Usual Energy Intake Mediates the Relationship Between Food Reinforcement and BMI

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The relative reinforcing value of food (RRVfood) is positively associated with energy consumed and overweight status. One hypothesis relating these variables is that food reinforcement is related to BMI through usual energy intake. Using a sample of two hundred fifty-two adults of varying weight and BMI levels, results showed that usual energy intake mediated the relationship between RRVfood and BMI (estimated indirect effect = 0.0027, bootstrapped 95% confidence intervals (CIs) 0.0002–0.0068, effect ratio = 0.34), controlling for age, sex, minority status, education, and reinforcing value of reading (RRVreading). Laboratory and usual energy intake were correlated (r = 0.24, P < 0.001), indicating that laboratory energy intake could provide an index of eating behavior in the natural environment. The meditational relationship observed suggests that increasing or decreasing food reinforcement could influence body weight by altering food consumption. Research is needed to develop methods of modifying RRVfood to determine experimentally whether manipulating food reinforcement would result in changes in body weight.

INTRODUCTION

Food is a powerful primary reinforcer that motivates people to eat (1). The reinforcing value (or reinforcing efficacy) of food (RRVfood) is assessed by how hard participants will work to obtain food. Based on procedures used to establish the reinforcing efficacy of drugs of abuse (2–4), the work requirements to obtain food are progressively increased and the schedule breakpoint, or the highest level of responding met by the subject, provides an index of food reinforcement. Using these methods, RRVfood has been cross-sectionally (5,6) and prospectively (7) related to obesity. RRVfood has further been associated with energy intake, as persons who find food more reinforcing eat more food during ad libitum eating tasks (8,9).

One way in which RRVfood is associated with obesity may be through energy intake, as people gain weight because they are in positive energy balance and obese individuals often consume more energy than leaner counterparts. The primary goal of this study was to assess whether usual energy intake, as assessed by a validated food frequency questionnaire (10,11) mediates the relationship between RRVfood and BMI. A secondary goal was to assess the relationship between laboratory energy and macronutrient intake in comparison to usual energy and macronutrient intake. Research has shown that RRVfood is related to energy intake in the laboratory (8,9) as well as usual energy intake assessed by repeated 24-h dietary recalls (12).

The most commonly used method of mediation analysis is the causal steps approach described by Baron and Kenny (13,14). In this model, the role of the mediating variable (M) in the relationship between the dependent variable (X) and the independent variable (Y) is confirmed if: (i) all three variables are significantly correlated and (ii) if the significant relationship between X and Y is reduced to a nonsignificant level by addition of M into the regression model. However, the causal steps approach has been criticized for low statistical power, for drawing conclusions based on the inference rather than the quantification of the indirect (mediating) effect and for inherent susceptibility to both type I and type II error (15). Several methodologists have recommended newer tests of mediation (15–17). We test whether usual energy intake mediates the relationship between food reinforcement and BMI using the approach proposed by Preacher and Hayes (18) based on the (i) existence of a total effect to be mediated (e.g., a significant relationship between RRVfood and BMI) and (ii) a statistically significant indirect effect in the direction predicted, determined by the product of the regression coefficients of the RRVfood → increased energy intake (X→M) and increased energy intake → increased BMI (M→Y) paths with confidence intervals (CIs) generated by nonparametric bootstrapping procedures.

METHODS AND PROCEDURES

Participants

Full details of the study design and participant recruitment have been reported elsewhere and are summarized below (12). Two-hundred fifty-two participants (71 nonobese females, 70 nonobese males, 51 obese females, 60 obese males) visited the laboratory for two sessions: an ad libitum snack-eating task and a food reinforcement task. The sample

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After the first session, participants completed the self-administered eating task and a food reinforcement task scheduled 2–3 weeks apart. On arrival at the laboratory, participants gave their written informed consent and completed dietary recalls to ensure adherence to study protocol. Subjects responded by clicking a mouse button. Participants were asked to refrain from consuming food or drinking beverages other than water for at least 3 h and to not consume the experimental foods at least 24 h before the test session. Upon initial arrival at the laboratory, participants gave their written informed consent and completed dietary recalls to ensure adherence to study protocol. Before each session, participants were then provided a choice of three isocaloric energy bar preloads (Clif Bar & Company; Berkeley, CA; 42 g, 150 kcal, 4 g fat, 23 g carbohydrates, 7 g protein) to minimize the effects of hunger on energy intake and food reinforcement. The preload was provided in both sessions to keep the experimental conditions across days as similar as possible, and inclusion of a standard preload increases the ability to show individual differences in food reinforcement (21). Demographic information, height and weight measurements and three dietary habits questionnaires were administered at the end of the ad libitum eating session.

