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AN EVENT-RELATED POTENTIAL STUDY OF INHIBITION TO SUGAR-SWEETENED BEVERAGES

Hanel Watkins

Honors Thesis

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By
Hänel Watkins

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Advisor: Michael Larson, PhD

Honors Coordinator: Rebekka Matheson, MD

ABSTRACT

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Hänel J. Watkins

Department of Neuroscience

Bachelor of Science

In the United States, the intake of sugar-sweetened beverages per capita from 1977 to 2002 doubled across all age groups. One factor that may contribute to the consumption of sugar-sweetened beverages is inhibitory control, or the ability to withhold a dominant response in order to correctly respond to one's environment. Studies suggest that increased recruitment of inhibitory control resources plays a role in decreasing the consumption of high-calorie foods and that strengthening an individual's inhibitory control may help them manage their food intake. However, the neural response to sugar-sweetened beverages versus non-sweetened beverages is unknown. Thus, we tested event-related potential (ERP) manifestations of inhibitory control, including the N2 and P3 components of the ERP, to sugar-sweetened beverages (in this case, soda beverages versus bottles of water) using a go/no-go task in a sample of 116 healthy individuals (M = 20.56; SD = 2.08; 47.4% female). We hypothesized that individuals would recruit increased levels of inhibitory control (i.e., larger N2 and P3 ERP components) toward soda beverages than neutral cues due to soda's rewarding nature. ERP results indicated inhibitory control was greater when individuals withheld their

dominant responses to soda stimuli compared to when they withheld their response to neutral stimuli. Neither weight, N2 difference amplitude on the soda task, nor P3 difference amplitude on the soda task predicted measures of soda intake. We conclude that greater inhibitory control resources are required when withholding responses to soda beverages compared to water, and that inhibitory control mechanisms do not predict soda intake.

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Introduction

In the United States between 1977 and 2002, the intake of sugar-sweetened beverages per capita doubled across all age groups (Brownell et al., 2009). Sugar-sweetened beverage consumption in the United States in 2009 was estimated to be 45 gallons per year, nearly half of total beverage intake (Andreyeva, Chaloupka, & Brownell, 2011). Increased consumption of sugar-sweetened beverages in today's society, including carbonated soft drinks, sports drinks, fruit drinks, and energy drinks is a major concern, as sugar-sweetened beverages are positively linked to obesity (Babey, Jones, Yu, & Goldstein, 2009), cardiovascular disease (Bernstein, de Koning, Flint, Rexrode, & Willett, 2012), and chronic metabolic diseases such as Type-2 diabetes (Malik et al., 2010). Despite the adverse health outcomes and efforts to decrease intake of sugar-sweetened beverages, the United States market for soft drinks reached around 207 billion dollars in 2019 ("Market Value of Soft Drinks in the United States from 2015 to 2020", 2019). In an effort to decrease soda consumption, 33 states have enacted sales taxes on soft drinks (Brownell et al., 2009), but soda consumption – especially among adolescents – remains high. For individuals who are at least six years old, approximately 14.1% of total dietary energy is accounted for by added sugar, with soda and energy drinks being the largest source of added sugars (Drewnowski & Rehm, 2014). Fourteen percent is alarming, as Dietary Guidelines for Americans 2015-2020 recommend that United States residents reduce consumption of sugar-sweetened beverages and treats with added sugar to less than 10% of calories per day ("2015-2020 Dietary Guidelines for Americans", 2015). In light of the health concerns added sugar poses, excess consumption of soda beverages could have serious public health repercussions.

Beverages, compared to matched solid foods, elicit a weaker compensatory dietary response--meaning individuals tend to still feel hungry and may continue to eat after consuming a beverage (Mourau, Bressan, & Mattes, 2007). As such, beverages pose a greater risk than solid foods for promoting a positive energy balance (i.e., people are more likely to overconsume food in liquid form as opposed to solid form; Mourau, Bressan, & Mattes, 2007). The palatable nature of sugar-sweetened beverages and their high availability contributes to the growing health concerns caused by soda beverages. Given the pervasive negative effects that excessive soda consumption can have on an individual's health, it is important to understand what factors contribute to the decision to drink sugar-sweetened beverages.

A possible factor that might contribute to the increased intake of rewarding beverage products is poor inhibitory control. Inhibitory control is defined as the ability to suppress a dominant response in order to respond correctly to environmental cues and obtain a desired goal (Ko & Miller, 2013). Research on diet and food intake suggests that inhibition toward high-calorie foods is important for managing food intake, and individuals with higher inhibitory control abilities may be less likely to consume high-calorie food compared to those with less inhibitory control abilities (Carbine et al., 2017; Houben, 2011). Individuals with a weakened ability to withhold a dominant response have a tendency to act more impulsively, which might be associated with a greater likelihood of seeking out rewarding stimuli such as sugar (Guerreri, Nederkoorn, Schrooten, Martijn, & Jansen, 2009; Ames et al., 2014). Furthermore, strengthening inhibitory control may help individuals gain control over their dominant responses to consume high-calorie foods (Houben, 2008).

The role of inhibitory control has been examined in sweet and salty snack food and sugar sweetened beverage consumption in an adolescent population. For example, poorer inhibitory control abilities were associated with higher sugar-sweetened beverage consumption in males but not females using a generic (not food-specific) go/no-go task (Ames et al., 2014). Furthermore, Ames et al., (2017) evaluated the effect of self-regulation interventions in modifying inhibitory control to reduce the consumption of sugar-sweetened beverages. The results of this study are promising and show that inhibitory control interventions may aid individuals with weaker inhibitory control abilities in relation to sugar-sweetened beverage consumption (Ames et al., 2017). However, these results have not been observed using soda-specific go/no-go tasks. With numerous studies showing a relationship between food-related inhibitory control and high-calorie food consumption, it's possible that a similar relationship is observed with highly palatable sugar-sweetened beverages. Moreover, interventions that strengthen inhibitory control mechanisms may be able to reduce sugar-sweetened beverage consumption, which would have positive ramifications for public health.

