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Daily exposure to either a high- or low-energy-dense snack food reduces its reinforcing value in adolescents

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Abstract

Objective—The purpose of this study was to examine the impact of daily exposure to a low-energy-dense (LED) or a high-energy-dense (HED) snack food on its reinforcing value (RRV) in adolescents with healthy weight, overweight, or obesity.

Methods—We used a parallel-group, randomized trial to assess RRV of LED or HED snack food at baseline and again after exposure to that snack food daily for two weeks in 77 adolescents, aged 13 – 17 years. Information on eating-related subject characteristics was also collected at baseline.

Results—After two weeks of daily exposure, the RRV of the snack foods was significantly reduced in all participants, regardless of energy density or participant weight status. Among individuals who were high in dietary restraint only, those randomized to LED food found their snack food less reinforcing at baseline than those who were randomized to HED food. Baseline eating-related variables also differed as a function of weight status.

Conclusions—Daily exposure to snack food in adolescents reduces the RRV of that food regardless of snack food energy density or weight status of the adolescent. This finding differs from adults, suggesting that increases in RRV of HED food after repeated exposure may develop after adolescence.

Keywords

body mass index; adolescents; energy density; food intake

Introduction

Adolescence may be a sensitive time period for the development of obesity due to differential brain maturation that favors reward responsivity over impulse control[1–3]. This

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heightened reward responsivity makes the relative reinforcing value (RRV) of food an attractive target for obesity prevention[4, 5]. Our previous studies have shown that adults with obesity who are high in RRV of high-energy-dense (HED) snack food at baseline show increases in RRV of HED food after two weeks of daily snack food intake[6, 7]. Focusing on snack food may be particularly relevant, as snack food intake has been increasing in the US[8, 9] and HED snack food can contribute to increased body weight[10].

Baseline RRV of food and changes in RRV of food after repeated exposure may be influenced by several factors. The energy density (ED) of snack food can have an impact, with HED foods having higher RRV than low-energy-dense (LED) foods and greater likelihood of increasing RRV after repeated exposure[6, 11, 12]. Another factor that influences RRV of food is delay discounting (DD), with adults[13] and adolescents[14] with obesity showing greater DD for both monetary and food rewards than do individuals with a healthy weight. Dietary restraint is also related to both obesity[15] and RRV of snack food[16], with higher dietary restraint scores associated with increased BMI among adults and adolescents[17, 18], greater weight gain among adults[19, 20], earlier obesity onset among adolescents[21], and greater RRV of snack food in females with a greater BMI[16].

The purpose of this study was to test the hypothesis that adolescents with obesity will increase RRV of food after two weeks of daily HED snack food exposure, whereas adolescents with a healthy weight will show a decrease in RRV of HED food. Additionally, we hypothesized that adolescents will show a decrease in RRV of LED food after repeated exposure, regardless of weight status. Finally, we characterized some basic eating-related phenotypes in an adolescent population and to investigate whether these influenced baseline RRV of food or the change in RRV of food after repeated exposure.

METHODS

Sample size determination and Study Participants

Prior to beginning this study, we conducted a power analysis and found that significant interactions among three weight status categories and two snack food types could be observed with a sample size of 12 participants per cell (total of 72), assuming an effect size of 0.45, a power of 0.81 and a $p < 0.05$. Eighty boys and girls between the ages of 13 and 17 were recruited using flyers, email announcements, and word-of-mouth. Eligible participants had no allergies to the study foods, were not taking any medications affecting their appetite or causing weight changes, and had a willingness to eat the assigned study snack daily for two weeks. Two participants dropped out due to time constraints, and one was removed by the research team for not complying with study protocol. This left 77 participants' records included in this analysis. Experimental procedures were approved by the University at Buffalo Institutional Review Board.

Study Procedures

Participants were randomized to either and HED or LED snack food type using a random number table. For each item within their assigned snack food type (Table 1), participants were asked to rate their "liking", frequency of consumption (from 'never' to 'daily') and willingness to eat the snack each day for 2 weeks (yes/no). A single food was selected for the participants to consume (both in and out of the laboratory) based on liking (>50mm), willingness to eat daily for two weeks, and consuming ≤ two servings per week in their usual diet.

Participants visited the Nutrition and Health Research Laboratory on two occasions, separated by 14 days. They were instructed to refrain from food or beverages other than water for ≥ 3 and ≤ 5 hours before each appointment. Parents completed informed consent forms and participants completed assent forms and other assessments described in detail below. Participants then consumed a pre-load (Wegmans fruit and grain bar; 140 kcal) to reduce potential variability in hunger[7, 22]. Each participant then completed the RRV task where they earned portions of their assigned snack food on one computer and a non-food alternative (reading) on another. Once the participant had finished eating and reading, baseline weight and height were recorded.

