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Reinforcing value and hypothetical behavioral economic demand for food and their relation to BMI

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Abstract

Food is a primary reinforcer, and food reinforcement is related to obesity. The reinforcing value of food can be measured by establishing how hard someone will work to get food on progressive-ratio schedules. An alternative way to measure food reinforcement is a hypothetical purchase task which creates behavioral economic demand curves. This paper studies whether reinforcing value and hypothetical behavioral demand approaches are assessing the same or unique aspects of food reinforcement for low (LED) and high (HED) energy density foods using a combination of analytic approaches in females of varying BMI. Results showed absolute reinforcing value for LED and HED foods and relative reinforcing value were related to demand intensity (r's=0.20–0.30, p's < 0.01), and demand elasticity (r's=0.17–0.22, p's < 0.05). Correlations between demographic, BMI and restraint, disinhibition and hunger variables with the two measures of food reinforcement were different. Finally, the two measures provided unique contributions to predicting BMI. Potential reasons for differences between the reinforcing value and hypothetical purchase tasks were actual responding versus hypothetical purchasing, choice of reinforcers versus purchasing of individual foods in the demand task, and the differential role of effort in the two tasks. Examples of how a better understanding of food reinforcement may be useful to prevent or treat obesity are discussed, including engaging in alternative non-food reinforcers as substitutes for food, such as crafts or socializing in a non-food environment, and reducing the value of immediate food reinforcers by episodic future thinking.

Keywords

Food reinforcement; Behavioral demand; Behavioral economics; Obesity

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Conflict of interest

Dr. Epstein was a consultant to and had equity in Kurbo when this study was implemented. Dr. Bickel is a consultant or has equity in HealthSim LLC, NotifiUs LLC, Sober Grid Inc., DxRx, Prophase LLC, Teva Branded Pharmaceuticals, General Genetic Corporation. The other authors do not declare any conflict of interest with respect to the authorship or publication of this article.

The reinforcing value of a food is measured by having people respond for food, with the response requirements for earning food specified by a schedule of reinforcement. The schedules, or the amount of work required to earn food, increasing progressively. The schedule may start requiring people to make 10 responses to earn a portion of food, and then double after each time they met the schedule requirements. Initially, people will work for a reinforcer they want. However, as the amount of work increases they will reach a point in which they do not feel the reinforcer is worth the effort, and they will stop responding. Reinforcing value is assessed by determining the last work requirement or schedule a participant completes (Epstein, Leddy, Temple, & Faith, 2007). Absolute reinforcing value is measured for an individual food. Relative reinforcing value is measured using a concurrent schedules of reinforcement paradigm in which the person has a choice to respond for two concurrently available reinforcers, which can include two types of food or food versus an alternative commodity (Epstein, Leddy, et al., 2007).

The reinforcing value of food has been cross-sectionally and prospectively related to obesity in infants (Kong, Feda, Eiden, & Epstein, 2015), children (Hill, Saxton, Webber, Blundell, & Wardle, 2009; Temple, Legierski, Giacomelli, Salvy, & Epstein, 2008), adolescents (Epstein, Yokum, Feda, & Stice, 2014) and adults (Carr, Lin, Fletcher, & Epstein, 2014; Epstein, Carr, Lin, Fletcher, & Roemmich, 2012; Giesen, Havermans, Douven, Tekelenburg, & Jansen, 2010; Saelens & Epstein, 1996). Reinforcing value is related to energy intake using laboratory, questionnaire, and food recall methods (Epstein, Carr, Lin, & Fletcher, 2011). The relationship between food reinforcement and obesity is mediated by energy intake (Epstein et al., 2012). Also, the relationship between low income or low education and BMI is mediated in part by food reinforcement (Lin, Carr, Fletcher, & Epstein, 2013).

