Variety influences habituation of motivated behavior for food and energy intake in children[1–3]

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ABSTRACT

Background: Research has shown that variety reduces the rate of habituation, or a general reduction in the rate of responding, for low-energy-density (LED) and high-energy-density (HED) foods.

Objective: We assessed whether the effects of variety on habituation of motivation to eat are different in overweight and lean children.

Design: Overweight and lean children ($n = 84$) were randomly assigned to groups that varied as to whether they received their favorite or a variety of LED or HED foods.

Results: Habituation was slower for overweight than for nonoverweight children ($P = 0.008$), for a variety of foods than for the same foods ($P < 0.001$), and for LED than for HED foods ($P < 0.001$). Energy intake was greater for overweight than for nonoverweight children provided with variety ($P = 0.004$) and was greater for overweight or nonoverweight children provided with the same food ($P < 0.001$). A variety of HED foods increased energy intake more than did the same HED foods ($P < 0.001$); this increase was greater than energy intake with the same or a variety of LED foods ($P < 0.001$). Children who sensitized, or showed an increase in responding before habituating, showed slower habituation ($P < 0.001$) and consumed more energy ($P = 0.039$) than did children who did not sensitize.

Conclusions: Habituation is influenced by variety of foods, and overweight children increase energy intake more with variety than do leaner children. Research is needed to evaluate mechanisms of how variety influences the motivation to eat and energy intake, and how the variety effect can be used to influence intake across multiple eating occasions in children. *Am J Clin Nutr* 2009;89:746–54.

INTRODUCTION

Variety influences habituation of motivated behavior for food and energy intake in children. Repeated presentation of food results in a reduction in motivated responding to food, and introduction of a new food results in recovery of motivation to eat, which is characteristic of habituation (1, 2). Presentation of a nonfood stimulus, such as watching television, can serve to recover the motivation to eat after motivation to eat has been reduced (3), which is consistent with the role of distractors in habituation (4, 5). Differences in the rate of habituation are associated with differences in energy intake, with faster habituation related to lower intake. Thus, it is not surprising that overweight adults (6) and children (7, 8) habituate more slowly to repeated food cues than do leaner peers.

It is well known that variety increases energy intake (9–11), and it is possible that one factor that stimulates the increased motivation to eat in overweight children is responsiveness to food variety. Obese children are more motivated to eat and consume more food than are leaner children (12), and one potential mechanism for this difference is slower habituation to food in obese children than in lean children (7). Because variety may increase energy intake, one approach to reducing energy intake may be to reduce the variety of high-energy-density (HED) foods (13–15). An alternative approach to treating obesity and improving health is to increase the variety of low-energy-density (LED), high-nutrient-density foods (16–18), while reducing access to HED alternatives. For this clinical approach to work, it is important that the effects of variety are observed for both LED and HED foods. Previous research in children suggests that variety influences intake of LED as well as HED alternatives, but additional research is needed to assess the generalizability of this concept.

Some subjects may sensitize, or increase responding, before habituating (19). This pattern was observed for changes in motivated responding to food cues (8), salivary responses to olfactory (20) and gustatory (21, 22) cues, and facial muscle responses to gustatory cues in adults (23). In previous research with children, those who first sensitized had a slower rate of habituation and consumed more energy than did those who did not sensitize, although overweight children were not more likely to sensitize responding than were leaner children (8).

The primary purpose of this study was to assess whether overweight and nonoverweight children differ in their response to variety, with the prediction that overweight children will consume more food when presented with a variety of food than when presented with one food. This represents the first test of this

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hypothesis in children or adults. Secondary goals are to assess the reliability of slower rates of habituation for overweight than for nonoverweight children, whether the effects of variety on slower habituation and greater intake are observed for both LED and HED foods, and whether the observation that children who sensitize before habituating show slower habituation as well as greater energy intake.

SUBJECTS AND METHODS

Participants

Participants were 42 female and 42 male 8–12-y-old children recruited from flyers, an existing database, and a direct mailing. Exclusionary criteria included taking medications that might affect appetite (eg, methylphenidate), medical or psychological conditions that might affect eating (eg, eating disorders, upper respiratory illness, or diabetes), current developmental disability or psychological disorder, allergies or unwillingness to eat the foods in the study, or prior participation in a laboratory study that used similar methods.

Design and procedures

The parents of 99 participants were screened with the use of a standardized telephone interview to ensure that children met the inclusion criteria. If eligible, they were scheduled for a 60–90-min visit to the laboratory on a weekday between 1400 and 1730. Children were stratified by overweight [≥85th body mass index (BMI; in kg/m^2) percentile (24)] status, and sex and randomly assigned into 1 of 4 groups: same food, HED; same food, LED; variety of food, HED; variety of food, LED. If participants were in the same food condition, children could work for access to their most highly rated (favorite) food on the basis of food ratings (described below). If they were in the variety condition, they worked for access to their 4 favorite foods presented in a randomized order, with the stipulation that the same food could not be presented consecutively.

