.3$, $p < 0.001$; such that P3 amplitude was larger on incongruent trials (4.6 ± 2.0 μV) relative to congruent trials (4.4 ± 1.9 μV), $d_{rm} = 0.11$ [95% CI: 0.05 to 0.16].

No interaction of Solution × Time, $F(1, 192) = 0.5$, $p = 0.5$, $f^2 = 0.02$ [95% CI: 0.0 to 0.09].

No interaction of Solution × Congruency, $F(1, 194) = 0.5$, $p = 0.5$, $f^2 = 0.02$ [95% CI: 0.0 to 0.10].

No interaction of Time × Congruency, $F(1, 188) = 1.6$, $p = 0.2$, $f^2 = 0.06$ [95% CI: 0.0 to 0.20].

No interaction of Solution × Time × Congruency, $F(1, 188) < 0.1$, $p = 0.96$, $f^2 = 0.0$ [95% CI: 0.0 to 0.01].

Table S7.
Mean (± SD) values for P3 amplitude (μV) elicited in response to the Flanker task for each experimental session.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse		
Congruent Trials	4.4 ± 1.8	4.2 ± 1.9
Incongruent Trials	4.6 ± 1.8	4.5 ± 1.9
Placebo Control		
Congruent Trials	4.6 ± 1.8	4.3 ± 2
Incongruent Trials	4.8 ± 2.1	4.6 ± 2.1

Note: Values are collapsed across electrode sites corresponding to the topographic maxima of the P3 (i.e., CP1/Z/2, P1/Z/2, PO3/Z/4).

Flanker Task P3 Latency

No main effect of Solution, $F(1, 47) = 0.9$, $p = 0.3$, $f^2 = 0.01$ [95% CI: 0.00 to 0.07].

No main effect of Time, $F(1, 49) = 1.9$, $p = 0.2$, $f^2 = 0.02$ [95% CI: 0.0 to 0.10].

A main effect of Congruency, $F(1, 48) = 67.4$, $p < 0.001$; such that P3 latency was shorter for congruent (411.5 ± 49.0 ms) relative to incongruent (434.2 ± 48.0 ms) trials, $d_{rm} = 0.60$ [95% CI: 0.41 to 0.78].

An interaction of Solution × Time, $F(1, 193) = 7.7$, $p = 0.006$, $f^2 = 0.10$ [95% CI: 0.0 to 0.28]. Post-hoc decomposition of the Solution × Time interaction was conducted by examining the effect of Time within each Solution condition. In the placebo control condition, P3 latency was shorter at posttest (413.1 ± 45.3 ms) relative to pretest (426.4 ± 45.2 ms), $t(94) = 2.6$, $p = 0.01$, $d_{rm} = 0.23$ [95% CI: 0.06 to 0.41]. No significant differences in P3 latency between pretest and posttest were observed in the carbohydrate mouth rinse condition, $t(92) = 0.4$, $p = 0.7$, $d_{rm} = 0.05$ [95% CI: -0.21 to 0.31].

No interaction of Solution × Congruency, $F(1, 194) = 0.1$, $p = 0.8$, $f^2 = 0.0$ [95% CI: 0.0 to 0.01].

No interaction of Time × Congruency, $F(1, 188) = 0.6$, $p = 0.4$, $f^2 = 0.01$ [95% CI: 0.0 to 0.05].

No interaction of Solution × Time × Congruency, $F(1, 188) = 0.5$, $p = 0.5$, $f^2 = 0.01$ [95% CI: 0.0 to 0.05].

Table S8.
Mean (± SD) values for P3 latency (ms) elicited in response to the Flanker task for each experimental session.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse		
Congruent Trials	413.4 ± 46.9	415.3 ± 58.7
Incongruent Trials	436.9 ± 45.9	438.5 ± 57.7
Placebo Control		
Congruent Trials	413.3 ± 42.5	404.1 ± 47.2
Incongruent Trials	439.5 ± 44.5	422.1 ± 41.8

Note: Values are collapsed across electrode sites corresponding to the topographic maxima of the P3 (i.e., CP1/Z/2, P1/Z/2, PO3/Z/4).

Flanker Task ERN Amplitude

No main effect of Solution, $F(1, 42) = 1.6$, $p = 0.2$, $f^2 = 0.30$ [95% CI: 0.06 to 0.71].
No main effect of Time, $F(1, 44) = 0.4$, $p = 0.5$, $f^2 = 0.08$ [95% CI: 0.00 to 0.25].
No interaction of Solution x Time, $F(1, 44) = 2.5$, $p = 0.1$, $f^2 = 0.48$ [95% CI: 0.16 to 1.05].

Additional exploratory analysis using a baseline period from -500 to -300 prior to the response (in contrast to the -100 to 0 ms pre response baseline period) similarly observed no main effects or interactions.

Table S9.
Mean (± SD) values for ERN amplitude (μV) elicited in response to the Flanker task for each experimental session. Below each amplitude value is the number of participants included in analysis for each condition.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse	-4.0 ± 2.2 N = 46	-3.8 ± 2.0 N = 41
Placebo Control	-3.9 ± 2.2 N = 42	-4.5 ± 2.4 N = 43

Note: Values are collapsed across electrode sites corresponding to the topographic maxima of the ERN (i.e., F1/Z/2, FC1/Z/2).

Sustained Attention

The rapid visual information processing task (Neale, Johnston, Hughes, & Scholey, 2015; Smit & Rogers, 2000) was used to index sustained attention. Analysis revealed:

RVIP Task Reaction Time

No main effect of Solution, $F(1, 48) = 1.2$, $p = 0.3$, $f^2 = 0.04$ [95% CI: 0.0 to 0.14].
A main effect of Time, $F(1, 48) = 30.1$, $p < 0.001$; such that participants responded faster at posttest (350.0 ± 53.8 ms) relative to pretest (375.8 ± 66.2 ms), $d_{rm} = 0.48$ [95% CI: 0.28 to 0.68].
No interaction of Solution × Time, $F(1, 48) = 0.7$, $p = 0.4$, $f^2 = 0.02$ [95% CI: 0.0 to 0.10].