At the end of the first session participants given a habit book and were instructed on how to record all food and beverage consumption using a sample meal as an example. They were provided with 14 portions of snack food (Table 1). Participants were instructed to consume one entire portion of the food provided each day (including the juice in the fruit cups), but no additional instructions were given as to when or how the snack food was consumed. Finally, participants were instructed to call the laboratory daily to verify that they had eaten their snack and completed their habit book. Daily phone calls and habit book entries were used to verify compliance. Eighty-one percent of participants ≥ 70% of phone calls and 97% of participants had 100% compliance on habit book recording.

Participants returned to the laboratory 14 days later and completed the RRV task a second time, working for the same food and reading activities as in the first session. They then completed the Dutch Eating Behavior questionnaire, were debriefed, and were compensated.

ASSESSMENTS

Reinforcing Value Task

Participants pressed the mouse button to earn portions of their assigned snack food (Table 1) on one computer and 2-minute allotments of time to spend reading age-appropriate magazines on the other. The non-food alternative was offered in order to assess the RRV of food compared to an alternative, non-eating activity. The schedules of reinforcement for each reward were independent from one another and were on a progressive, variable ratio (± 5%) schedule of: 20, 40, 80, 160, 320, 640, 1280, 2560, 5120, 10240 and 20480, with 20 mouse clicks required for the first reward, 40 for the second, and so on. Participants were told that the session would end when they no longer wished to earn points for either reward. Points were then redeemed for food and reading time and all eating and reading was completed in the laboratory. Dependent measures were the total number of responses made for each reward as well as the breakpoint of responding, defined as the highest trial (1 – 10) on which responses were made.

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Dutch Eating Behavior Questionnaire (DEBQ)

Participants completed the Dutch Eating Questionnaire revised for children ages 8–12 to measure dietary restraint[23]. There are 9 items on this questionnaire where the participant was asked to "circle answers that are true for you" from the choices of "never", "sometimes" and "very often", which were scored as 0, 1, and 2 respectively. The average score on this questionnaire was a 4.97 with a standard deviation of 3.6. We categorized participants with a DEBQ score of ≥ 9 (one standard deviation above the mean) as "high" in restraint.

Healthy Eating Self-Efficacy Questionnaire

Self-efficacy for healthy eating was measured using a nine-item scale developed for use with American adolescents[24] that assessed participants' self-confidence for making healthy food choices on a six-point scale ranging from "not at all sure" (1) to "very sure" (6). These scores were averaged and a median split to categorize individuals into "high" and "low" categories, when necessary.

Anthropometrics

Body weight was assessed using a SECA digital scale (Hanover, MD). Height was assessed using a SECA stadiometer (Hanover, MD). On the basis of the height and weight data, BMI percentile was calculated using the CDC Child BMI Calculator[25].

Appetite Sensations

Participants were asked to rate their degree of hunger, thirst, liking, and desire to eat the study foods by drawing a vertical line along a 100-mm visual analog scale anchored at 0-mm by "not at all" and 100-mm by "extremely"[26].

Kirby Delay Discounting Questionnaire

Participants completed a 27-item questionnaire assessed discounting of monetary values ranging from small ($25–$35), medium ($50–$60), and large ($75–$85). Participants were asked to make a choice between a small reward now or a larger reward later (Ex. "would you rather have $20 today or $55 in 7 days?") and was scored by calculating the percentage of time the delayed reward was chosen[27]. A smaller percentage indicates greater delay discounting.

Habit Book Analysis

All foods and beverages listed in the habit book were entered into Nutritionist Pro (Axxya Systems LLC, Redmond, WA) to determine daily energy intake and servings of food in different categories, as defined in the Health Eating Index[28, 29]. For physical activity, the Activity Reference Guide[30] was used determine Metabolic Equivalent of Task (METs) ranging from 1.0 (sitting, laughing) to 23 (running at 14 MPH pace). The METs score for each activity was then coded into Light Intensity (<2.9 METs), Moderate intensity (3.0–4.9 METs), Hard Intensity (5.0–6.9METs) or Very Hard Intensity (>7.0METs).

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STATISTICAL ANALYSIS

We used independent samples T-tests with snack food type (LED or HED) and weight status as the independent variables to examine potential group differences in baseline participant characteristics. The RRV breakpoint and changes in appetite sensations were analyzed using a mixed model analysis of covariance with snack food type and sex as between-subject variables, baseline vs. post-intervention as the within subjects factor, and BMI percentile, household income, parental education, and child race/ethnicity as covariates. All data were analyzed using SPSS version 24.

RESULTS

Participant Characteristics

There were no differences between the participants assigned to LED and HED snack food types for sex, BMI percentile, age, household income, parent education level, or race (all $p > 0.05$). Our study population was 14.8 ± 0.2 years of age, from well-educated, middle to upper middle class households and predominantly white (Table 2).