Parents were instructed to not have their child eat or drink anything (except water) 3 h before the experiment and to avoid the study foods on the day of the experiment. On arrival to the laboratory, parents and children completed consent and assent forms along with a 24-h food recall to ensure that the child had not eaten in the past 3 h and had avoided the study foods that day. Parents were escorted to the waiting room where they completed a demographics questionnaire. Families were called the day before they were to come to the laboratory to remind them of their appointment and the need to not eat within 3 h and avoid study foods that day. On 4 occasions children did not meet the requirement of not eating within 3 h before coming to the laboratory. On one occasion they were rescheduled, on 2 occasions they remained in the laboratory until the 3 h was complete, and on the fourth occasion the child had consumed <10 kcal, and it was felt that this amount of consumption would not influence responding to the experimental conditions. No child reported eating study foods the day he or she came to the laboratory.

Before the experimental task began, children rated their hunger. Next, they tasted samples of 6 foods (either HED or LED), rated their liking, and ranked the foods from favorite to least favorite. The experimental task involved the participant playing a computer game to earn points. After the computer task, participants rated their hunger and completed a Dutch Eating Behavior Questionnaire (DEBQ) adapted for children to assess dietary awareness (25). Height and weight were measured at the end of the experiment. Finally, both parent and child were debriefed about the purpose of the study and given written materials about the rationale behind the experiment. Participants were compensated with a $20 gift certificate for completing the experiment, and parents were compensated with $10 gift certificates for travel, child care expenses, or both. All procedures were conducted in accordance with guidelines for the ethical conduct of human research outlined by the National Institutes of Health and with the approval of the University at Buffalo Children and Youth Institutional Review Board.

Laboratory environment

The laboratory was designed for eating experiments and is equipped with a fresh air delivery system that circulates fresh air through each room ≈10 times/h. The experiment rooms have intercom systems that enable participants to communicate with the experimenters at any time.

Measurement

Sensitization and habituation of motivated responding

A computer-generated task programmed at a variable interval 120-s reinforcement schedule (120 s ± 35%) was used to measure instrumental responding for food. The computer task consisted of 2 squares, one that flashed red every time a mouse button was pressed and another that flashed green when a point was earned. Participants were reinforced with a 50-g portion of snack food for the first response made after the interval timed out. The task was presented for a 24-min period. Children could move over to an activity station with age-appropriate mazes and puzzle books if they did not want to work for food. Before beginning the task, each child was familiarized with the task by watching a staff member earn one portion of food. The child was then provided with one practice trial to ensure that he or she understood how to do the task.

For each point earned, children immediately received a bowl of snack food (50.3 ± 1.5 g of food). The foods in the HED condition were nacho chips (Doritos; Frito Lay, Plano, TX; 191.1 kcal/50.3 g; 3.8 kcal/g), potato chips (Pringles; Proctor & Gamble, Cincinnati, OH; 301.8 kcal/50.3 g; 6.0 kcal/g), chocolate sandwich cookies (Mini Oreos; Kraft Foods, Northfield, IL; 251.5 kcal/50.3 g; 5.0 kcal/g), fruit-flavored candy (Skittles; Mars Snackfood, Hackettstown, NJ; 201.2 kcal/50.3 g; 4.0 kcal/g), mini cakes (Little Debbie Zebra Cakes; McKee Foods, Collegedale, TN; 221.3 kcal/50.3 g; 4.4 kcal/g), and chocolate bars (Hershey's Miniatures; Hershey, Hershey, PA; 266.6 kcal/50.3 g; 5.3 kcal/g). The foods in the LED condition were pineapple chunks (Wegmans, Rochester, NY; 25.2 kcal/50.3 g; 0.5 kcal/g), mandarin oranges (Wegmans; 30.2 kcal/50.3 g; 0.6 kcal/g), baby carrots with nonfat dip (Wegmans; 25.2 kcal/50.3 g; 0.5 kcal/g), chocolate pudding (Hunt's Snack Pack Fat-Free Chocolate Pudding; ConAgra Foods, Omaha, NE; 45.3 kcal/50.3 g; 0.9 kcal/g), low-fat strawberry yogurt (Dannon Light and Fit Strawberry Yogurt; Dannon, White Plains, NY; 25.2 kcal/50.3 g; 0.5 kcal/g), and applesauce (Wegmans; 35.2 kcal/50.3 g; 0.7 kcal/g). Water was provided ad libitum throughout the experiment. The energy intake of the food was determined by weighing the foods before and after the task to the nearest 0.1 g and estimating energy intake according to the energy density of the food. Children could finish any food that was not eaten when the task was complete, but they were not allowed to take the food home.

Experimenters wore latex gloves for all food handling and maintained laboratory hygiene throughout the experiment. Food portions were controlled and placed on covered plates at room temperature until presentation to the participants. Specifics of the food preparation were pretested to provide appealing foods that participants would be motivated to eat.