One method to measure soda-related inhibitory control is through scalp-recorded event-related potential (ERP) components. Specifically, we tested the N2 and P3 components of the ERP. The N2 is a negative deflection in the ERP waveform that peaks approximately 200-350 ms after stimulus onset and is thought to reflect cognitive processes such as conflict monitoring and response inhibition (Folstein & Van Petten, 2008). The N2 is larger (i.e., larger negative amplitude) when an individual withholds a prepotent response to a stimulus, suggesting that the N2 is larger with more recruitment of inhibitory control processes. In regards to food and diet, the N2 had a larger amplitude

when females inhibited their responses toward food stimuli compared to nonfood stimuli (Watson & Garvey, 2013). Further, individuals tend to recruit more inhibitory control resources, as indicated by a larger N2 amplitude, when withholding responses toward high-calorie foods compared to low calorie foods (Carbine et al., 2017; 2018). Increased recruitment of inhibitory control to high-calorie foods also predicted lower calorie and carbohydrate intake, suggesting inhibitory control plays an important role in managing the consumption of foods high in calories and carbohydrates (Carbine et al., 2017). However, the direction of this result was not always consistent (Carbine et al., 2018). Given our ability to differentiate between stimuli and food types using the N2, we feel it will be able to show existing differences in soda-related inhibitory control.

Another ERP component that is often used to examine inhibitory control processes is the P3. The P3 is a positive deflection in the ERP waveform that occurs between 300 and 600 ms after stimulus onset (Falkenstein et al., 1999). The P3 also reflects various cognitive processes, including prepotent response inhibition and working memory (Brydges, Fox, Reid, & Anderson, 2014). During go/no-go and inhibition tasks, the P3 exhibits a larger (i.e., more positive) amplitude when participants withhold a dominant response (Smith, Johnstone, & Barry, 2008), suggesting that the P3 can be used to measure the allocation of inhibitory control resources. The actual significance of the P3 in go/no-go tasks is debated. Generally, a larger P3 amplitude (i.e., more positive) during a go/no-go task is said to reflect inhibitory control processes, but it is not clear whether this refers to inhibition of movement-related potentials (Smith, Johnstone, & Barry, 2008), task-extraneous events (Polich, 2007), or inhibition to a dominant response (Munro et al., 2007). Specifically, in food-related research, increased recruitment of

inhibitory control resources toward food images elicits a larger no-go P3 amplitude (Watson & Garvey, 2013). Taken together with existing N2 research, results suggest that individuals recruit more inhibitory control resources when they withhold dominant responses to food. Additionally, using both the N2 and P3 ERP components may help shed more light on the specific type of response inhibition involved when individuals respond to soda images.

While previous research has examined food-related inhibitory control, the current study examined neural indices of inhibitory control toward sugar-sweetened beverages, particularly soda, due to the increased consumption of and negative health consequences associated with sugar-sweetened beverages. Specifically, we examined neural indices of inhibitory control to images of soda versus images of bottled water. Soda images were chosen due to their palatable nature and high sugar content and water was used as an offset that represented an alternative and healthy low-calorie beverage. There were two primary hypotheses. First, based off the food-related inhibitory control research (e.g., Carbine et al., 2017, 2018; Watson & Garvey, 2013), we hypothesized that N2 and P3 ERP amplitudes would be larger when participants were inhibiting dominant responses toward soda images compared to a task where participants withhold their dominant responses toward neutral stimuli. Second, we hypothesized that N2 and P3 ERP difference waves (no-go minus go) for the soda task would predict measures of soda intake.

Method

Participants

All study procedures were approved by the Brigham Young University (BYU) Institutional Review Board. Participants were recruited from undergraduate classes for course credit. Exclusion criteria consisted of alcohol or tobacco use, females who were currently pregnant or lactating, individuals with a head injury that resulted in a loss of consciousness, and individuals diagnosed with an eating disorder, neurological disorder, learning disorder, psychiatric disorder, or chronic or metabolic disease. One-hundred and fifty-five participants signed consent forms and originally participated in the study. Of those 155, five participants had head injuries that resulted in a loss of consciousness, three were diagnosed with a psychiatric disorder, and five were diagnosed with a chronic or metabolic disease. Further, nine participants had missing EEG data, thirteen had messy EEG data that did not make it through the artifact correction process, and four had EEG data that was too messy and unreliable to perform data analysis on (see EEG Data Recording and Analysis). After excluding these participants, there were 116 participants that were included in the final data analyses.

The final 116 participants were between the ages of 18 and 28 (M = 20.56; SD = 2.08; 47.4% female) and were all native English speakers (see Table 1 for demographics). In order to control for potential confounding variables that can influence inhibitory control or food/beverage ingestion behaviors, including sleep (St-Onge, Wolfe, Sy, Shechter, & Hirsch, 2014), exercise (Hanlon, Larson, Bailey, & LeCheminant, 2012), caffeine, and hunger, participants were required to get at least seven hours of sleep the night before study participation, refrain from vigorous physical activity, refrain from consuming caffeine 24 hours before study participation, and to stop eating the meal

before coming in (9pm the night before for morning hours and four hours before for afternoon and evening hours; Carbine et al., 2017).

Table 1

Demographics and VAS

	Mean	SD	Minimum	Maximum
Age (years)	20.56	2.08	18.00	28.00
Height (cm)	172.01	9.33	150.00	200.66
Weight (kg)	70.64	14.34	46.70	125.00
BMI (kg/m^2)	23.76	4.10	18.10	39.00
VAS- Hunger (cm)	5.91	1.77	0.48	9.58
VAS- Thirst (cm)	5.85	1.35	1.67	8.58
VAS- Sleep (cm)	6.57	1.74	1.50	9.90

Note. VAS = visual analog scales; SD = standard deviation; cm = centimeters; kg = kilograms; m = meters

Power Analyses

In order to ensure that the study was powered enough to detect effects of interest, sample size calculations were conducted based off effects published in Carbine and colleagues (2018). To test if inhibitory control, as measured by the N2 and P3 ERPs, differed by soda and neutral images, we conducted a one group, two measurements, ANOVA: Repeated measures, within factors power analysis in G*Power (v3.1). Based on the observed Task by Trial interaction (partial eta squared = .19 as calculated by SPSS, which was converted into an F effect size of .48), 11 participants were needed to detect effects of interest at 80% power (alpha = .05). To test if neural indices of soda-related inhibitory control, as measured by the N2 and P3 ERPs, are associated with soda

consumption, we conducted a second power analysis using the linear multiple regression, fixed model, R-squared deviation from zero option. Based on the observed Cohen's *f*-squared value of .12 and four predictors, 105 participants were needed to detect the effects of interest at 80% power (alpha = .05). Therefore, the final study sample of 116 participants was adequately powered to detect all effects of interest.