Baseline Data

There were no differences in baseline RRV of food, thirst, desire to eat, 24-hour energy intake, moderate, hard, and very hard physical activity, or intake of most food groups as a function of weight status, snack food type or interactions between weight status and energy density (Table 3). There were significant differences by weight status in baseline hunger ($F(1, 74) = 4.98$; $p = 0.029$), dietary restraint score ($F(1, 74) = 6.0$; $p = 0.016$), and time spent in light physical activity ($F(1, 70) = 5.2$; $p = 0.025$) with adolescents with overweight or obesity reporting less hunger and light physical activity, and greater dietary restraint than those with a healthy weight. There was also an interaction between snack food type and food liking ($F(1, 74) = 5.0$; $p = 0.028$), with individuals assigned to LED food reporting less liking than those assigned to HED food. Finally, there was an interaction between weight status and snack food type on desire to eat ($F(1, 74) = 6.9$; $p = 0.01$), with participants with a healthy weight reporting greater desire to eat when assigned HED food compared with LED food, but participants with overweight or obesity reporting greater desire to eat when assigned LED food than HED food.

Changes in Breakpoint of the Reinforcing Value of Food from Baseline to Post Daily Exposure

There was a significant decrease in the breakpoint of the RRV of food from baseline to post-intervention ($F(1, 74) = 71.85$; $p < 0.0001$, Figure 1). There were no significant main effects or interactions with the type of food consumed or with weight status. When we examined this relationship as a function of sex, we found that there was no main effect of sex ($F(1, 73) = 0.001$; $p = 0.98$) and no interactions between sex and snack food type ($F(1, 73) = 0.12$; $p = 0.73$) on breakpoint of RRV of food.

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Appetite Sensations Within and Between Sessions

Hunger ($F(2, 148) = 121.7$; $p < 0.0001$), desire to eat ($F(2, 148) = 57.3$; $p < 0.0001$), and food liking ($F(2, 148) = 21.5$; $p < 0.0001$) decreased within each session from before the RRV task to after eating. Food liking ($F(1, 74) = 93.9$; $P < 0.0001$), desire to eat ($F(1, 74) = 60.7$; $p < 0.0001$), and hunger ($F(1, 74) = 5.7$; $p = 0.019$) also decreased from baseline to post daily intake regardless of assigned snack food type or weight status.

Relationship Among Dietary Restraint Score, Reinforcing Value of Food, and Snack Food Type

We found a significant interaction of dietary restraint (high vs. low) and snack food type on breakpoint for RRV of Food ($F(1, 73) = 7.06$; $p = 0.01$; Figure 2), with breakpoint being the same for HED and LED food among individuals who were low in dietary restraint ($F(1, 53) = 0.00$; $p = 0.98$), but restrained individuals had a low breakpoint for LED food and a high breakpoint for HED food ($F(1, 21) = 9.8$; $p = 0.005$).

Baseline Differences in Eating-Related Measures

There were no significant relationships between self-efficacy for healthy eating and reinforcing value of HED or LED food at baseline (all $p > 0.05$). Individuals with higher self-efficacy for healthy eating reported eating more fiber ($F(1, 69) = 7.26$; $p = 0.009$), more servings of fruit ($F(1, 69) = 9.1$; $p = 0.004$), more "non-whole" fruit ($F(1, 69) = 10.14$; $p = 0.002$), and more "healthy snacks"[28, 29] ($F(1, 69) = 9.16$; $p = 0.003$). There was a significant effect of weight status on delay discounting for small ($F(2, 73) = 3.23$; $p = 0.045$) and medium ($F(2, 73) = 4.1$; $p = 0.021$) rewards, but not large rewards, with participants with obesity more likely to choose immediate rewards compared with participants with healthy weight or overweight (Figure 3).

Discussion

The purpose of this study was to investigate the impact of two weeks of daily LED or HED snack food intake on the RRV of food in adolescents. Two weeks of exposure to snack food reduced the RRV of food, regardless of the snack food energy density or weight status of the participant. This reduction in RRV corresponded with a similar reduction in ratings of food liking. There was an interaction among RRV of food, dietary restraint, and snack food type, with individuals high in dietary restraint finding LED food significantly less reinforcing than HED food, but no differences by snack food type in participants low in dietary restraint. Individuals with a healthy weight had lower delay discounting than individuals with obesity for small and medium rewards. Finally, self-efficacy for healthy eating was positively associated with fruit, fiber, and healthy snack consumption.

In previous studies in adults, repeated intake of LED snack food led to a reduction in RRV of food regardless of weight status, but for HED food, women with obesity only showed an increase in RRV of food. In the current study, we found that adolescents showed a reduction in RRV of food after two weeks of daily exposure, regardless of ED of the food or participants weight status. These decreases in RRV were associated with decrease in ratings of food liking. Decreases in liking of foods eaten over days or weeks have been attributed to

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"boredom" or "satiation" to the sensory properties of the foods[31] and the degree of change is related to initial liking of the food, with liking of more preferred foods decreasing more than less preferred[32]. A study by Hetherington and colleagues showed that daily intake of bread with butter resulted in no change in hedonic ratings over a three week period, but daily intake of chocolate reduced hedonic ratings over time[33]. These findings suggest that some foods can be eaten frequently without changes in hedonic ratings, whereas other foods, perhaps less commonly eaten or more preferred at baseline, are more likely to show fluctuation in ratings of pleasantness and desire to eat. In the current study, we specifically chose foods that were not consumed frequently in order to maximize the possibility of observing changes in RRV of food after daily exposure. In addition, we chose foods that were highly liked at baseline. When taken together, these two criteria may have skewed the findings toward observing decreases in RRV of food after repeated exposure.

