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The relative reinforcing value of sweet versus savory snack foods after consumption of sugar- or non-nutritive sweetened beverages

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A B S T R A C T

The effects of sugar-sweetened (SSB) and non-nutritive sweetened (NSB) beverages on the regulation of appetite, energy intake and body weight regulation remain controversial. Using a behavioral choice paradigm, we sought to determine the effects of consuming a SSB or NSB on appetite and the reinforcing value of sweet relative to salty/savory snack foods. In a randomized crossover study, 21 healthy weight adults consumed 360 ml of SSB (sucrose; 31 g) or NSB (sucralose; 4 g) with a standardized meal. Hedonic ratings for the sweet and salty/savory snack foods used for the reinforcement task were assessed prior to the start of the study. Satiety and the desire to eat foods with a specific taste profile were assessed before and every 30 min post-meal for 4 h. The relative reinforcing value of the snack foods was assessed using a computer-based choice task (operant responding with concurrent schedules of reinforcement) 4 h post-meal. Hedonic ratings did not differ between the most highly liked sweet and salty/savory snack foods. Beverage type did not influence measures of satiety or the desire to eat foods with a specific taste. However, sweet snacks were more ($p < 0.05$) reinforcing relative to salty/savory snack foods after consuming a NSB than after a SSB. In conclusion, this is the first study to demonstrate that NSB can increase the motivation to gain access to sweet snacks relative to salty/savory snack foods later in the day.

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1. Introduction

Sugar-sweetened beverages (SSBs) are the largest single source of added sugar and discretionary energy intake in the U.S. diet (Drewnowski & Rehm, 2014). As such, a great deal of research has focused on their role in the etiology of obesity (see reviews (Kaiser, Shikany, Keating, & Allison, 2013; Malik, Pan, Willett, & Hu, 2013; Pereira, 2014)). Both clinical and observational studies demonstrate associations of SSB consumption with increased energy intake and body weight (Bachman, Baranowski, & Nicklas, 2006; Bray & Popkin, 2014; Hu, 2013; Kaiser et al., 2013; Malik et al., 2013; Malik, Schulze, & Hu, 2006; Mattes, Shikany, Kaiser, & Allison, 2011; Pereira, 2014). However, there are not yet definitive conclusions regarding the nature and strength of SSB consumption on appetite, energy intake and body weight regulation (Bachman et al., 2006; Bray & Popkin, 2014; Hu, 2013; Kaiser et al., 2013; Malik et al., 2013; Malik et al., 2006; Mattes et al., 2011; Pereira, 2014). Even so, there is a general consensus that the U. S. population would benefit from a reduction in added dietary sugars, including SSB intake ("2015–2020 Dietary Guidelines for Americans," December 2015).

Non-nutritive sweeteners (NNS), also called low-calorie sweeteners (LCS) or sugar substitutes, were first introduced to the market as a specialty food for diabetics, but later gained mass appeal as a way to reduce energy intake (Yang, 2010). As with SSBs, there is continued debate about the effects of non-nutritive sweetened beverages (NSBs), which are the most common vehicles of NNS consumption (Mattes & Popkin, 2009), on appetite, energy intake and body weight regulation (Peters & Beck, 2016; Rogers et al., 2016). It has been suggested that NSB consumption may increase energy intake via an uncoupling of sweet taste with its anticipated post-ingestive consequences (Burke & Small, 2015). In animal models, NNS mixed into solid foods reduces the ability to use sweet taste to predict the energy content of the food (Rogers et al., 2016; Swithers, 2016). In humans, habitual NSB consumption is associated with alterations in the reward experienced from both nutritive and nonnutritive sweet tastes (Green & Murphy, 2012). Thus, one possible mechanism by which NNS, and NSB, consumption may lead to increased energy intake is by increasing the appetite for

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sweet tasting foods.

Another mechanism by which NSB or SSB may affect energy intake in humans is through changes in food choices by altering the reinforcing value of foods with specific taste profiles. Sugar and NNS affect central food reward areas that stimulate reward-driven eating behavior (Burke & Small, 2015; Epstein, Carr, Lin, & Fletcher, 2011; Sylvetsky, Rother, & Brown, 2011; Yang, 2010), and sugar as a component of a food particularly increases the reinforcing value of that food (Avena, Rada, & Hoebel, 2008; Epstein et al., 2011). Food reinforcement motivates people to eat and predicts energy intake (Epstein, Leddy, Temple, & Faith, 2007; Temple, 2014). Given the potential of NSB consumption to uncouple sweet taste and post-ingestive consequences (Burke & Small, 2015) and that the sugar content of a food increases its reinforcing value (Epstein et al., 2011), it can be posited that NNS, including those in NSBs, may increase the reinforcing value of sugar-rich sweet tasting foods later in the day in an attempt to recouple sweet taste with energy and post-ingestive consequences (Yang, 2010). However, the effect of NNS on the reinforcing value of foods with specific taste profiles is not yet known. The present study employed questionnaires and operant responding methods to test the effects of NSB consumption on later appetite and the reinforcing value of foods with sweet or salty/savory taste profiles.