Procedure

Participants provided informed written consent upon arrival to the lab and confirmed the sleep, exercise, caffeine, and fasting pre-study requirements. Participants then completed a soda (SPQ) and water (WPQ) preference questionnaire, which helped the researchers determine which pictures to use for the soda go/no-go task. After the SPQ and WPQ, participants completed a fluid intake diary (where they recorded all the fluids they consumed in a typical day), a demographic survey, and a soda adaptation of the Food Frequency Questionnaire used in Bernstein, de Koning, Flint, Rexrode and Willett (2012) in order to assess average frequency of daily soda and water consumption over the past year. Participants also indicated how often they drank soda and water in the past 7 days, ranging from never to 3+ a day (Warner, Harley, Bradman, Vargas, & Eskenazi, 2006). After the surveys were completed, height and weight were obtained, using a stadiometer and weight scale, respectively. Body mass index (kg/m2) was determined using height and weight measurements.

After height and weight measurements, participants were brought to the electroencephalography (EEG) acquisition room and fitted for an EEG net. During this process, participants completed three visual analog scales (VAS): one assessing hunger levels, one assessing thirst levels, and one assessing sleep quality. Completing the

surveys, height and weight measurements, and VAS provided researchers the time needed to update the soda task with the participant-specific pictures. After the net was fitted, participants completed two go/no-go tasks (one using soda and water pictures, one using tools and flower pictures) while EEG data were recorded. Completion of the EEG task concluded study participation and participants were granted class credit for their time.

Soda and Water Preference Questionnaires

Questionnaires were adapted from previous food preference questionnaires (Catanzaro, Chesbro, & Velkey, 2013; Smith, 2018). On the questionnaires, participants were presented with a variety of different sodas, such as caffeinated low-calorie cola (e.g., Diet Coke, Coke Zero, Diet Pepsi, etc.), low-calorie sodas (e.g., Diet 7-Up, Fresca, Diet Mountain Dew, diet ginger ale), cola (e.g., Coke, Pepsi), and other sodas (e.g., 7-Up, Mountain Dew, Dr Pepper), and a variety of different bottled water (e.g., Arrowhead, Aquafina, Dasani). For every soda and water, participants were asked to rate how much they liked the beverage on a 5-point Likert scale, from dislike a lot to like a lot. The top three sodas and top three waters that participants indicated they liked the most were then used as the stimuli in the soda go/no-go task (see Go/No-Go Tasks). If more than three sodas or waters received the participants' highest ratings, participants were asked to rank their top three sodas and their top three waters from their highest rated beverages, and the top three beverages in each category were then used as stimuli.

Fluid Intake Diary

In order to obtain a brief overview of daily fluid intake, participants completed a fluid intake diary at the beginning of the lab session. Participants were given a list of

different beverages and different times of day and asked to indicate which of the listed beverages they consumed (if any) at each time of day. Participants were also asked to indicate the amount of liquid consumed based off pictures provided at the bottom of the page. Our fluid intake diary was adapted from Khan and colleagues (2019), who used a similar measure to assess fluid intake and urinary habits in children. Fluid intake from the diaries was assessed as a descriptive measure only. Average daily fluid intake for each beverage are reported in Table 2.

Table 2

Average Daily Fluid Intake Diary

	Mean	SD	Minimum	Maximum
Water (fl oz)	52.14	25.41	6.00	138.00
Coffee/Tea (fl oz)	0.10	0.94	0.00	10.00
Hot Chocolate (fl oz)	0.77	2.81	0.00	20.00
Milk (fl oz)	2.78	8.25	0.00	53.00
Drinkable Yogurt (fl oz)	0.50	1.87	0.00	10.00
Juice (fl oz)	2.56	5.38	0.00	30.00
Fruit/Sweet Drink (fl oz)	3.33	9.42	0.00	68.00
Fizzy Drink/Soda (fl oz)	4.03	7.64	0.00	44.80
Sports Drink (fl oz)	2.02	6.21	0.00	48.00
Other (fl oz)	1.98	5.84	0.00	33.80

Note. fl oz = fluid ounces

Soda Frequency Questionnaire

The soda frequency questionnaire (SFQ), adapted from Bernstein and colleagues (2012), assesses the average frequency of daily soda consumption over the past year for

caffeinated low-calorie colas, low-calorie colas without caffeine, low-calorie sodas, caffeinated colas, colas without caffeine, and other sodas. It also assesses the frequency of water consumption. Specifically, participants answered eight questions indicating how often they consumed a glass, bottle, or can of a listed soda or water type. There were seven possible responses, ranging from "never" up to "more than two times a day". The reliability and validity of food frequency questionnaires for beverages are reasonable, as previously described by Feskanich and colleagues (1993) and the correlation of frequency questionnaires with beverage intake ranges from 0.36 to 0.84 (Bernstein et al., 2012). We also adapted two questions from Warner and colleagues (2006) that ask participants how often they drank sodas and water in the past seven days.There were also seven response options, ranging from “never” to “3+ per day”. Having the adapted questionnaires from both Bernstein and colleagues (2012) and Warner and colleagues (2006) allowed us to look at soda consumption in general over the past year and recent average soda consumption over the past week.