Our previous studies showed that two weeks of HED snack food consumption increased the RRV of food in women with obesity. Here, we did not find any increase in RRV after two weeks of HED food exposure nor did we observe differences in baseline or post-intervention RRV of food as a function of weight status in adolescents. There are several potential explanations for this difference. First, it is possible that the snack foods were not consumed as instructed or intended. Although participants were reporting daily consumption at a high rate, we did not have a way to independently verify this. Second, it is possible that this increase in RRV of HED food after repeated exposure happens at a later developmental stage. Finally, it is possible that individual differences in changes in RRV of food after repeated exposure are not related to current weight in adolescents, but may related to future weight gain.

In addition to the primary outcome of changes in RRV of food, we also examined DD. Individuals with greater rates of DD are more likely to be obese[34] and consume more food in *ad libitum* eating tasks[35]. Our data support these findings, with adolescents with obesity having greater rates of DD for small and medium rewards compared with adolescents with a healthy weight or overweight. Previous studies have shown that individuals who are both high in RRV of HED food and high in DD are at the highest risk of obesity[36]. This suggests that examining both RRV of food and DD may provide a more comprehensive picture of risk factors for weight change. Here, we did not find any interactions among RRV of food, DD, and BMI percentile. One potential explanation for this is that the majority of the studies on DD and RRV of food have been conducted in adults[36, 37]. It is possible that these relationships are not yet established in adolescents or that adolescents have more variability in their DD and less variability in their BMI percentile, making it difficult to detect these interactions.

Several other individual difference characteristics are related to body weight and weight gain over time, including dietary restraint, self-efficacy for healthy eating, and physical activity. High levels of dietary restraint are associated with higher body weight and greater weight gain over time[17–21]. In this study, we found a similar relationship between dietary restraint and BMI percentile, with heavier individuals reporting greater levels of dietary restraint. In addition, we found that individuals who were high in dietary restraint had greater RRV for HED food than for LED food. This suggests that, among individuals with low dietary

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restraint, the RRV of LED and HED foods is similar, but among individuals with high dietary restraint, the RRV of HED food may be greater than the RRV of LED food. We also examined self-efficacy for healthy eating. Our results in adolescents support what has been reported for adults, with lower self-efficacy for healthy eating associated with greater BMI percentile.

This study had many strengths. We used a large population of adolescents and collected data on a number of eating-related phenotypes. We conducted a well-controlled, laboratory based study in which HED and LED snack foods were provided. Finally, our sample was fairly representative of the Buffalo area in terms of race/ethnicity and income. However, this study was not without limitations. First, we used a between-subjects design to examine changes in the RRV of HED and LED food. This reduced our statistical power and limited our ability to examine potential relationships among RRV of each snack food type and BMI percentile within individuals. Future studies will employ a fully within subjects cross-over design to be able to better characterize these relationships. Second, we relied on self-report to assess compliance with daily snack food intake. We could conduct a study where participants come into the laboratory to consume snack foods each day, which would improve compliance, but create a greater time burden. Third, our groups had around 20 participants each, making it difficult to generalize to a larger population. Fourth, the LED and HED portions provided were determined based on what was available in pre-packaged form (e.g. a container of yogurt or a fruit cup). We made the energy content of the LED foods approximately 50% of the HED portions, but the foods were not standardized based on weight, volume, or energy. Finally, we had no control over other foods being consumed in the diet of our participants. It is possible that participants who consumed snack foods with similar properties to the ones provided may have been less impacted by our manipulation.

Conclusions and Future Directions

Repeated exposure to both LED and HED food for two weeks decreased the RRV of these foods in adolescents. Dietary restraint, DD, self-efficacy for healthy eating, and physical activity were also cross-sectionally related to BMI percentile in this population. Our future research will focus on identifying which of these factors, alone or in combination, predicts weight change over time.

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References

1. Konrad K, Firk C, Uhlhaas PJ. Brain development during adolescence: neuroscientific insights into this developmental period. Dtsch Arztebl Int. 2013; 110:425–431. [PubMed: 23840287]
2. Moreno-Lopez L, Soriano-Mas C, Delgado-Rico E, et al. Brain structural correlates of reward sensitivity and impulsivity in adolescents with normal and excess weight. PLoS One. 2012; 7:e49185. [PubMed: 23185306]
3. Vara AS, Pang EW, Vidal J, et al. Neural mechanisms of inhibitory control continue to mature in adolescence. Dev Cogn Neurosci. 2014; 10C:129–139.
4. Epstein LH, Leddy JJ. Food reinforcement. Appetite. 2006; 46:22–25. [PubMed: 16257474]