2. Methods

2.1. Participants

Healthy weight adults (Table 1) were recruited from the greater Grand Forks, ND area. Screening for study eligibility included height, weight, taste testing of study foods, fasting glucose level (Accu-Chek), and a medical health history questionnaire. Exclusion criteria included: BMI >25 kg/m^2, allergies to any study foods, recent weight loss or gain, pregnancy, lactation, fasting glucose >100, active cancer or in short-term remission (less than 3 years), infectious diseases, alcohol or drug abuse, tobacco use, presence of acute illness, or taking medications known to affect energy expenditure and appetite. The study (clinicaltrials.gov as NCT02211599) was approved by the University of North Dakota Institutional Review Board and informed written consent was obtained from all participants prior to any study-related procedures.

2.2. Experimental procedures

Prior to testing, each participant tasted and rated their liking on a 10-point scale of each food to be used for the food reinforcement task (Table 2). The evening before each testing session participants were admitted to the Metabolic Research Unit (MRU) at the Grand Forks Human Nutrition Research Center (GFHNRC) and provided a standardized meal to control for nutrient intake. Participants completed 2 testing sessions separated by a minimum of 7 days and were instructed not to exercise for at least 48 h prior to admission. The day of testing participants were provided a research specific breakfast at 08:00 and lunch at 12:00, and were required to consume all foods and beverages within 30 min. Meals provided 500 non-beverage kcals and consisted of the same foods (potatoes, ham, cheddar cheese, white bread and butter). To minimize the monotony of consuming the same foods repeatedly for all meals, the foods were presented differently for breakfast and lunch. Breakfast was presented as a potato, cheese and ham casserole with a side of buttered toast and lunch was presented as a ham and cheese sandwich with a side of buttered potatoes. The amount of protein in the meals varied between the two visits. However, there was no effect of protein on the relative reinforcing value of sweet to salty/savory foods (primary outcome; $p = 0.7$); therefore, protein was not included as a factor in the final analysis. The test beverage was presented with the lunch meal and was comprised of 360 mL of water, black cherry powdered drink mix, and either sugar (31 g) or a non-nutritive sweetener (sucralose; 4 g). Sucralose (Splenda®) was matched to the sugar based on manufacturer conversions and blindly taste tested by study personnel to ensure that the same level of pleasantness and sweetness was achieved. The test beverage was presented to participants in a double-blind, randomized order to reduce cognitive bias. Satiety and the desire to consume foods with a specific taste profile was assessed before and every 30 min post-meal for a total of 4 h. The reinforcing value of sweet snack foods relative to salty/savory snack foods was assessed 4 h after lunch using a computer choice task (Epstein et al., 2011). Participants received detailed instruction and were allowed a practice session. Water was provided *ad libitum*.

Table 1
Participant characteristics.

N (F/M)	21 (11,10)
Age, yrs	24 ± 6
Height, cm	174 ± 11
Weight, kg	69 ± 14
BMI, kg/m^2	23 ± 2
Body fat, %	19 ± 7
Fat mass, kg	16 ± 11
Fat-free mass, kg	55 ± 18

Values are means ± SD.

Table 2
Foods used for the food reinforcement task.

		Macronutrient breakdown per gram				
		Kcal	CHO	Fat	Protein	Sugar
Sweet snack foods	Mini Oreos	4.59	0.71	0.18	0.04	0.39
	M&Ms	4.94	0.71	0.21	0.04	0.63
	Skittles	4.03	0.93	0.03	0.00	0.76
	Reese's Pieces	5.00	0.63	0.26	0.07	0.53
Salty/Savory snack foods	Doritos	4.94	0.57	0.29	0.07	0.00
	Cheez-Its	5.00	0.63	0.27	0.10	0.00
	Pretzels	3.88	0.81	0.00	0.04	0.02
	Pringles	5.26	0.58	0.32	0.04	0.00

2.3. Food reinforcement task

The relative reinforcing value (RRV) of sweet and salty/savory snack foods was assessed via a computer game that requires operant responding. Operant responding is a classical means of measuring the reinforcing value of rewards such as a sugary or savory snack (Epstein et al., 2007). Two separate computer workstations made up the experimental environment. At one station the participant could complete button presses to earn their most liked sweet snack food and at the other station they could work for their most liked salty/savory snack food. Participants could work at their pace and move freely back and forth between the computer workstations. The computer program mimics a slot machine and points are earned each time 3 matching shapes appear. For each 5 points earned, participants received a small portion ($\sim 14-24$ g) of the food reward they were working toward. The work to gain access to each snack food increased on independent and concurrent $\log_2(x)$ variable reinforcement schedules (± 25%) beginning at 4 clicks per point.

The session ended when the participant no longer wanted to earn points. Participants were monitored at all times during testing. The breakpoint (P_{max}, last schedule completed) and the total