For scoring these questionnaires, responses were coded as the numerical value of the selected response (e.g. 1 a day was coded as 1). For categories with ranges, we followed Warner and colleagues’ (2006) protocol by assigning the midpoint of each category as the numerical value of the response (e.g. 1-2 per day was coded as 1.5). Finally, all surveys included questions where the responses ranged from a number per week to a number per day. In order to get all responses on the same scale, any response that indicated how many beverages per week someone consumed was divided by 7 in order to calculate the amount consumed per day. Thus, all responses were on an “amount consumed per day” scale. Finally, the first six questions from the adapted Bernstein and

colleagues' (2012) questionnaire that asked about soda consumption were added together, in order to get an overall soda consumption score that was not split by soda type. The summed score from Bernstein and colleagues' (2012) questionnaire (referred to as "general soda intake") and the soda question from the Warner and colleagues' (2006) questionnaire (referred to as "recent soda intake") were then used in all soda consumption analyses.

Visual Analog Scales

The VAS questionnaires were administered immediately prior to the EEG testing. Questions consist of a 10-centimeter line that is anchored with extremes, such as from "Not at all" on one side to "Extremely" on the other (Flint, Raben, Blundell, & Astrup, 2000). Individuals are asked to make a vertical line along the continuum that best describes how they feel. VAS questionnaires have strong test/retest reliability (Porrini, Crovetti, Testolin, & Silva, 1995; Lappalainen, Mennen, van Weert, & Mykkänen, 1993) and strong validity for assessing subjective satiety and hunger measurements (Porrini et al., 1995; Parker et al., 2004). Six questions were used to assess subjective measures of hunger, six questions were used to assess subjective measures of thirst, and one question was used to assess subjective quality of the previous night's sleep. For scoring, the second question in the hunger VAS and the second question of the thirst VAS were reversed scored. Then, the six hunger questions were averaged together and the six thirst questions were averaged together to get overall hunger and thirst ratings (Carbine et al., 2017; 2018). Please refer to Table 1 for the average hunger, average thirst, and single sleep VAS scores.

Go/No-Go Tasks

During EEG data recording, participants completed two go/no-go tasks. For the tasks, participants were asked to respond to certain pictures with a button press of their index finger (go stimuli) and withhold responses to other pictures (no-go stimuli). For both tasks, there were two blocks of 100 trials each, 70 of them go trials and 30 of them no-go trials in order to elicit inhibition of a dominant or automatic response (Benikos, Johnstone, & Roodenrys, 2013), presented in random order. Each picture was shown on a white background for 500 milliseconds with an interstimulus interval of 1200 to 1400 milliseconds consisting of a black fixation cross on a white background. For the soda go/no-go task, participants were asked to respond to pictures of water bottles (go trials) and withhold responses to soda bottles (no-go trials). For the neutral go/no-go task, participants were asked to respond to pictures of household tools (go trials) and withhold responses to pictures of flowers (no-go trials). Tasks were presented using E-prime 2.0 (Psychology Software Tools, Inc., 2012).

The soda and water stimuli consisted of the same soda and water brands listed on the SPQ and WPQ. Due to copyright issues, we took our own pictures of the specified sodas and water stimuli. Photoshop was used to ensure that pictures were the same size, contrast, and brightness across the soda and water bottles. Pictures were 2-liter bottles for sodas and 16.9 fluid ounces for water bottles and were all placed on a white background. For each participant, only their top-three rated sodas and water were used in the soda go/no-go task. For the neutral task, pictures were selected from the standardized Food-Pics database (Blechert, Meule, Busch, & Ohla, 2014), which contained 315 normed non-food items on a white background. Thirty-eight pictures from the flower/leaves category

were randomly selected for our flower no-go trials and thirty-eight pictures from the tools category were randomly selected for the tools go trials.

EEG Data Recording and Analyses

We used 128 equidistant passive Ag/AgCl electrodes on a hydrocel geodesic sensor net and an Electrical Geodesics, Inc., (EGI) NA300 amplifier system (20K gain, nominal bandpass=.10-100Hz; Eugene, Oregon) to collect EEG data. Online, we used Cz as the reference and an electrode approximately 2 inches behind the Cz as common ground. Data were digitized continuously at 250Hz while maintaining impedance below 50kΩ. Once offline, EEG data were first filtered in NetStation (v.5.3.0.1) using a 0.1hz high-pass filter (0.30hz roll off) and then with a 30hz low-pass filter (2.0hz roll off). After filtering, EEG data were segmented from 200 milliseconds before stimulus presentation to 1,000 milliseconds after stimulus presentation (Carbine et al., 2018).

Data were then exported to ERP PCA Toolkit in MatLab (Dien, 2010) to conduct artifact correction. To correct eye blinks and saccades, independent components analysis utilizing an infomax rotation was used. If an extracted ICA component correlated at .9 or higher with either two blink or two saccade templates, it was removed from the data. One blink and one saccade template were created from previous data collected in our lab and one blink and one saccade template were provided by the ERP PCA Toolkit. After ICA, if the fast average amplitude of an electrode exceeded 100 microvolts (μV) or the differential average amplitude of an electrode exceeded 50 μV, the electrode was marked as bad and data was interpolated using the nearest neighbor approach with the six surrounding electrodes (Dien, 2010). For re-referencing, an average reference was used

and finally data were baseline corrected using the -200 to 0 millisecond pre-stimulus time window.

For both the N2 and P3 amplitudes, we averaged over four electrode sites chosen *a priori* and based off previous research (Carbine et al., 2017; Carbine et al., 2018): 6, 7, 106, and 129 (ref; see Larson, Farrer, Clayson, 2011 for electrode montage). For time windows of interest, the N2 ERP component was quantified as the mean amplitude between 200 to 300 milliseconds post-stimulus, determined *a priori* and based off previous research (Carbine et al., 2017; Carbine et al., 2018). For the P3 ERP component, it was decided *a priori* that a collapsed localizer approach would be used to determine the time window of interest (Luck & Gaspelin, 2017). As such, the P3 component was quantified as the mean amplitude between 350 and 500 milliseconds post-stimulus.