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5. Epstein LH, Leddy JJ, Temple JL, et al. Food reinforcement and eating: a multilevel analysis. Psychol Bull. 2007; 133:884–906. [PubMed: 17723034]

6. Clark EN, Dewey AM, Temple JL. Effects of daily snack food intake on food reinforcement depend on body mass index and energy density. Am J Clin Nutr. 2010; 91:300–308. [PubMed: 20016012]

7. Temple JL, Bulkley AM, Badawy RL, et al. Differential effects of daily snack food intake on the reinforcing value of food in obese and nonobese women. Am J Clin Nutr. 2009; 90:304–313. [PubMed: 19458018]

8. Piernas C, Popkin BM. Trends in snacking among U.S. children. Health Aff (Millwood). 2010; 29:398–404. [PubMed: 20194979]

9. Piernas C, Popkin BM. Snacking increased among U.S. adults between 1977 and 2006. J Nutr. 2010; 140:325–332. [PubMed: 19955403]

10. Larson NI, Miller JM, Watts AW, et al. Adolescent Snacking Behaviors Are Associated with Dietary Intake and Weight Status. J Nutr. 2016; 146:1348–1355. [PubMed: 27281807]

11. Temple JL. Factors that influence the reinforcing value of foods and beverages. Physiol Behav. 2014; 136:97–103. [PubMed: 24793218]

12. Temple JL. Behavioral Sensitization of the Reinforcing Value of Food: What food and drugs have in common. Preventive Medicine. 2016 in press.

13. Weller RE, Cook EW 3rd, Avsar KB, et al. Obese women show greater delay discounting than healthy-weight women. Appetite. 2008; 51:563–569. [PubMed: 18513828]

14. Fields SA, Sabet M, Reynolds B. Dimensions of impulsive behavior in obese, overweight, and healthy-weight adolescents. Appetite. 2013; 70:60–66. [PubMed: 23831015]

15. Ruderman AJ. Dietary restraint: a theoretical and empirical review. Psychol Bull. 1986; 99:247–262. [PubMed: 3515384]

16. Goldfield GS, Lumb A. Effects of dietary restraint and body mass index on the relative reinforcing value of snack food. Eat Disord. 2009; 17:46–62. [PubMed: 19105060]

17. Price M, Higgs S, Lee M. Self-reported eating traits: Underlying components of food responsivity and dietary restriction are positively related to BMI. Appetite. 2015; 95:203–210. [PubMed: 26162952]

18. Ting WH, Huang CY, Tu YK, et al. Association between weight status and depressive symptoms in adolescents: role of weight perception, weight concern, and dietary restraint. Eur J Pediatr. 2012; 171:1247–1255. [PubMed: 22644990]

19. Hays NP, Roberts SB. Aspects of eating behaviors “disinhibition” and “restraint” are related to weight gain and BMI in women. Obesity (Silver Spring). 2008; 16:52–58. [PubMed: 18223612]

20. van Strien T, Herman CP, Verheijden MW. Dietary restraint and body mass change. A 3-year follow up study in a representative Dutch sample. Appetite. 2014; 76:44–49. [PubMed: 24480668]

21. Stice E, Presnell K, Shaw H, et al. Psychological and behavioral risk factors for obesity onset in adolescent girls: a prospective study. J Consult Clin Psychol. 2005; 73:195–202. [PubMed: 15796626]

22. Temple JL, Chappel A, Shalik J, et al. Daily consumption of individual snack foods decreases their reinforcing value. Eat Behav. 2008; 9:267–276. [PubMed: 18549985]

23. Hill AJ, Pallin V. Dieting awareness and low self-worth: related issues in 8-year-old girls. Int J Eat Disord. 1998; 24:405–413. [PubMed: 9813765]

24. French SA, Story M, Neumark-Sztainer D, et al. Fast food restaurant use among adolescents: associations with nutrient intake, food choices and behavioral and psychosocial variables. Int J Obes Relat Metab Disord. 2001; 25:1823–1833. [PubMed: 11781764]

25. CDC. BMI Calculator. Jul 7. 2015 http://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/english_bmi_calculator/bmi_calculator.html

26. Stubbs RJ, Hughes DA, Johnstone AM, et al. The use of visual analogue scales to assess motivation to eat in human subjects: a review of their reliability and validity with an evaluation of new hand-held computerized systems for temporal tracking of appetite ratings. Br J Nutr. 2000; 84:405–415. [PubMed: 11103211]

27. Myerson J, Baumann AA, Green L. Discounting of delayed rewards: (A)theoretical interpretation of the Kirby questionnaire. Behav Processes. 2014; 107:99–105. [PubMed: 25139835]