**Ad Libitum eating task.** The ad libitum food consumption task was presented as a taste test (12). Participants were provided 210–305 kcal (42–60 g) servings of six palatable, high-energy dense snack foods (amount of food presented (g) and energy density (kcal/g) shown in parentheses): Wavy Lay's Potato Chips (57 g, 5.4); Cooler Ranch Doritos (56 g, 5.4); plain M&M's (60.5 g, 5); Twix (46 g, 5); Kit Kat (42 g, 5); and Butterfinger (57 g, 4.5). Water was provided ad libitum. Participants were told that they could consume as much or as little of the food that they wanted as long as they tasted each food so that they could accurately rate the food on pleasantness, sweetness, blandness, flavorfulness, and bitterness using 9-point Likert-type scales. Afterwards, participants were given several dietary habits questionnaires to complete. They were also told that the food would be discarded after the session and so they were free to continue eating. When participants indicated that they were finished, they were asked to identify their favorite food from among the six available and told that this would be the food used in the food reinforcement test session. The primary dependent variables were laboratory energy and macronutrient intake.

**Food reinforcement task.** Specifics of the food reinforcement task have been previously described (12). The task was implemented as a computer program in which participants could choose to work for food (RRVfood) or reading (RRVreading) on concurrent schedules of reinforcement. Subjects responded by clicking a mouse button. Participants earned a point by meeting the schedule requirement, and they received a 70–101 kcal (14–20 g) portion of their or her preferred snack food selected during the ad libitum eating session or 2 min of time to spend reading for every five points earned, depending on which reward they were working for. Progressive fixed-ratio schedules were programmed for food and reading, with response requirements of 4, 8, 16, 32, 64, 128, 256, 512 and so forth for each point. Water was provided ad libitum. The dependent measure that we used was the breakpoint, or $P_{\text{max}}$ (2), which is the schedule (i.e., 4, 8, 16, 32, etc.) at which subjects last met response requirements for access to the food or non-food alternative. The test–retest reliability of RRVfood has been demonstrated (8), and RRVreading has been positively associated with energy intake in the ad libitum eating task (8,9) and with weight status (5,6,8).

**Usual dietary intake.** The self-administered version of the 2005 Block Food Frequency Questionnaire (Nutrition Quest, Berkeley, CA) was used to measure usual dietary intake. This 110-item questionnaire was designed to estimate usual and customary intake of a wide array of nutrients and food groups. Methodology for questionnaire development (10,22) and validation (11,23) are available. The food list for the 2005 revision was developed from NHANES 1999–2002 dietary recall data, and the nutrient database for that revision was developed from the USDA Food and Nutrient Database for Dietary Studies (FNDDS), version 1.0. Participants are asked to complete all questions including how frequently they consume specific foods and the usual portion size. The primary dependent variables were usual energy and macronutrient intake.

**Height and weight.** The participant’s weight and height were measured using a digital scale (TANITA, Arlington Heights, IL) and a digital stadiometer (Measurement Concepts & Quick Medical, North Bend, WA). On the basis of height and weight data, BMI was calculated according to the following formula: BMI = kg/m².

**Food liking and hunger.** Subjective ratings of hunger and food hedonics were collected before and after consumption of the preload using Likert-type scales. For hunger, 1 indicated not at all hungry/not at all full and 10 indicated extremely hungry/extremely full, while for hedonics 1 indicated not liking at all and 9 indicated liking very much.

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**Table 1** Participant characteristics

| Characteristics                        | Mean ± SD     |
|----------------------------------------|---------------|
| N                                      | 252           |
| Age                                    | 34.7 ± 10.7   |
| BMI                                    | 29.7 ± 7.2    |
| Hunger*                                | 5.6 ± 2.1     |
| Liking of study foods*                 | 7.1 ± 0.9     |
| Liking of food reinforcer              | 8.2 ± 1.0     |
| Sex (M/F)                              | 130/122       |
| Education                              |               |
| Some high school or completed high school | 37           |
| Some college/vocational training       | 76            |
| Completed college                      | 109           |
| Completed graduate/professional school | 30            |
| Minority status                        |               |
| Minority (non-white)                   | 64            |
| Non-minority (white)                   | 188           |
| RRVfood                                | 61.8 ± 132.0  |
| RRVreading                             | 81.6 ± 116.9  |
| Laboratory energy intake (kcal)        | 593.0 ± 316.4 |
| Usual energy intake (kcal)             | 1,945.2 ± 853.0 |

Plus-minus values are means ± s.d.

RRVfood: relative reinforcing value of food; RRVreading: relative reinforcing value of reading.