Finally, we conducted reliability analyses on the N2 and P3 amplitudes using the ERP Reliability Analysis (ERA) Toolbox v 0.3.2 (Clayson & Miller, 2017a) in order to ensure ERP data had enough trials to produce a reliable signal. The ERA toolbox estimates the dependability (the generalizability theory [G theory] analogue of reliability) of the data using formulas by Baldwin and colleagues (2015), and provides the number of trials needed for each trial and condition in order for the data to be considered reliable. *A priori*, we decided participants must have enough trials to produce a dependability estimate of at least 0.7 in order to be included in data analyses. Of the 120 participants who had data from all tasks that made it through the artifact correction processes, four were excluded for having unreliable and messy EEG data, resulting in the final sample of 116 participants with excellent dependability for all trials, tasks, and ERPs (.90 - .97 dependability; Clayson & Miller, 2017b). Final dependability estimates, 95% credible intervals, trial cut off values, mean number of trials, and trial range as a function of task

and trial for the N2 and P3 are presented in Table 3.

Table 3

N2 and P3 Dependability by Task and Trial

	Dependability	95% CI	Cut off	Mean Trials	Trial Range
N2: Neutral Go Trials	.96	.94 - .97	13	118.57	33 - 140
N2: Neutral No-Go Trials	.91	.89 - .94	10	45.82	15 - 57
N2: Soda Go Trials	.97	.96 - .97	10	121.72	39 - 139
N2: Soda No-Go Trials	.90	.87 - .92	13	49.51	18 - 60
P3: Neutral Go Trials	.96	.94 - .97	13	118.57	33 - 140
P3: Neutral No-Go Trials	.93	.91 - .95	8	45.82	15 - 57
P3: Soda Go Trials	.97	.96 - .98	10	121.72	39 - 139
P3: Soda No-Go Trials	.91	.88 - .93	12	49.51	18 - 60

Note. CI = credible interval

Statistical Analyses

All statistical analyses were conducted in the Statistical Package for Social Sciences (SPSS; v. 25). For behavioral data, median reaction times (RTs; to avoid undue influence of outliers) were calculated for correct go trials for both tasks. Differences in RTs between tasks were tested using a paired samples *t*-test. Within-subjects Cohen's *d* is reported as a measure of effect size. Accuracy was also calculated for go and no-go trials for both tasks. Differences in accuracy were calculated using a 2-Trial (Go, No-Go) by 2-Task (Soda, Neutral) repeated measures ANOVA. To test the first hypothesis that sodas require increased recruitment of inhibitory control processes, 2-Trial (Go, No-Go) by 2-Task (Soda, Neutral) repeated measures ANOVAs were conducted on both N2 and P3

amplitudes. For all ANOVAs, Greenhouse-Geisser correction was used when needed for violations of sphericity and partial eta squared (η_p^2) is reported as a measure of effect size.

To test the second hypothesis that soda-related inhibitory control relates to soda intake, we conducted four multiple regression analyses. In the regressions, age, sex (male=0; female=1), weight, and soda inhibitory control were used to predict soda intake. In the first regression, N2 difference amplitude was used to predict general soda intake. In the second regression, N2 difference amplitude was used to predict recent soda intake. In the third regression, P3 difference amplitude was used to predict general soda intake. In the fourth regression, P3 difference amplitude was used to predict recent soda intake. Difference amplitudes were calculated as no-go trials minus go trials, so that a more negative N2 difference wave and a more positive P3 difference wave still reflected increased recruitment of inhibitory control processes. In order to meet linear regression assumptions, the square root of general and recent soda intake were used as the dependent variables. Basic assumptions for multi-collinearity, homoscedasticity, and normality of residuals were good for models predicting general soda intake and fair for models predicting recent soda intake. Standardized betas, variance inflation factors (VIF) as measures of multi-collinearity, and adjusted R^2 and Cohen's f^2 as measures of effect sizes are reported.

Results

Behavioral Data

Means and standard deviations for behavioral data are reported in Table 4. For RTs, participants were faster at responding to correct go trials on the soda task (i.e.,

responding to water images) than the neutral task (i.e., responding to tool images; t[105] = 15.12, $p < .001$, $d_z = 1.47$). For accuracy, the 2-Trial (Go, No-Go) by 2-Task (Soda, Neutral) repeated measures ANOVA revealed a main effect of Trial (F[1,105]=90.45, $p<.001$, $\eta_p^2=.46$), with greater accuracy on go trials than no-go trials. There was also a main effect of Task (F[1,105]=76.06, $p<.001$, $\eta_p^2=.42$), with greater accuracy on the soda task than the neutral task. Finally, the Trial by Task interaction was significant (F[1,105]=23.89, $p<.001$, $\eta_p^2=.19$). Follow-up post-hoc t-tests revealed that the difference between go and no-go trial accuracy was larger on the neutral task than the soda task (t[105] = 4.88, $p < .001$, $d_z = 0.48$). Further, the difference in accuracy between soda and neutral no-go trials was larger than the difference between soda and neutral go trials (t[105] = 4.88, $p < .001$, $d_z = 0.48$). In sum, behavioral findings suggest faster response times and increased accuracy for the soda go/no-go task compared to the neutral go/no-go task.

Table 4

Behavioral Data by Task and Trial

	Mean	SD	Minimum	Maximum
Neutral: Go Trial Accuracy (%)	97.57	6.37	51.00	100.00
Neutral: No-Go Trial Accuracy (%)	87.90	10.14	45.00	100.00
Soda: Go Trial Accuracy (%)	99.50	1.18	90.00	100.00
Soda: No-Go Trial Accuracy (%)	95.36	4.83	70.00	100.00
Neutral: Correct Go Trial RT (ms)	390.38	49.43	301.00	719.00
Soda: Correct Go Trial RT (ms)	345.55	46.31	287.00	742.00

Note. SD = standard deviation; % = percentage; RT = reaction time; ms = milliseconds

Hypothesis One: Increased Inhibitory Control for Soda

Means and standard deviations for each go/no-go task, trial, and ERP component are reported in Table 5. ERP waveforms are displayed in Figure 1. The 2-Trial (Go, No-Go) by 2-Task (Soda, Neutral) repeated measures ANOVA for N2 amplitude revealed a main effect of Trial (F[1,115]=23.88, p<.001, η_p^2=.17), with no-go trials being larger (i.e., more negative) than go trials, as expected. The main effect of Task was not significant (F[1,115]=0.33, p=.57, η_p^2=.003); however, the Trial by Task interaction was significant (F[1,115]=27.92, p<.001, η_p^2=.20). Follow-up paired samples t-tests revealed that no-go trials were larger (i.e., more negative) than go trials on the soda task (t[115]=6.90, p<.001, d_z=.64), but not the neutral task (t[115]=0.51, p=.61, d_z=.05). Further, go trials did not differ between the two tasks (t[115]=1.44, p=.15, d_z=.13), but no-go trials on the soda task were larger (i.e., more negative) than no-go trials on the neutral task (t[115]=2.10, p=.04, d_z=.20). Overall, N2 ERP findings show that withholding responses to soda stimuli compared to neutral stimuli requires increased recruitment of inhibitory control resources.