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28. Guenther PM, Reedy J, Krebs-Smith SM. Development of the Healthy Eating Index-2005. J Am Diet Assoc. 2008; 108:1896–1901. [PubMed: 18954580]
29. Guenther PM, Reedy J, Krebs-Smith SM, et al. Evaluation of the Healthy Eating Index-2005. J Am Diet Assoc. 2008; 108:1854–1864. [PubMed: 18954575]
30. Epstein LH, Paluch RA, Coleman KJ, et al. Determinants of physical activity in obese children assessed by accelerometer and self-report. Med Sci Sports Exerc. 1996; 28:1157–1164. [PubMed: 8883004]
31. Zandstra EH, Weegels MF, Van Spronsen AA, Klerk M. Scoring or boring? Predicting boredom through repeated in-home consumption. Food Quality and Preference. 2004; 15:549–557.
32. Zandstra EH, De Graaf C, Mela DJ, et al. Short- and long-term effects of changes in pleasantness on food intake. Appetite. 2000; 34:253–260. [PubMed: 10888288]
33. Hetherington MM, Pirie LM, Nabb S. Stimulus satiation: effects of repeated exposure to foods on pleasantness and intake. Appetite. 2002; 38:19–28. [PubMed: 11883914]
34. Price M, Higgs S, Maw J, et al. A dual-process approach to exploring the role of delay discounting in obesity. Physiol Behav. 2016; 162:46–51. [PubMed: 26884122]
35. Ely AV, Howard J, Lowe MR. Delayed discounting and hedonic hunger in the prediction of lab-based eating behavior. Eat Behav. 2015; 19:72–75. [PubMed: 26183899]
36. Epstein LH, Salvy SJ, Carr KA, et al. Food reinforcement, delay discounting and obesity. Physiol Behav. 2010; 100:438–445. [PubMed: 20435052]
37. Rollins BY, Dearing KK, Epstein LH. Delay discounting moderates the effect of food reinforcement on energy intake among non-obese women. Appetite. 2010; 55:420–425. [PubMed: 20678532]

What is already known about this subject?

1. Daily exposure to a single low-energy-dense (LED) food reduces its reinforcing value (RRV) in adults
2. Daily exposure to a single high-energy-dense food (HED) reduces its RRV in adults with a healthy weight.
3. Daily exposure to a single HED food increases its RRV in adults with obesity.

What does this study add?

1. Daily exposure to an individual snack food reduces its RRV regardless of energy density in adolescents.
2. Change in RRV of a snack food after daily exposure did not differ by weight status in adolescents.
3. Adolescents high in dietary restraint at baseline differed in RRV of LED or HED foods.

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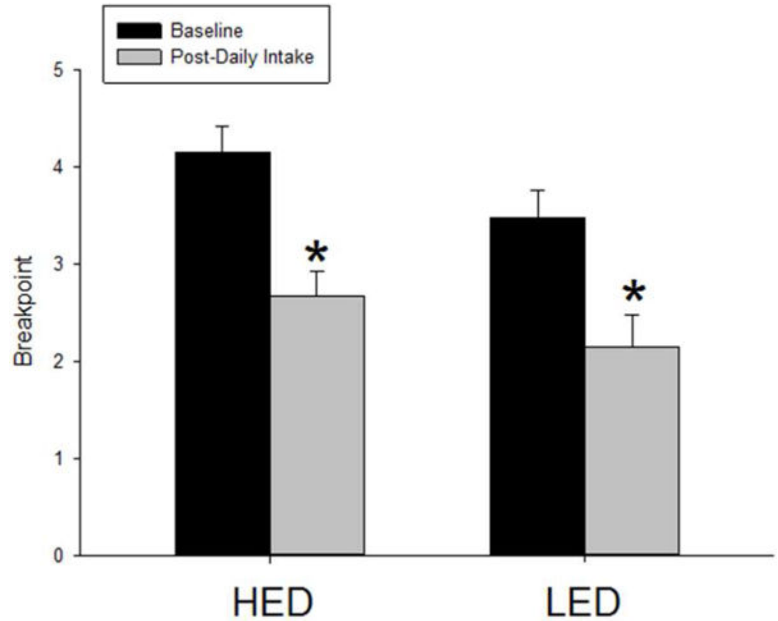

Figure 1.

Mean ± SEM breakpoint (highest trial on which responses were made out of 10 trials) for responses for high-energy-dense (HED; left; n = 38) and low-energy-dense (LED; right; n = 39) snack foods at baseline (black bars) and again after two weeks of daily consumption (gray bars). For both HED and LED food, there was a significant decrease in the breakpoint after two weeks of daily consumption ($F(1, 74) = 71.85$; $p < 0.0001$). * = significantly different from baseline.