Food hedonics and hunger

The liking of study foods was assessed by 5-point Likert scales, anchored by 1 (do not like) and 5 (like very much). Participants rated the study foods from 1 (most liked) to 6 (least liked). Hunger was measured at the beginning and end of the session and was assessed by a Likert scale, anchored by 1 (extremely hungry) and 5 (extremely full).

Same-day food recall

Same-day food recalls were conducted as an interview with the child and with the parent present. This measure was used to verify adherence to the study protocol, ensuring that the child had not consumed food or drink (except water) 3 h before the appointment and that the child had not consumed the study foods that day.

Dietary awareness

The DEBQ revised for children 8–12 y of age was used to measure dietary awareness (25). A score >7 on questions 1–6 indicated dietary restraint. Examples of questions on the DEBQ are "I have tried to lose weight" and "I try not to eat between meals because I want to be thinner."

Demographics

A general demographics questionnaire was used to assess education, annual income, socioeconomic status, class, race, and ethnicity.

Anthropometrics

Height (in cm) and weight (in kg) were measured without shoes and in light clothing with the use of a Heightronic digital stadiometer (Quick Medical, Arlington Heights, IL) and a Tanita digital weight scale (Arlington Heights, IL), respectively, after the participant had voided. These measurements were used to calculate BMI. For purposes of stratification to equate BMI *z* score (zBMI) between groups, children with BMI <85th percentile were considered nonoverweight ($n = 47$), and children with BMI ≥85th percentile were considered overweight ($n = 37$) (24, 26). zBMI values represent age- and sex-standardized BMI.

Analytic plan

Participant characteristics (eg, age or BMI), food liking, subjective hunger, and dietary awareness before the testing session were compared between the 4 experimental groups with the use of 2-factor analysis of variance, with energy density (HED or LED) and variety (same or variety) as the between factors. Categorical variables, such as sex, parental income, and percentage of minority, were analyzed with the use of the chi-square test.

Motivated responding (mouse button presses) to obtain food across minute time blocks was analyzed with the use of mixed effects regression models (MRMs) that allow for the evaluation of repeated measures that take into account differences in variability of responding across time blocks that are observed as the number of time block increases (27). These models also allow for the specification of the pattern of data, such that the model can be fit as a linear model if a linear reduction in responding is observed, or as a quadratic (trials × trials) function if the pattern represents a shift in the direction of the responding, as if responding stabilized before it decreased. The MRM provides for the opportunity to study main effects (same or variety, HED or LED, and zBMI) and control for factors that may be related to motivation to eat (age, sex, minority status, parental income, or dietary awareness). zBMI was used as a continuous variable to represent overweight status, rather than using nonoverweight or overweight status as a categorical variable. The use of zBMI as a continuous variable increases power and considers the relation between zBMI and responding across the full spectrum of zBMI scores. The analytic plan was to use log likelihood tests in a hierarchical approach to test whether adding variables to the base model improved the fit. The best-fitting base model included linear and quadratic effects of trials. First-order interactions (zBMI × trials, same or variety × trials, HED or LED × trials) were tested to determine whether they improved the fit of the base model, and then second-order interactions (eg, zBMI × same or variety × trials) were tested to determine whether they improved the fit beyond first-order interactions, etc. The models for first- or second-order interactions simultaneously tested the effects of zBMI, same or variety, and energy density. A significant effect was one in which the term was a significant predictor of motivated behavior, and the model significantly improved the fit. Significant interactions were probed to establish β coefficients from mixed regression models that represent the differential rates of change (slopes) in responding for samples on the basis of high compared with low zBMI, same compared with variety, and LED compared with HED.

Energy (in kcal) consumed during the testing session was analyzed by analysis of covariance (ANCOVA), with overweight status, same or variety, and energy density as between factors, controlling for the same covariates as in the regression models. The relations between the amount of food earned and the amount of food consumed were analyzed by comparing *z* score differences between independent correlations (28).

Sensitization was defined similarly to our previous research (8). We used 4 definitions that fit the criteria of an increase in responding before the reduction in responding observed during habituation. Although almost all (83 of 84) subjects showed an increase in responding from the first to the second minute, considerable variability was observed in responding beyond the second minute, and our definitions were designed to capture those differences. The patterns were defined by a ≥10% increase in responding in a subsequent time block above responding during the first 2-min time block, a 20% increase in responding during a 2-min time block, and either a 10% or 20% increase in responding over two 2-min time blocks. The choice of which definition to use was based on graphical examination of the patterns of responding that were associated with each definition, as well as log likelihood tests from the MRM that tested whether adding information on sensitization to the basic regression model improved fit in comparison to the basic model without sensitization. Log likelihood tests were also used to explore whether sensitization moderated any of the effects of zBMI, same or variety, or energy density on the motivation to eat. The effect of sensitization was first tested to assess whether children who sensitized consumed more energy than did children who did not sensitize, and then sensitization was included as a moderator in the ANCOVA to test whether it moderated the effects of zBMI, energy density, or same or variety on energy intake.

