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Effects of learning and food form on energy intake and appetitive responses☆,☆☆

Joshua B. Jones, Richard D. Mattes *

Department of Nutrition Science, Purdue University, West Lafayette, IN, USA

HIGHLIGHTS

- Participants did not improve dietary compensation after the intervention phase.
- Lean participants could compensate for energy from solid foods at challenge meals.
- Obese participants could not compensate for energy from solid foods or beverages.
- Total daily energy intake was increased by high-energy beverages and solids.
- Lean and obese participants do not respond to solid and beverage energy equally.

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ABSTRACT

Energy-yielding beverages reportedly contribute to positive energy balance uniquely. They are highly consumed and evoke weaker satiety signaling and dietary energy compensation than solid foods of the same energy content. This study measured the contribution of learning to appetitive sensations and adjustments of energy intake for preloads varying in energy content and food form in lean and obese adults. One-hundred seven participants received four preload trials before and after a dietary intervention in this randomized cross-over trial with the stipulation that lean and obese individuals were evenly assigned to each intervention. The study entailed monitoring appetitive sensations and daily energy intake after consumption of low and high energy beverage and solid food loads on weekly visit days. Preload testing was conducted at baseline, followed by daily ingestion of one load for 14 days and then retesting responses to the four treatments. Lean individuals compensated precisely for the high energy beverage and solid loads from the onset of the study, whereas the obese did not alter eating patterns after consuming the higher energy beverage load. The learning intervention did not have an effect on the responses to the preloads, as responses in both lean and obese participants did not differ from baseline values. Responses to personality and eating behavior questionnaires revealed differences between the lean and obese groups and weakly, but significantly, predicted challenge meal and total daily energy intake. These data suggest that lean and obese individuals respond to energy in beverage form differently, and this is not altered by purposeful daily exposure to loads varying in physical form and energy content for two weeks.

1. Introduction

Consumption of energy-yielding beverages has paralleled the incidence of obesity [1]. A causal relationship has been proposed based on the weak satiety properties of beverages [2–6] leading to incomplete energy compensation [7,8]. Contributing to this are cognitive factors, as expectations about the satiating effect of a food may influence the behavioral and physiological responses to beverage and solid food consumption [9]. In addition, obese individuals may exhibit a less precise compensatory response to ingested energy as compared to lean individuals [10,11], especially for beverages [12]. In post-hoc analyses, several trials have noted especially high energy intake among the obese when consuming energy as a beverage [12–14].

Food choice, eating frequency, and portion size are largely driven by cues learned through prior dietary experiences, where cognitive impressions acquire predictive value for the likely post-ingestive consequences of ingesting a given food or meal [9,15–17]. Food choice and eating behaviors are frequently driven by personality traits and conditioned behaviors as well [18]. Beverages and solid foods present distinct

Abbreviations: HB, high-energy beverage; HS, high-energy solid; LS, low-energy solid; LB, low-energy beverage.

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* Corresponding author at: Department of Nutrition Science, Purdue University, 212 Stone Hall, 700 W State Street, West Lafayette, IN 47907-2059, USA. Tel.: +1 765 494 0662; fax: +1 765 494 0674.
E-mail address: mattes@purdue.edu (R.D. Mattes).

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sensory experiences with markedly different physiological responses. Beverages have lower anticipatory satiety value [9,15,19,20], require less oral processing [19,21–23], empty from the stomach faster [9,24–26], and have shorter GI transit times [9,25] than solid foods. Consequently, it is hypothesized that beverages may foster weaker sensory-metabolic learning, which would be consistent with evidence of less precise dietary compensation for beverages compared to solid food energy intake. Also, given differences in BMI, which stem from chronic energy imbalance (i.e., imprecise dietary compensation), it is hypothesized that lean individuals more precisely adjust to varying energy loads than overweight/obese individuals due to stronger food form-energy learning.

To test these hypotheses, participants consumed preloads differing in energy content and food form, and subsequent eating behaviors and appetitive sensations were monitored. Participants completed testing at baseline and a two-week dietary intervention. This intervention involved repeated consumption of one of the test loads in an attempt to condition metabolic consequences of ingesting a food along with cognitive impressions of the food. The preload testing was then repeated to measure the effect of the intervention. Measurement of energy intake, meal timing, and appetitive responses before and after the intervention was conducted to allow assessment of the conditioning intervention.

2. Methods

2.1. Recruitment

Eligibility requirements included the following: ages 18–60 years, either lean (BMI 18–25 kg/m^2) or obese (30–40 kg/m^2), weight stability (<3 kg weight change within the last 3 months), constant habitual activity patterns (variation of <30 min/week within the past 3 months), no purposeful dietary restrictions or supplementations within the last 3 months, willingness to consume a familiar chocolate-flavored beverage or bar at test sessions and a two week training period, no allergies to test foods, no plan to change use of medications known to influence appetite or metabolism, and not diabetic. Eligibility was assessed by using a prescreening form emailed to interested participants. The study was conducted between September 2011 and November 2013 at Purdue University, West Lafayette, IN.