Table 5

ERP Data by Task and Trial

	Mean	SD	Minimum	Maximum
N2: Neutral Go Trial (μV)	-1.17	2.04	-7.87	4.28
N2: Neutral No-Go Trial (μV)	-1.12	2.43	-8.68	6.69
N2: Soda Go Trial (μV)	-0.91	1.94	-6.74	4.64
N2: Soda No-Go Trial (μV)	-1.60	2.07	-8.08	2.53
P3: Neutral Go Trial (μV)	0.71	1.98	-5.92	5.96
P3: Neutral No-Go Trial (μV)	1.75	2.81	-8.66	10.33
P3: Soda Go Trial (μV)	1.38	2.14	-3.03	9.02

P3: Soda No-Go Trial (μV)	2.13	2.19	-2.40	8.67

Note. SD = standard deviation; μV = microvolts

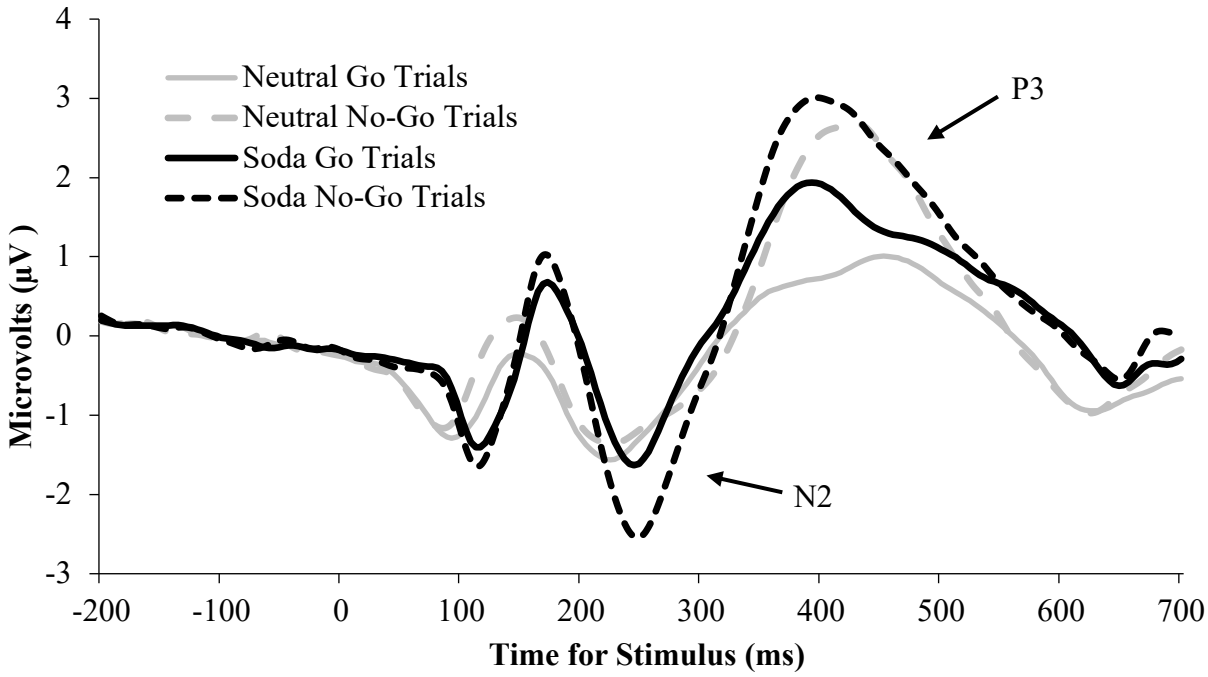

Figure 1. N2 and P3 ERP waveforms during the neutral and soda go/no-go tasks.

The 2-Trial (Go, No-Go) by 2-Task (Soda, Neutral) repeated measures ANOVA for P3 amplitude revealed a main effect of Trial (F[1,115]=76.74, p<.001, η_p^2=.40), with no-go trials being larger (i.e., more positive) than go trials, as expected. The main effect of Task was also significant (F[1,115]=5.57, p=.02, η_p^2=.05), with P3 amplitude overall being larger during the soda task compared to the neutral task. The Trial x Task interaction, however, was non-significant (F[1,115]=3.64, p=.06, η_p^2=.03). In sum, P3 amplitude was larger towards beverage-related items than neutral items, regardless of if participants were inhibiting responses or not (i.e., the effect was not specific to soda).

Hypothesis Two: Inhibitory Control Predicting Soda Intake

On average, participants consumed 0.44 soda beverages (measured in bottles, glasses, or cans) per day (*SD* = 0.48) over the past year (general intake) and 0.21 soda beverages (measured in bottles, glasses, or cans) per day (*SD* = 0.28) over the previous seven days (recent intake). Figure 2 depicts scatter plots between ERP amplitudes and measures of soda intake (the square root of soda intake due to transformation).