RESULTS

Participant characteristics

The average participant was 10.8 ± 1.5 y of age and had a BMI of 20.9 ± 4.6 (**Table 1**). The majority of the families had a parent who completed college (72.6%) and had a household income >$50,000 per year (70.2%). There were no differences ($P > 0.05$) between children in the groups for age, parental education, household income, food liking, hunger, dietary awareness, or percentage of minority participants.

Habituation

Including the first-order interactions of the main effects by trials improved the fit of the model beyond the base model ($P < 0.0001$). The best-fitting model included linear trends for zBMI and energy density and a linear plus quadratic trend for same or variety. The MRM showed that children habituated more slowly when provided with a variety ($\beta_{\text{linear}} = -9.12$; $\beta_{\text{quadratic}} = 0.06$) of foods in comparison to being provided with the same ($\beta_{\text{linear}} = -16.65$; $\beta_{\text{quadratic}} = 0.37$) foods during the habituation series, with significant linear and quadratic estimates in the MRM (Estimate$_{\text{linear}} = 7.41$, $P = 0.0001$; Estimate$_{\text{quadratic}} = -0.31$, $P = 0.00003$). Heavier children ($\beta_{\text{linear}} = -6.27$) habituated more slowly than did leaner children ($\beta_{\text{linear}} = -9.07$; Estimate = 0.62, $P = 0.008$), and LED foods ($\beta_{\text{linear}} = -9.88$) were associated with slower habituation than were HED foods ($\beta_{\text{linear}} = -15.57$; Estimate = −2.53, $P < 0.001$). To illustrate the effects, differences in the rate of habituation for variety compared with the same foods are shown in **Figure 1**. No interactions between zBMI, same or variety, and energy density were observed in tests of second- and third-order interactions.

The ANCOVA of energy intake data showed a significant effect of same or variety ($P < 0.0001$; **Figure 2**, top), energy density ($P < 0.0001$), and the interactions of same or variety × overweight status ($P = 0.034$; Figure 2, middle) and same or variety × energy density ($P < 0.0001$; Figure 2, bottom). Contrasts showed that energy intake was greater for nonoverweight subjects who were provided with variety than for either nonoverweight or overweight subjects who were provided with the same foods (all $P < 0.001$), who did not differ ($P = 0.63$). Energy intake was greater for overweight subjects provided with variety than for nonoverweight subjects provided with variety ($P = 0.004$). In addition, subjects provided with the same HED foods consumed more calories than did subjects provided with the same or a variety of LED foods ($P < 0.001$). Subjects did not differ in their energy intake when provided with the same or a variety of LED foods ($P = 0.49$). The intake of those provided with a variety of HED foods (668.3 ± 341.9 kcal) was greater than the intake of those provided with a variety of LED foods (173.0 ± 80.8, $P < 0.001$).

Sensitization

Almost all children (83 of 84) showed an increase in responding for food from the first minute to the second minute.

TABLE 1
Participant baseline characteristics by variety and energy density[1]

	Same		Variety		
Characteristic	HED	LED	HED	LED	Total
Subjects (*n*)	21	20	22	21	84
Males [*n* (%)]	11 (52.4)	9 (45.0)	12 (54.5)	10 (47.6)	42 (50.0)
Minority [*n* (%)]	7 (33.3)	5 (25)	4 (18.2)	4 (19)	20 (23.8)
Income [*n* (%)]					
<$50,000	8 (38.1)	7 (35.1)	7 (31.8)	3 (14.3)	25 (29.8)
$50,000–$89,999	8 (38.1)	8 (40.1)	11 (50.0)	10 (47.6)	37 (44.0)
≥$90,000	5 (23.1)	5 (25.0)	4 (18.2)	8 (38.1)	22 (26.2)
Age (y)	11.2 ± 1.3[2]	10.5 ± 1.6	11.2 ± 1.6	10.3 ± 1.4	10.8 ± 1.5
Overweight (%)	15.7 ± 22.4	22.5 ± 27.9	27.0 ± 29.3	17.9 ± 19.6	20.8 ± 25.1
zBMI	0.6 ± 1.1	0.8 ± 1.1	1.0 ± 1.0	0.8 ± 0.7	0.8 ± 1.0
Food liking score[3]	4.8 ± 0.4	5.0 ± 0.2	4.4 ± 0.6	4.2 ± 0.5	4.6 ± 0.5
Hunger score[4]	2.7 ± 0.9	2.4 ± 0.9	2.4 ± 0.7	2.6 ± 0.7	2.5 ± 0.8
Dietary awareness score[5]	4.3 ± 2.8	5.3 ± 3.6	5.5 ± 2.3	5.0 ± 2.5	5.0 ± 2.8

[1] HED, high energy density; LED, low energy density; zBMI, BMI *z* score. Between-group differences were assessed with the use of 2 × 2 chi-square tests for categorical variables and 2 × 2 ANOVA for continuous variables, with energy density (HED or LED) and variety (same or variety) as between variables. Children in the HED groups were older than children in the LED groups ($P = 0.018$), and children receiving the same foods reported higher liking than did children who received a variety of foods ($P < 0.0001$).