*Post-preload hunger scores at the start of the ad libitum eating session. *Post-preload liking scores for all foods presented during the ad libitum eating session.
Analytic plan
The goals of the analyses were to assess whether RRVfood is related to BMI, and whether usual energy intake mediates this relationship. Mediation models were established using multiple regression, controlling for age, sex, education, minority status, and RRV maintaining as covariates. The relationship between RRVfood and BMI was first evaluated. If there was a significant total effect of RRVfood on BMI, the size and significance of the indirect effect of RRVfood on BMI through energy intake was then estimated by the product of the regression coefficients of the predictive variables from the RRVfood → energy intake and the energy intake → BMI paths. CIs were constructed from 10,000 bootstrap resamples of the data (of the same size as the original study population, with replacement) and implemented via a macro developed by Preacher and Hayes (18). We present three ways to interpret the magnitude of the meditational effect. First, the mediator is considered to be significant if the indirect effect of RRVfood on BMI through energy intake is significantly different from 0 (the bootstrapped 95% CI does not contain 0). Second, the magnitude of the indirect effect reflects the change in the dependent variable (BMI) indirectly through the mediator variable (energy intake) per a unit change of the independent variable (RRVfood) (15). Third, the percent of the total effect of RRVfood on BMI explained by the indirect effect of RRVfood on BMI through energy intake was quantified by calculation of the effect ratio (indirect effect divided by the total effect) (24).

RESULTS
Characteristics of the sample are presented in Table 1. RRVfood was related to BMI, \( (b = 0.0079, P = 0.031, n = 252) \), indicating the presence of a significant total effect. The indirect effect of RRVfood on BMI through usual energy intake was significant \( (\text{estimate} = 0.0027, 95\% \text{CI} = 0.0002, 0.0068) \), suggesting that usual energy intake is a mediator of the relationship between RRVfood and BMI. The size of the indirect effect on BMI mediated through usual energy intake can be estimated by comparing BMI at the average breakpoint of responding for food to BMI at a one-s.d. increase in the breakpoint of responding for food, which would predict an increase of 0.36 BMI units. Based on the effect ratio, usual energy intake explained 34% of the association between RRVfood and BMI.

RRVfood was related to laboratory \( (r = 0.31, P < 0.001) \) as well as usual energy intake \( (r = 0.35, P < 0.001) \). Usual and laboratory energy intake were significantly related \( (r = 0.24, P < 0.001) \). Laboratory and usual consumption of protein \( (r = 0.23, P < 0.001) \), fat \( (r = 0.25, P < 0.001) \), and carbohydrates \( (r = 0.20, P = 0.002) \) were also significantly related.

DISCUSSION
This study provides support for the hypothesis that energy intake mediates the relationship between food reinforcement and BMI. These results integrate previous findings showing that food reinforcement is related to body weight (6,8) and that food reinforcement is related to energy intake (8,9) to provide insight into the relationship between behavioral phenotypes, dietary behaviors, and obesity. The relationship observed suggests that modifying food reinforcement could influence body weight by altering energy intake. This is very relevant for weight control, as obese persons may find food more reinforcing than other behaviors and thus overeat, contributing to positive energy balance (1). It is also possible that the relationship could be extended towards understanding how to increase body weight in malnourished individuals.

Obesity in influence body weight by altering energy intake. This is very observed suggests that modifying food reinforcement could similarly influence food selection (32).
that the ad libitum eating session may provide an index of eating in the natural environment. This would be a very useful addition to the tools available to assess energy intake, given challenges in measuring usual energy intake. It is recognized that self-reports of energy intake are compromised by underestimation (33,34). Treatment studies may benefit from including a standardized eating task as part of the outcome assessment. It might be useful to consider combining multiple measures of dietary intake to develop the most valid measure of eating, which could include laboratory eating, food frequency questionnaires, and dietary recalls.

There are several aspects of the study methods that may limit the generalization of the results. Dieters were excluded, since they may not want to eat in the laboratory and thus would not work for food. Given the challenges of measuring food reinforcement and ad libitum consumption of people who do not want to eat in the laboratory, it is unclear whether the results can be generalized to obese people who are dieting. In addition, all subjects were provided a preload before the food reinforcement and ad libitum snack-eating session to focus the task on hedonic, rather than homeostatic hunger (35). However, many eating situations occur when people are energy-deprived and research is needed to assess whether results obtained after a preload can be generalized to eating while experiencing homeostatic hunger. Finally, the current mediation analysis is based on cross-sectional data. A stronger test of whether energy intake mediates the effect of food reinforcement on body weight is through experimental analysis (16).

Food reinforcement may play a central role in the regulation of energy balance and of body weight, but experimental research investigating whether energy intake mediates the relationship between food reinforcement and body weight is needed. For example, a study could be designed to randomly assign one group of participants to an intervention that reduces food reinforcement and another group of participants to a control condition while tracking changes in energy intake and body weight. If decreased food reinforcement mediates the reduction in body weight through negative energy balance, then it would be expected that the groups would differ in body weight changes. Moreover, changes in food reinforcement and energy intake would be correlated in the experimental group but not in the control group. Such experiments would facilitate the development of new methods of modifying food reinforcement as well as confirm the mediating role of energy intake in the relationship between food reinforcement and body weight.

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DISCLOSURE

The authors declared no conflict of interest.

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