Daily Exposure to Either a High- or Low-Energy-Dense Snack Food Reduces its Reinforcing Value in Adolescents

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Objective: 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: A parallel-group, randomized trial was used to assess RRV of LED or HED snack food at baseline and again after exposure to that snack food daily for 2 weeks in 77 adolescents, aged 13 to 17 years. Information on eating-related subject characteristics was also collected at baseline.

Results: After 2 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.

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 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 2 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 U.S. (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 2 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 investigated whether these influenced baseline RRV of food or the change in RRV of food after repeated exposure.

Methods

Sample size determination and study participants

Before 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 2 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 an 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 (>50 mm), willingness to eat daily for 2 weeks, and consuming ≤2 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 preload (Wegmans Fruit & 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 nonfood 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 were 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. Seventy-one percent of participants completed ≥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 (DEBQ), were debriefed, and were compensated.

**Assessments**

**Reinforcing value task.** Participants pressed the mouse button to earn portions of their assigned snack food on one computer and 2-minute allotments of time to spend reading age-appropriate magazines on the other. The nonfood alternative was offered in order to assess the RRV of food compared with 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, 1,280, 2,560, 5,120, 10,240, and 20,480, 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 were 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.

**Dutch Eating Behavior Questionnaire (DEBQ).** Participants completed the DEBQ revised for children ages 8 to 12 to measure dietary restraint (23). There are nine items on this questionnaire, and participants are asked to “circle answers that are true for you” from the choices of “never,” “sometimes,” and “very often,” which are 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 ≥7 (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

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**TABLE 1 Demographic information based on participants’ assigned food group**

| Low-energy-dense snack \( n = 38 \) | High-energy-dense snack \( n = 39 \) |
|--------------------------------------|--------------------------------------|
| **Gender**                           |                                     |
| Male/female                          | 19/19                                |
|                                       | 20/19                                |
| **BMI percentile**                   | 68.2 (4.5)                           |
|                                       | 72.7 (4.4)                           |
| **Age**                              | 15.2 (0.2)                           |
|                                       | 14.4 (0.2)                           |
| **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 or more                     | 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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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 DD questionnaire.** Participants completed a 27-item questionnaire that assessed discounting of monetary values ranging from (3.0–4.9 METs), hard intensity (5.0–6.9 METs) or very hard intensity (7.0 METs). A smaller percentage indicated greater DD.

**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 to determine METs score for each activity, then coded into light intensity (<2.9 METs), moderate intensity (3.0–4.9 METs), hard intensity (5.0–6.9 METs) or very hard intensity (>7.0 METs).

**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 versus post-intervention as the within-subject 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 was predominantly white (Table 1).

**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 ED (Table 2). 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.

**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 “nonwhole” 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 DD 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 2 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 ED 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 DD 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 this study, we found that adolescents showed a reduction in RRV of food after 2 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 “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 3-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 this study, we specifically chose foods that were not consumed frequently in order to maximize the possibility

| 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 %** | **BMI > 85th %** | **BMI ≤ 85th %** | **BMI > 85th %** | **Weight status, energy density, P | **Weight status × energy density, P** |
| **BMI ≤ 85th %** (n = 22) | **BMI > 85th %** (n = 16) | **BMI ≤ 85th %** (n = 20) | **BMI > 85th %** (n = 19) | **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-h energy intake (kcal) | 1919 (104) | 1720 (126) | 2016 (109) | 1950 (115) | NS | NS | NS |
| Physical activity (min/d) | 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 | Fruits | 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 (0.28) | 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 |

Measurements taken at baseline of appetite sensations, dietary restraint score, self-efficacy for healthy eating, physical activity, 24-h energy intake, and daily servings of different food groups from individuals assigned to low-energy-dense (LED) or high-energy-dense (HED) food who had a healthy weight (BMI < 85th%-ile) or had overweight or obesity (BMI > 85th%-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.
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 2 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 2 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 be 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 have obesity (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 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, NY, 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 crossover 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 approximately 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 prepackaged 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.

Conclusion

Repeated exposure to both LED and HED food for 2 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.© 2017 The Obesity Society

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