[2] Mean ± SD (all such values).

[3] Measured with the use of a 5-point Likert-type scale, with 1 for low liking and 5 for high liking.

[4] Measured with the use of a 5-point Likert-type scale, with 1 being hungry and 5 being full.

[5] Measured with the use of the Dutch Eating Behavior Questionnaire (25).

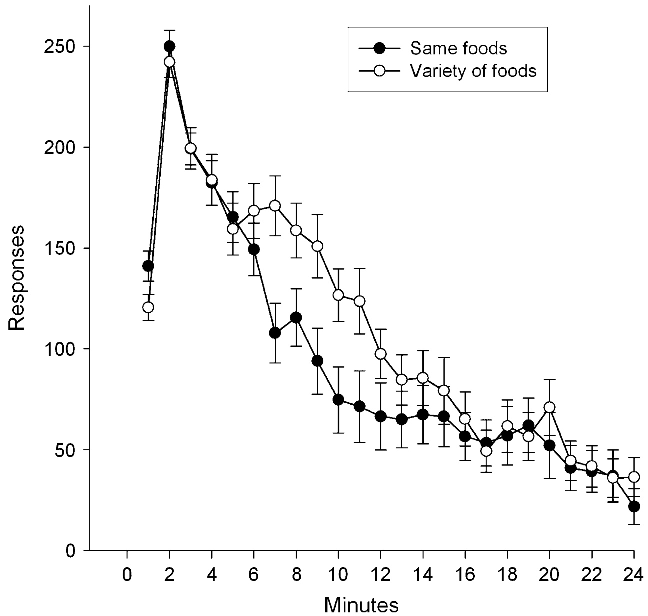

FIGURE 1. Motivated responding over time for variable ratio 120-s schedules of reinforcement for same ($n = 41$) or variety ($n = 43$) groups (mean ± SEM). Mixed regression models showed variety of foods ($P < 0.001$) influenced the rate of habituation.

There was variability in initial responding, with some children showing a gradual decrease in responding, but other children showed a further increase in responding before showing a decrease. The increase can be interpreted as sensitization of responding (29). Significant differences in responding were observed for the children who showed an increase in responding from the first 2 min to the third and fourth minutes compared with those who did not increase responding from the first 2 min to the third and fourth minutes for each definition of sensitization (all $P < 0.0001$). The number of participants who met criteria for sensitization was reduced as the criteria became more stringent, with 38 participants meeting the criteria of a 10% increase for at least one 2-min block, 24 participants meeting the criteria of a 20% increase for one 2-min block, 16 participants showing a 10% increase for two 2-min blocks, and only 11 participants met the criteria of a 20% increase for two 2-min blocks. Mixed models to assess whether adding sensitization as a moderator improved the fit of the models predicting the patterns of responding. The largest effect was for the 10% increase for one 2-min block ($P = 0.0005$), with smaller effects for the 20% increase for one 2-min block ($P < 0.004$), 10% for two 2-min blocks ($P < 0.005$), or 20% for two 2-min blocks ($P = 0.014$). Because the definition of a 10% increase for one 2-min block included the most participants and most improved the fit of the model, this definition was used to study how sensitization moderated responding.

In the MRMs, sensitization was a predictor of motivated responding for food ($\text{Estimate}_{\text{linear}} = -1.94$, $P < 0.001$), and the model with sensitization × trials improved the fit beyond the basic model ($P < 0.001$; **Figure 3**). Sensitization did not interact with zBMI ($P = 0.56$), same or variety ($P = 0.16$), or energy density ($P = 0.23$) to influence habituation of motivated responding for food.

As shown in **Figure 4**, an effect of sensitization on food intake was observed when sensitization was considered separately ($P = 0.039$), but sensitization did not interact with zBMI, energy density, or same or variety when included as a moderator in ANCOVA. Individual differences between children who did and who did not sensitize were explored to determine potential factors that might explain differences in responding. No significant differences were observed between children who did or did not sensitize for variables of sex ($P = 1.00$), age ($P = 0.15$), percentage of overweight ($P = 0.40$), dietary awareness ($P = 0.16$), baseline hunger ($P = 0.55$), average food liking ($P = 0.81$), hunger ($P = 0.33$), or minority status ($P = 0.07$).