Table S10.
Mean (± SD) values for RVIP task reaction time (ms) for each experimental session.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse	369.7 ± 65.4	348.0 ± 52.2
Placebo Control	381.9 ± 67.3	352.1 ± 55.9

RVIP Task Response Accuracy

No main effect of Solution, $F(1, 48) = 0.1$, $p = 0.8$, $f^2 = 0.0$ [95% CI: 0.0 to 0.02].
A main effect of Time, $F(1, 48) = 52.8$, $p < 0.001$; such that participants responded more accurately at posttest (85.2 ± 13.1 ms) relative to pretest (78.3 ± 16.0 ms), $d_{rm} = 0.47$ [95% CI: 0.31 to 0.63].
No interaction of Solution × Time, $F(1, 48) = 0.2$, $p = 0.7$, $f^2 = 0.0$ [95% CI: 0.0 to 0.03].

Table S11.
Mean (± SD) values for RVIP task response accuracy (% correct) for each experimental session.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse	78.3 ± 15.1	85.6 ± 11.3
Placebo Control	78.3 ± 17.1	84.8 ± 14.8

RVIP Task P3 Amplitude

No main effect of Solution, $F(1, 48) = 0.1$, p = 0.7, $f^2 = 0.03$ [95% CI: 0.0 to 0.11].
A main effect of Time, $F(1, 48) = 5.1$, p = 0.028; such P3 amplitude was larger at posttest (4.2 ± 1.8 μV) relative to pretest (3.8 ± 1.7 μV), $d_{rm} = 0.24$ [95% CI: 0.03 to 0.46].
No interaction of Solution × Time, $F(1, 48) < 0.1$, p = 0.9, $f^2 = 0.00$ [95% CI: 0.00 to 0.01].

Table S12.
Mean (± SD) values for P3 amplitude (μV) elicited in response to the RVIP task for each experimental session.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse	3.9 ± 1.6	4.3 ± 2.0
Placebo Control	3.8 ± 1.8	4.2 ± 1.7

Note: Values are collapsed across electrode sites corresponding to the topographic maxima of the P3 (i.e., CP1/Z/2, P1/Z/2, PO3/Z/4).

RVIP Task P3 Latency

No main effect of Solution, $F(1, 48) = 0.9$, $p = 0.3$, $f^2 = 0.17$ [95% CI: 0.0 to 0.43].
A main effect of Time, $F(1, 48) = 3.9$, $p = 0.05$; such that P3 latency was shorter at posttest (357.5 ± 46.0 ms) relative to pretest (366.9 ± 52.0 ms), $d_{rm} = 0.22$ [95% CI: 0.01 to 0.45].

No interaction of Solution × Time, $F(1, 48) < 0.1$, $p = 0.8$, $f^2 = 0.01$ [95% CI: 0.0 to 0.06].

Table S13.
Mean (± SD) values for P3 latency (ms) elicited in response to the RVIP task for each experimental session.

Condition	Pretest	Posttest
Carbohydrate Mouth Rinse	370.2 ± 59.2	361.8 ± 49.6
Placebo Control	363.7 ± 42.9	353.2 ± 41.8

Note: Values are collapsed across electrode sites corresponding to the topographic maxima of the P3 (i.e., CP1/Z/2, P1/Z/2, PO3/Z/4).

Correlations between behavioral performance and neuroelectric activity

Table S14.
Pearson correlations between changes in behavioral performance and changes in neuroelectric activity in response to the Flanker task in the placebo control condition.

	Reaction time change	Response accuracy change	P3 amplitude change	P3 latency change	ERN amplitude change
Reaction time change	---				
Response accuracy change	.177	---			
P3 amplitude change	.048	-.089	---		
P3 latency change	.262	.223	-.229	---	
ERN amplitude change	-.231	-.032	-.126	.037	---

Note: All p's ≥ .15.

Table S15.
Pearson correlations between changes in behavioral performance and changes in neuroelectric activity in response to the Flanker task in the carbohydrate mouth rinse condition.

	Reaction time change	Response accuracy change	P3 amplitude change	P3 latency change	ERN amplitude change
Reaction time change	---				
Response accuracy change	-.056	---			
P3 amplitude change	.159	.080	---		
P3 latency change	-.238	-.165	-.137	---	
ERN amplitude change	-.021	-.098	-.142	.066	---

Note: All p's ≥ .12.

Table S16.
Pearson correlations between changes in behavioral performance and changes in neuroelectric activity in response to the RVIP task in the placebo control condition.

	Reaction time change	Response accuracy change	P3 amplitude change	P3 latency change
Reaction time change	---			
Response accuracy change	-.393**	---		
P3 amplitude change	-.352*	.192	---	
P3 latency change	.124	-.067	-.497**	---

Note: *denotes correlation was significant at $p < .05$. **denotes correlation was significant at $p < .01$. All other p's ≥ .20.

Table S17.
Pearson correlations between changes in behavioral performance and changes in neuroelectric activity in response to the RVIP task in the carbohydrate mouth rinse condition.

	Reaction time change	Response accuracy change	P3 amplitude change	P3 latency change
Reaction time change	---			
Response accuracy change	-.498**	---		
P3 amplitude change	.041	-.061	---	
P3 latency change	.206	-.243	.077	---

Note: *denotes correlation was significant at $p < .05$. **denotes correlation was significant at $p < .01$. All other p's ≥ .09.

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