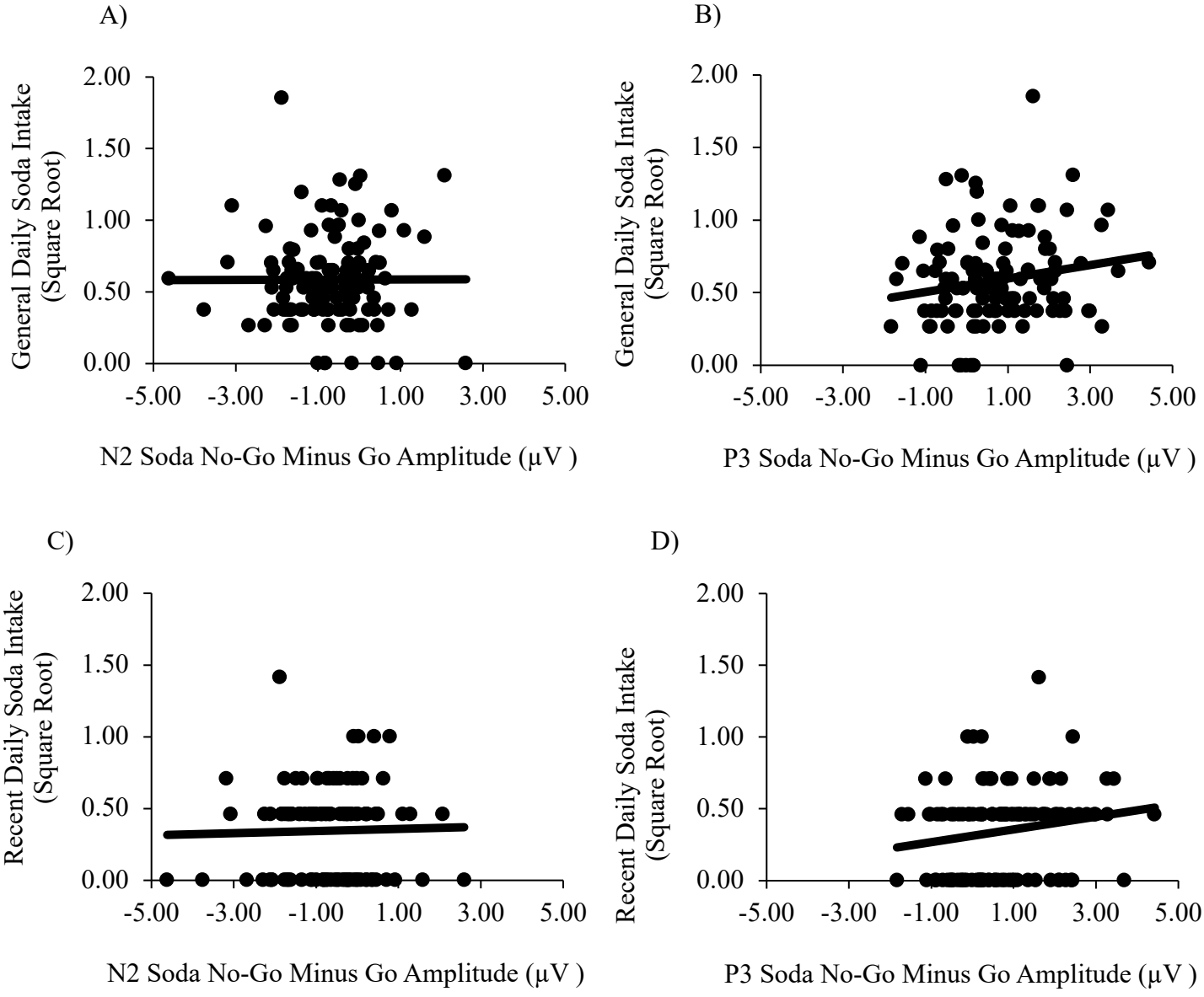

Figure 2. Scatter plots between A) N2 amplitude and general soda intake, B) P3 amplitude and general soda intake, C) N2 amplitude and recent soda intake, and D) P3 amplitude and recent soda intake.

All results from regression analyses are reported in Tables 6 and 7; a summary of the regression results are reported here. For general soda intake, as individuals got older in age, they consumed less soda (*p*s < .02). Females also on average consumed less soda than males (*p*s < .02). Neither weight, N2 difference amplitude on the soda task, nor P3 difference amplitude on the soda task predicted general soda intake (*p*s > .05). For recent soda intake, we saw the same pattern as for general soda intake wherein older individuals and females consumed less soda (*p*s < .04). Again, neither weight, N2 difference amplitude on the soda task, nor P3 difference amplitude on the soda task predicted recent soda intake (*p*s > .06). In summary, contrary to our hypothesis, N2 and P3 component difference amplitudes did not predict reported soda intake.

Table 6

Multiple Linear Regressions Predicting General Soda Intake

	β	*t*	VIF	*F*	df	Adj. R^2	Cohen's f^2
Soda No-Go Minus Go N2 amplitude model				2.86*	4, 111	.06	.06
Age	-.24	-2.49*	1.11				
Sex	.24	2.43*	1.23				
Weight	.08	0.77	1.18				
Soda N2 No-Go Minus Go	.003	0.03	1.02				
Soda No-Go Minus Go P3 amplitude model				3.92**	4, 111	.09	.10

Age	-.25	-2.67**	1.11
Sex	.23	2.34*	1.23
Weight	.07	0.73	1.17
Soda N2 No-Go Minus Go	0.18	1.97	1.02

Note. Dependent variable for both models was generic soda intake. VIF= variance inflation factor. *p<.05. **p<.01.

Table 7

Multiple Linear Regressions Predicting Recent Soda Intake

	β	t	VIF	F	df	Adj. R^2	Cohen's f^2
Soda No-Go Minus Go N2 amplitude model				1.90	4, 111	.03	.03
Age	-.18	-1.89	1.11				
Sex	.23	2.23*	1.23				
Weight	.02	0.24	1.17				
Soda N2 No-Go Minus Go	.03	0.31	1.01				
Soda No-Go Minus Go P3 amplitude model				2.82	4, 111	.06	.06
Age	-.20	-2.06*	1.11				
Sex	.21	2.13*	1.23				
Weight	.02	0.20	1.17				
Soda N2 No-Go Minus Go	.17	1.89	1.02				

Note. Dependent variable for both models was recent soda intake. VIF= variance inflation factor. *p<.05.

Discussion

The current study tested soda-related inhibitory control abilities between a soda-specific go/no-go task and a neutral task as well as whether ERP component measures (N2 and P3 amplitude) of neural inhibition predict general and recent soda intake. Results showed more errors and larger N2 ERP amplitude and P3 ERP amplitude for no-go trials compared to go trials, as predicted—indicating the go/no-go tasks were successful in separating inhibitory responses from non-inhibition trials.