Relation between food presented and food consumed

All children did not consume the food they earned. The correlation between the energy of the food earned and consumed was $r(82) = 0.80$, $P < 0.0001$. No differences were observed in this relation for nonoverweight [$r(45) = 0.76$] or overweight [$r(35) = 0.84$] subjects. However, the relations between energy earned and energy consumed were different ($P < 0.01$) for subjects given the same [$r(39) = 0.58$] foods than those given a variety of foods [$r(41) = 0.93$] or subjects given LED [$r(39) = 0.90$] compared with HED [$r(41) = 0.52$] foods ($P < 0.01$). When subjects were provided with LED foods, a strong correspondence between the amount of food earned by responding and consumption in the same [$r(18) = 0.97$] or variety [$r(19) = 0.89$] conditions was shown. However, the relation between amount of food earned and responding for HED foods was significantly less for the same foods [$r(19) = 0.29$, $P < 0.0001$] and for the variety of foods [$r(20) = 0.63$, $P < 0.05$]. Children who were provided with a variety of foods consumed almost all they earned whether lean [$r(22) = 0.90$] or overweight [$r(17) = 0.94$], whereas the correspondence between what the lean [$r(21) = 0.63$, $P < 0.05$] and overweight [$r(16) = 0.58$, $P < 0.05$] children earned and consumed was less if they were provided with the same food.

DISCUSSION

The results are consistent with previous research, which shows that variety slows the rate of habituation and increases energy intake in children (30) and extends the types of HED foods studied from meal foods, such as hamburgers, cheese pizza, chicken nuggets, and french fries (30) to snack foods of nacho chips, potato chips, cookies, pastries, and candies in this study. The results also replicate research that shows that overweight children habituate at a slower rate than do leaner children (7, 8), with differences in the rate of habituation observed for cheeseburgers (7), pizza, macaroni and cheese (8), and snack foods in the current study. The results also replicate the observation that those who sensitize to food respond more to food and consume more food than those who do not sensitize (8).

The primary new findings are that variety interacts with energy density and overweight to influence energy consumption. The interaction of variety with energy density suggests that the biggest effect of variety on energy intake is for HED foods. An intervention that simultaneously targets reducing the variety of HED foods and increasing the variety of LED foods would be predicted to reduce energy intake by reducing intake of HED foods and increase satiety by increasing intake of LED foods.