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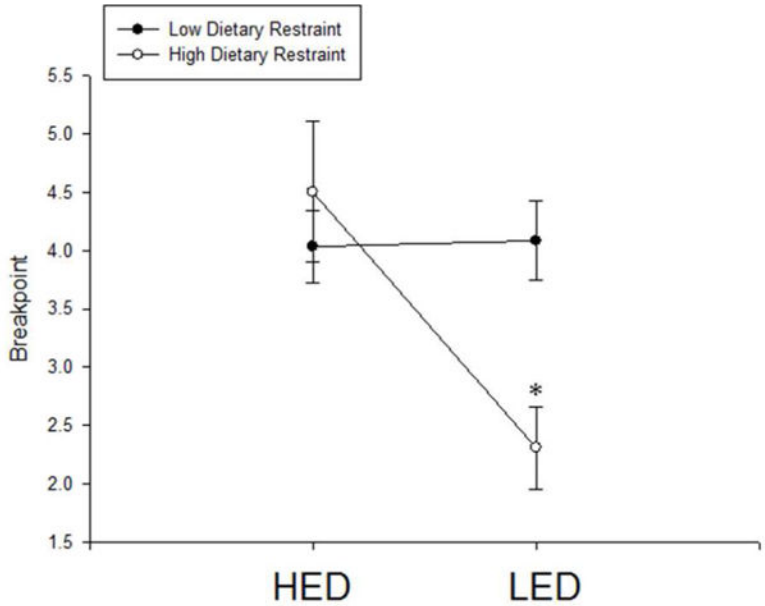

Figure 2.

Mean ± SEM breakpoint for responses for high-energy-dense (HED; left; n = 38) and low-energy-dense (LED; right; n = 39) snack foods at baseline in individuals who were low in dietary restraint (black circles; n = 54) or high in dietary restraint (white circles; n = 23). Individuals who were high in dietary restraint had a significantly lower breakpoint for LED food compared with HED food ($F(1, 21) = 9.8$; $p = 0.005$), but no difference by snack food type among individuals who were low in dietary restraint. * = significant difference as a function of dietary restraint category for breakpoint for LED food.

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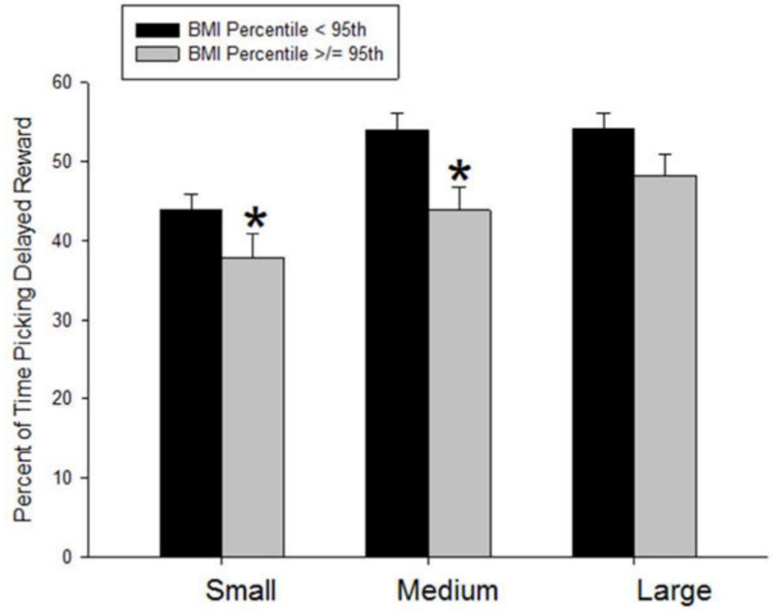

Figure 3.

Mean ± SEM percent of 27 trials on which participants picked the delayed reward over the immediate reward for small (left), medium (middle), and large (right) rewards in adolescents with BMI percentile < 95th (black bars; n = 59) or BMI percentile ≥ 95th (gray bars; n = 18). Participants who have obesity were less likely to select the delayed reward than participants with a healthy weight or overweight when the rewards were small ($F(2, 73) = 3.23$; $p = 0.045$) and medium ($F(2, 73) = 4.1$; $p = 0.021$). * = significantly different from participants with a BMI percentile < 95th.

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TABLE 1

Demographic Information Based on Participants' Assigned Food Group

	Low-Energy-Dense Snack (n = 38)	High-Energy-Dense Snack (n= 39)
Male/Female	**19/19**	**20/19**
	Mean (SEM)	**Mean (SEM)**
BMI Percentile	68.2 (4.5)	72.7 (4.4)
Age	15.2 (0.2)	14.4 (0.2)
	N (%)	**N (%)**
Education Level of Primary Caregiver		
Completed High School	7 (18%)	4 (10%)
Some College	6 (16%)	7 (18%)
Completed College	17 (45%)	18 (46%)
Completed graduate degree	8 (21%)	10 (26%)
Family Income		
Under $9,999	2 (5%)	2 (5%)
$10k–49,999	11 (30%)	5 (13%)
$50k–69,999	2 (5%)	6 (16%)
$70k–89,999	4 (12%)	12 (32%)
$90k–109,999	11 (30%)	5 (13%)
$110k–139,999	7 (18%)	3 (8%)
➢$140,000	0 (0%)	5 (13%)
Race		
White	25 (66%)	32 (82%)
Black/African American	11 (28%)	7 (18%)
Other	1 (3%)	0 (0%)
Multiracial	1 (3%)	0 (0%)