At the screening visit, participants ingested approximately 20 g of each of four test foods (high-energy beverage—HB, high-energy solid—HS, low-energy solid—LS, low-energy beverage—LB), and each was rated greater than "neither like nor dislike" on an unnumbered labeled affective magnitude (LAM) scale [27] with anchors "greatest imaginable dislike" and "greatest imaginable like." Physical characteristics of the test loads are given in Table 1, and test load recipes are given in Table 2. Participants then completed the Eating Attitudes Test-26 to disqualify disordered eaters (scores >20) from the participant pool [28]. BMI was calculated by obtaining participants' weight to the nearest 0.1 kg using a digital clinical scale and height to the nearest cm using a Holtain stadiometer. In total, 124 participants completed the screening visit, and 110 were enrolled in the study. Three participants dropped out of the study due to time conflicts within the first four weeks and are not included in the analysis. Of the remaining 107 participants, 104 completed the entirety of the study, and 3 completed the majority of the study and were included in the analyses. Overall, 94.5% of enrolled participants completed the study, and 97.3% of the participants are included in analyses. Demographics of the participant pool are given in Table 3. All participants provided written informed consent as approved by the Purdue University Biomedical Institutional Review Board. The study was registered on clinicaltrials.gov under number NCT01490034.

Table 1
Physical properties of finished test loads.

	HS	LS	HB	LB
Mass (g)	106	48	521	447
Volume (cm^3 or mL)	210	210	470	430
Energy Content (kcal)	430	155	430	155

Table 2
Test load recipes (mass in grams).

	HS	LS	HB	LB
Water	7.0	7.0	400.0	400.0
Cocoa	2.4	1.8	2.4	2.4
Marshmallow	35.0	21.0	–	–
Polycose™	27.5	–	103.1	27.5
Rice cereal	24.5	24.5	–	–
Butter	13.5	–	–	–
Splenda™	–	0.65	–	1.95
Sugar	–	–	15.0	15.0

2.2. Visits

Participants were asked to consume the same type of breakfast throughout the study. They reported to the laboratory at their customary lunchtime after having fasted (except water) for at least 3 h since breakfast. They were then allotted 15 min to consume their test food in its entirety. They were required to stay in the laboratory for 1 h, after which they were given 15 min to consume a challenge meal consisting of macaroni and cheese (Easy Mac, Kraft Foods, Northfield, IL) and 8 oz. of water. Challenge meal intake was measured by weighing the portion prior to and after consumption. During the hour interval, they estimated the mass (<500 g) of five objects by holding them in their hands. This served as a cross-modality index of learning unrelated to ingestion during the study period. Practice weights were standardized to a visual analog scale, and responses were recorded on the same scale. Participants were not given feedback as to their responses. In addition, over the course of the nine visits, each participant completed the following nine questionnaires pertaining to personality or ingestive behavior: the Food Craving Questionnaire—State [29], Perceived Stress Scale [30], Zung Self-Rating Scale of Depression [31], Eysenck Personality Questionnaire—Revised [32], Food Attitudes Survey [33], Brief Sensation Seeking Scale 4 [34], Three-Factor Eating Questionnaire [35], Power of Food Scale [36], and Physical Activity Questionnaire [37]. On trial days, participants completed digital appetite logs on a hand-held electronic device (PalmPilot™) every 15 min while in the laboratory and every hour after their laboratory visit until retiring for the night. Responses were recorded on visual analog scales with anchors of "not at all" and "extremely" for each of nine appetitive sensations: "hunger," "fullness," "desire to eat," "prospective food consumption," "preoccupation with food," "thirst," "desire to eat salty food," "desire to eat fatty food," and "desire to eat sweet food," following previously validated methods [38–40]. Participants also kept a food diary, including the time (to the nearest minute) of eating occasions, for the remainder of the day following each laboratory visit. Fig. 1 is a diagram of visit procedures.

Fig. 2 illustrates the design of the study. Participants completed weekly visits for four weeks (first time point). This was followed by a two week intervention during which participants reported to the laboratory at lunchtime daily to consume one of the randomly-assigned test

Table 3
Study participant (n = 107) demographics.

Mean age	26.8 ± 7.9 yrs.	
Gender	n	Percentage
Male	41	38.3
Female	66	61.7
Race/ethnicity		
White	77	72.0
Asian	18	16.8
Black	7	6.5
Hispanic	2	1.9
Others/unknown	3	2.8