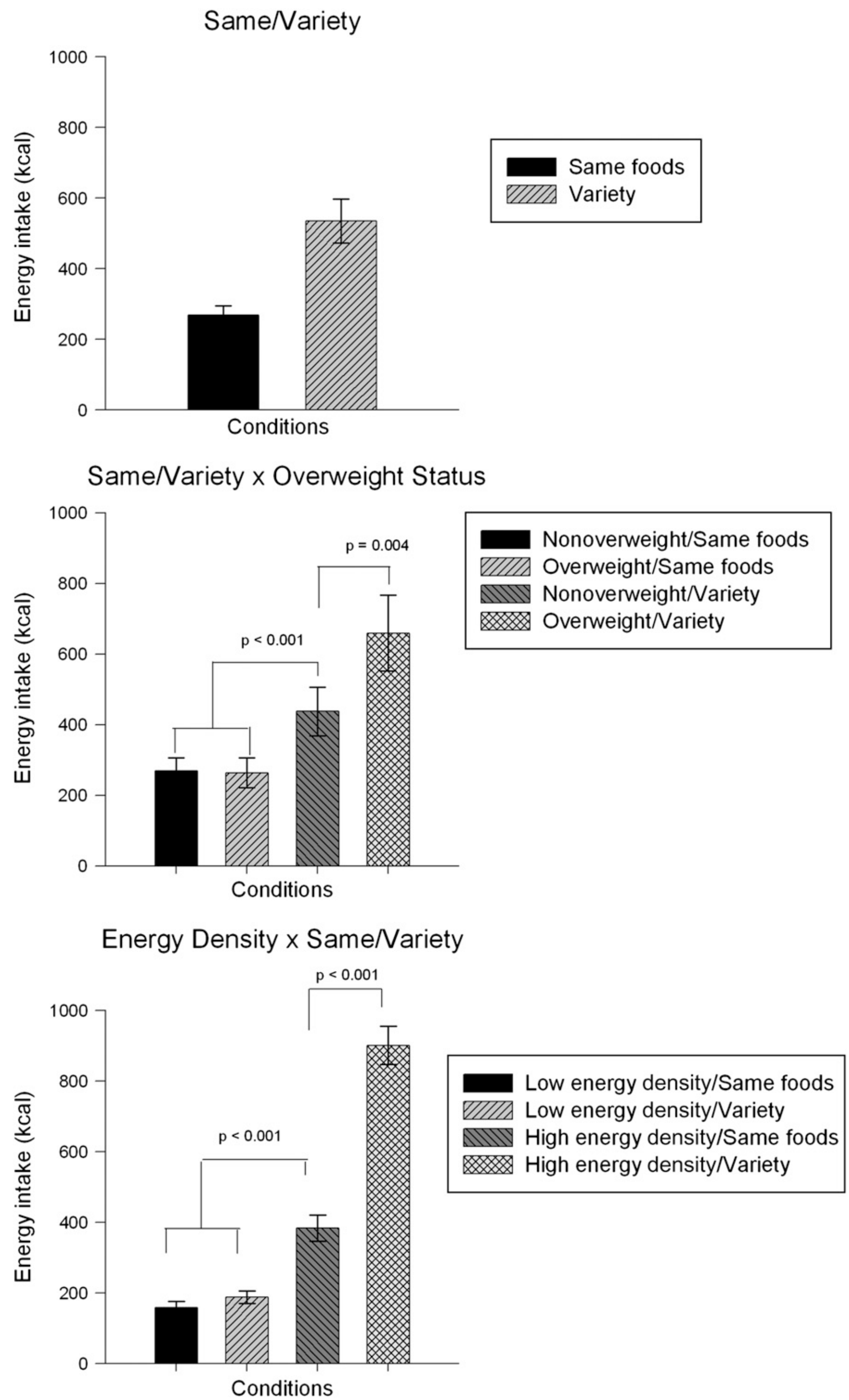

FIGURE 2. Energy consumption (mean ± SEM) for children in the same ($n = 41$) and variety ($n = 43$) groups (top), and the interactions of same or variety and overweight status (middle), and same or variety × energy density (bottom). ANOVA showed greater energy intake for variety than for same ($P < 0.0001$). Contrasts showed greater energy intake for nonoverweight subjects provided with the same ($n = 23$) than for variety ($n = 24$; $P < 0.001$), and overweight subjects consumed more energy in variety ($n = 19$) than did nonoverweight subjects ($n = 18$; $P = 0.004$). Subjects provided with the same high-energy density foods consumed more calories than did subjects provided with the same ($n = 20$) or a variety ($n = 21$) of low-energy density foods ($P < 0.001$).

This approach would modify the food environment and stimulus cues that influence eating. Reducing stimulus cues for HED foods reduces the need for repeated bouts of self-control in choosing healthier rather than less-healthy options. Self-control inevitably breaks down, and investigators have recommended the shift to environmental manipulations to treat obesity (31). Altering the variety of healthy LED rather than HED foods may lead to simple environmental strategies for weight control.

Although no differences were observed in liking of LED and HED foods in this study, it is possible that in many situations children would find HED foods more palatable, which could shift choice to these foods, and palatability could interact with variety,

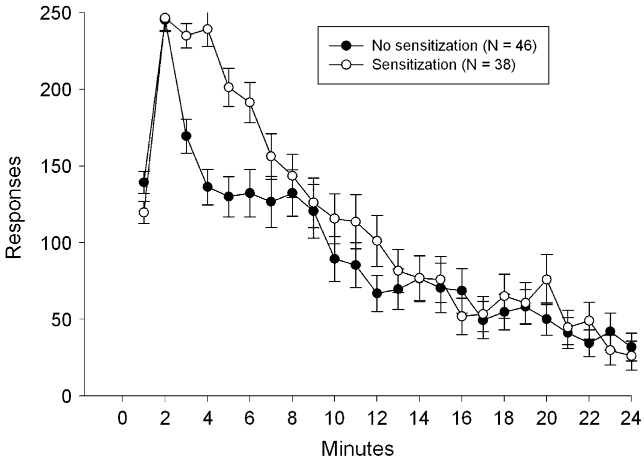

FIGURE 3. Motivated responding (mean ± SEM) on variable ratio 120-s schedules of reinforcement for children who did (n = 38) and did not (n = 46) sensitize with the definition of an increase in responding of ≥10% for minutes 3 and 4 compared with minutes 1 and 2. There was a significant difference in the rate of habituation between those who did and did not sensitize ($P < 0.001$).

just as energy density interacted with variety in this study to influence energy intake. There were reliable differences in liking of the same rather than variety of foods, with greater liking for the same food, because children only received their favorite food in the same condition, whereas in the variety condition they received their favorite food in addition to other foods. The greater liking of food did not translate to slower habituation, because children habituated more slowly to food variety, although they did not rate liking of these foods as highly as their favorite food that was presented in the same condition.

The data suggest that overweight children may be more responsive than leaner children to the effects of variety. This highlights the importance of understanding how variety may be involved in the development of obesity. If obese children are more responsive to variety of both HED and LED foods than are leaner children, they may be prone to gain weight in an environment with a lot of variety, as well as find it harder to reduce energy intake when a variety of HED foods are available. An important research question for understanding how variety may relate to habituation and the development or treatment of obesity is what are the stimulus variables (eg, sight, taste, smell, or texture) that constitute the same compared with a different stimulus? Do people generalize along dimensions of taste so that all chocolate foods are perceived as the same and people would habituate to them, or would people recover the motivation to eat if they had just consumed a chocolate candy bar and now had access to chocolate pudding? Stimulus generalization may be at the core of understanding limits of manipulating variety to influence the motivation to eat and energy consumption.