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Table 2

Demographic Information Based on Assigned Snack Food Type

	Low-Energy-Dense Snack (*n* = 38)	High-Energy-Dense Snack (n= 39)
Male/Female	**19/19**	**20/19**
	Mean (SEM)	**Mean (SEM)**
BMI Percentile	68.2 (4.5)	72.7 (4.4)
Age	15.2 (0.2)	14.4 (0.2)
	N (%)	**N (%)**
Education Level of Primary Caregiver		
Completed High School	7 (18%)	4 (10%)
Some College	6 (16%)	7 (18%)
Completed College	17 (45%)	18 (46%)
Completed graduate degree	8 (21%)	10 (26%)
Family Income		
Under $9,999	2 (5%)	2 (5%)
$10k–49,999	11 (30%)	5 (13%)
$50k–69,999	2 (5%)	6 (16%)
$70k–89,999	4 (12%)	12 (32%)
$90k–109,999	11 (30%)	5 (13%)
$110k–139,999	7 (18%)	3 (8%)
➢$140,000	0 (0%)	5 (13%)
Race		
White	25 (66%)	32 (82%)
Black/African American	11 (28%)	7 (18%)
Other	1 (3%)	0 (0%)
Multiracial	1 (3%)	0 (0%)

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Table 3

Baseline Measurements as a Function of Weight Status and Snack Food Type

	Low-Energy-Dense Snack (n = 38)		High-Energy-Dense Snack (n= 39)		Statistical significance		
	BMI ≤ 85th % (n=22)	BMI > 85th % (n=16)	BMI ≤ 85th % (n=20)	BMI > 85th % (n=19)	Weight Status	Energy Density	Weight Status * energy Density
	Mean (SEM)	Mean (SEM)	Mean (SEM)	Mean (SEM)	p	p	p
Hunger	65.3 (4.7)	53.9 (5.7)	63.3 (4.9)	53.9 (5.0)	0.03	NS	NS
Thirst	58.6 (5.4)	62.1 (6.5)	58.9 (5.6)	59.8 (5.8)	NS	NS	NS
Food Liking	77.3 (3.1)	77.9 (3.8)	84.8 (3.3)	85.2 (3.4)	NS	0.03	NS
Food Wanting	61.7 (4.2)	72.9 (5.1)	75.9 (4.4)	62.5 (4.6)	NS	NS	0.01
Dietary Restraint Score	4.3 (0.8)	6.3 (0.9)	3.9 (0.8)	6.0 (0.8)	0.014	NS	NS
Self-Efficacy for Healthy Eating	3.4 (0.2)	3.1 (0.2)	3.1 (0.2)	3.0 (0.2)	NS	NS	NS
24-hour Energy Intake (kcal)	1919 (104)	1720 (126)	2016 (109)	1950 (115)	NS	NS	NS
Physical Activity (minutes/day):							
Light	7.9 (1.9)	0 (2.3)	2.3 (2.0)	0.6 (2.1)	0.027	NS	NS
Moderate	37.5 (12.2)	9.8 (14.7)	23.4 (12.8)	11.4 (13.1)	NS	NS	NS
Hard	13.2 (6.1)	7.4 (1.0)	9.5 (6.4)	16.9 (6.5)	NS	NS	NS
Very Hard	17.4 (5.0)	11.8 (6.1)	12.3 (5.3)	11.9 (5.4)	NS	NS	NS
Daily Servings of Food Types:							
Fruit	0.41 (0.09)	0.28 (0.11)	0.49 (0.09)	0.52 (0.09)	NS	NS	NS
Vegetables	0.61 (0.10)	0.54 (0.13)	0.91 (0.11)	0.83 (0.11)	NS	0.019	NS
Starchy Vegetables	0.59 (0.09)	0.52 (0.12)	0.52 (0.09)	0.62 (0.09)	NS	NS	NS
Low-Energy-Dense Snacks (≤ 1.0 kcal/g)	0.21 (0.06)	0.09 (0.08)	0.16 (0.06)	0.27 (0.07)	NS	NS	NS
High-Energy-Dense Snacks (> 1.0 kcal/g)	2.54 (0.38)	2.01 (0.49)	2.63 (0.41)	1.92 (0.42)	NS	NS	NS
Sugar Sweetened Beverages	1.34 (0.22)	1.09 (0.29)	1.31 (0.24)	1.02 (0.24)	NS	NS	NS
Dairy	1.99 (0.18)	1.57 (0.23)	1.57 (0.19)	1.58 (0.19)	NS	NS	NS
Whole Grain	0.58 (0.15)	0.65 (0.19)	0.21 (0.16)	0.78 (0.16)	NS	NS	NS

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Measurements taken at baseline of appetite sensations, dietary restraint score, self-efficacy for healthy eating, physical activity, 24 hour energy intake, and daily servings of different foods groups from individuals assigned to low-energy-dense (LED) or high-energy-dense (HED) food who had a healthy weight (BMI<85^{th}%-ile) or had overweight or obesity (BMI > 85%-ile). Main effects of weight status and food energy density and interactions between the two are shown in the columns to the right. NS = not significant.