More specific to soda, there were differences in the behavioral performance on the soda go/no-go task compared to the neutral go/no-go task. Specifically, participants responded more quickly and accurately on the soda task compared to the neutral task. The pattern of behavioral responses may be due to the difference in stimuli presented. In the soda go/no-go task, participants were specifically asked to withhold their response to their three highest-rated sodas and respond to their three highest-rated pictures of water brands, while for the neutral task participants responded to household tools but withheld their responses to flower stimuli. Both the flowers and the soda are hedonic (pleasant) stimuli, but it is possible that participants had greater attention to the soda stimuli as soda and other sugary drinks have a high reinforcement value (Carbine et al., 2018) and were specifically chosen by the participants as drinks they find enjoyable. Whereas for the flower stimuli, the flowers were simply standardized pictures that may have held less reinforcement value and attention demand. Thus, participants may not have performed as quickly or accurately on the neutral go/no-go task relative to the soda go/no-go task.

The idea of different levels of attention to the two go/no-go tasks is supported by the differences in P3 amplitude between the tasks. Specifically, the amplitude of the P3

component, an ERP component often associated with attention to the task stimuli (as well as inhibition in a go/no-go task), was larger toward beverage stimuli than neutral stimuli. Notably, there was also a difference between the task in the degree of inhibitory control required to withhold to the no-go trials. There was a significant Trial by Task interaction for the N2 amplitude that showed larger relative N2 amplitude between go and no-go trials for the soda go/no-go task compared to the neutral go/no-go task and absolute larger N2 amplitude on no-go trials during the soda task compared to the neutral task. N2 amplitude significantly differed between the tasks for the no-go, but not go, stimuli—suggesting some degree of specificity in the amount of inhibitory control required between the two tasks. As a whole, the combination of the behavioral and ERP results suggests that the participants had better performance to the task using soda stimuli that may represent increased attention to the soda task relative to the neutral task and that the soda-related go/no-go elicited increased inhibitory control compared to the neutral task.

The findings of increased inhibitory control to soda related to non-food or beverage stimuli is consistent with findings from previous research, where individuals were found to recruit additional inhibitory control resources when withholding their responses to highly palatable foods compared to less palatable foods (Carbine et al., 2017). One possible explanation for this is that more palatable foods provide a more valid way to measure food- and beverage-related inhibition. This is supported by a study done by Carbine et al., where it was found that the high calorie N2 difference predicted caloric intake (2017). While the P3 did not show a significant Trial x Task interaction, we see a similar pattern where P3 amplitude is larger (i.e., more positive) during no-go trials than go trials.

A difference in the current study relative to that of Carbine et al. (2017) is that the soda go/no-go ERP amplitudes, whether for the N2 or P3 components, did not significantly predict general or recent soda intake. One possible reason for the lack of an association is the measurement of soda intake was retroactive. Participants may not have accurately recorded their soda consumption as free recall of diet information is quite difficult to do with high accuracy. In addition, it is possible that the amount of inhibitory control required to inhibit to a soda pictorial stimulus is quite different from day-to-day inhibition toward soda consumption. Finally, there may have been a lack of range and floor effect in the soda consumption, as our participants did not consume large quantitates of soda, thus reducing the variability and the amount of variance that could be predicted in the regression models.

Our study adds incremental validity to existing studies by examining inhibitory control processes in soda vs water as opposed to just examining high-calorie vs low-calorie foods or just high-calorie foods (Carbine et al., 2018; Watson & Garvey, 2013). To date the relationship between soda beverage consumption and neural inhibition has not been examined. One study aimed to investigate the effects of inhibitory control in dietary decision making among adolescents in Southern California (Ames et al., 2014). While the findings indicated that poorer decision-making was associated with higher sweetened beverage consumption, the task itself didn't use any sugar-sweetened beverage signals. We aimed to examine a similar effect in dietary decision making using a specific task that used sugar-sweetened beverage signals and water signals as an offset. In the male model specifically, indicators of inhibitory control were predictors of sweet snack consumption. Our study found that the inhibitory control measures such as the N2 and P3

were not accurate predictors of soda intake, but women and older adults consumed less soda overall. It is possible that these findings could indicate gender differences in food-related behavior. Killgore &Yurgelun-Todd (2012) found that women showed a higher activation in areas that are involved in response inhibition and decision making, such as the dorsolateral, ventrolateral, and ventromedial prefrontal cortex compared to men. This suggests that women may be more susceptible to behavioral interventions targeting soda-related inhibitory control than men.

Soda-related intervention measures may be a promising way to decrease national soda consumption and consequently facilitate weight loss and lessen the burden of metabolic disease on society. Several studies utilizing short-term interventions were effective in decreasing food consumption among those with lower levels of inhibitory control (Houben et al., 2011). We are not aware of studies that examine the long-term effects of inhibitory control interventions on food consumption, and the exact mechanism by which inhibition training alters dietary decision making.

Building off prior research, our study used both high- and low- calorie image equivalents (i.e., soda and water images) in our go/no-go tasks in order to gain a better understanding of soda-related inhibitory control as it relates to the decision to consume sugar-sweetened beverages. We also controlled for variables such as gender, BMI, and neurological or psychological diseases that could be potential confounds for N2 and P3 amplitude. Participants were required to rank their favorite soda and water beverages before beginning the task. We hoped that this would elicit a larger ERP response and facilitate analysis. Future research could utilize more generalized stimuli to examine participants' responses to sugar-sweetened beverages.

Conclusion

We found that inhibiting toward soda beverages compared to water elicited larger inhibitory control responses, as seen by larger no-go N2 and P3 amplitudes, and that participants had improved accuracy and faster RTs to the soda stimuli compared to neutral. Findings suggest increased levels of attention and inhibition needed for the soda stimuli compared to the control task. However, body weight, P3 amplitude, and N2 amplitude were not significant predictors of general soda intake. Overall, women and older individuals consumed less soda on average. Future research should investigate the role of soda-related inhibitory control in sugar-sweetened beverage consumption habits.

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