Given the role of habituation in regulating meal intake, research is needed to understand how habituation can influence intake across meals. The prominent theoretical model for habituation is the memory-based SOP (Standard Operating Procedure) model (32), which has been extended into how emotional factors may influence habituation and associational processes (33). These memory-based models are ideal for the study of habituation across meals, because it is necessary to carry a representation of what was consumed in the previous meal into the next meal for the effects of habituation to extend beyond one meal. Research has shown long-term habituation, although to our knowledge this research has not been conducted with food and the variables that govern long-term habituation are not known (34–36).

Habituation provides one model to understand how manipulating variety influences the motivation to eat or energy intake (37). The other model that is commonly used to describe how variety influences eating is sensory-specific satiety (38). The typical sensory-specific satiety paradigm is to measure liking of a number of foods before eating, have subjects consume one type of food to satiety, and then remeasure liking of the variety of foods. Sensory-specific satiety is observed when the reduction in liking is specific to the food being consumed. This paradigm has led to a large body of interesting research (38–40), with perhaps the major contribution of the sensory-specific model is that food consumption is regulated by more than energy needs. There are several methodologic differences between habituation and sensory-specific satiety, with one important difference being that habituation tracks changes in physiologic or behavioral determinants of eating during repeated food presentations, whereas sensory-specific satiety focuses on changes in liking before and after food consumption (37). There are similarities to the 2 approaches, but potentially important differences in the depth and breadth of the theoretical models and methods used to study habituation and sensory-specific satiety were discussed in depth elsewhere (37). It will be interesting to compare the utility of these different theoretical approaches to understand how variety is related to the development of treatment of obesity.

In general, there was correspondence between factors that influence habituation of the motivation to eat and energy consumption. The exception was that energy consumption showed main effects of variety and energy density as well as the interaction between the two, whereas responding for food showed main effects of variety and energy density on habituation but no interaction of variety and energy density. This may be due in part to a discrepancy between the relation between calories of food presented and consumed in some conditions. For example, when lean or overweight children were provided with a variety of foods, they generally consumed the full amount they earned, whereas

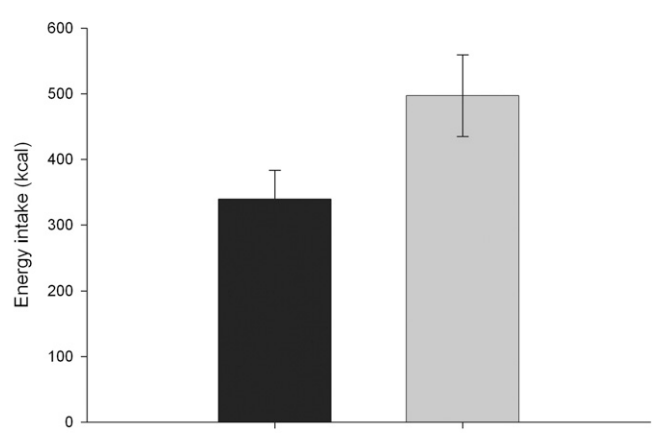

FIGURE 4. Energy consumption (mean ± SEM) for subjects who did (n = 38) and did not (n = 46) sensitize during the habituation task. Children who sensitized consumed more food ($P = 0.039$).

children showed less correspondence between the amount of food earned and food consumed when provided with the same food. One way to improve the correspondence between motivation to eat and consumption in future protocols would be to require that subjects consume the food as it was earned and not continue to work for food that would not be consumed.

This study provides support for research into sensitization before habituation, because individual differences in this pattern of responding was associated with more motivation to eat and greater intake in this and previous research (8). Differences in responding were observed for the first 7 min, because by the eighth minute responding was the same for those who did or did not sensitize, and these differences were enough to result in significant increases in energy intake. Sensitization and habituation may be mediated by different physiologic processes (19). As suggested by Swithers (29), sensitization may be mediated by dopaminergic activity, whereas research by Geyer and Tapson (41) has shown habituation may be more related to serotonergic activity. If these distinctions are supported in future research, then the sensitization component of the curve may provide information relevant to understanding the initial appetitive aspects of the motivation to eat, whereas the habituation component of the curve may be more informative about factors relevant for satiation and the reduction in the motivation to eat a specific food.

This research supports the continued study of habituation as a factor that may influence the motivation to eat as well as energy intake. Research is needed on the basic mechanisms that regulate habituation, characteristics of foods that facilitate or impair habituation, and how habituation and memory processes extend beyond an individual meal to influence intake across multiple meals. There is great potential for using variety to manipulate the motivation to eat and energy consumption, because basic research on the neurobiology of habituation may make important contributions to the translation of basic research to new and effective clinical interventions.

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