A second way to measure food reinforcement is based on behavioral economic demand curves (Bickel, Marsch, & Carroll, 2000; Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1989; Hursh & Silberberg, 2008) in which the relationship between price and purchasing is established (Johnson & Bickel, 2006). Participants indicate how much of a commodity they would purchase at progressively increasing prices (Hursh, Galuska, Winger, & Woods, 2005; Jacobs & Bickel, 1999; Johnson & Bickel, 2006). As the price increases, people indicate they would purchase less of the food until a point is reached in which an individual will no longer purchase that food. Hypothetical purchasing tasks provide demand curves that are similar to actual purchasing tasks (Amlung, Acker, Stojek, Murphy, & MacKillop, 2012; Wilson, Franck, Koffarnus, & Bickel, 2016).

Demand curves provide a number of indices of food reinforcement, including intensity, or how much people would consume if it was free (or minimally priced); breakpoint, the price at which purchases are zero; elasticity, the quantitative relationship between price and purchasing; Omax, the maximum amount people will expend on the commodity, and Pmax, the maximal price before demand become highly price sensitive (Bickel et al., 2000; MacKillop et al., 2009).

To our knowledge, one study compared reinforcing value and hypothetical demand tasks in 24 adults balanced for sex (12 M, 12F) and obesity (12 non-obese, 12 obese) status, with an average BMI of 30.9 (Epstein, Dearing, & Roba, 2010). Reinforcing value and behavioral demand Omax were related, and both were related to BMI. Reinforcing value Omax and demand elasticity were related to laboratory energy intake, but only reinforcing value Omax was related to usual energy intake, food liking or hunger. Demand elasticity was related to dietary restraint. These results show some aspects of the two measurement approaches were related and both were related to BMI. Differences were observed in relationship to laboratory or usual energy intake and restraint and hunger. The fact that the two measures of food reinforcement are related, and both types of measures were related to BMI suggest that laboratory and hypothetical approaches to measuring demand assess a similar construct, though they each may assess different aspects of food reinforcement.

The purpose of this study was to extend this research using a larger data set to investigate the relationships between the two measurement approaches across both low (LED) and high (HED) energy dense foods, whether reinforcing value and behavioral demand measures make independent contributions to the prediction of BMI, and how reinforcing value and hypothetical behavioral demand measures are related to BMI and to dietary restraint, disinhibition and hunger. Based on our previous work, we hypothesized that the two measurement approaches would be correlated, and both would independently predict BMI. However, we predict that the pattern of correlations with demographic, restraint, disinhibition and hunger would be different for the two approaches.

1. Method

1.1. Participants

The study used data from a study designed to examine the effects of taxes and subsidies on food purchasing in 217 participants (9 male/208 female). (Epstein, Dearing, Roba, & Finkelstein, 2010). The small sample of males was dropped from analysis, as the sample was too small to generalize results to men and women, or to make any gender comparisons. Data for four participants were not included based on medical problems that could interfere with task completion or food reinforcement measures (Crohn's disease, head trauma, gastric bypass), and data from 13 subjects were removed who violated trend criteria for inconsistent responding criteria in the hypothetical demand task (Stein, Koffarnus, Snider, Quisenberry, & Bickel, 2015). From the 191 participants who had valid reinforcing value and behavioral demand measures, four did not have BMI, two did not report minority status, one did not report their education level, and 23 did not report income.

1.2. Measures and derived predictor variables

1.2.1. Demographics—Information about age, race/ethnicity, income, and educational level were obtained using a standardized questionnaire (Adler, Epel, Castellazzo, & Ickovics, 2000).

1.2.2. Anthropomorphic measurement—Standardized protocols were used to assess both height and weight. Since posture, distance between feet spread apart, and orientation of the head can influence height measures, we requested people take off their shoes, stand against a wall, using markings on the floor to orient their feet, and look straight ahead. To ensure an accurate height, it was measured three times with a digital stadiometer

(Measurement Concepts & Quick Medical, North Bend, WA). The median height was used for data analysis. Weight was without shoes, assessed using a Tanita digital scale (Arlington Heights, IL) removing coats or sweaters and with pockets empty. Measurements were used to calculate BMI (kg/m2).

1.2.3. Behavioral demand purchasing task—Participants completed food purchase tasks for their preferred LED and HED snack foods chosen from a list of foods. LED foods have an energy density (ED) ED≤2.0 and included apples, bananas, mandarin oranges, low-fat strawberry yogurt, celery with dip, carrots with dip, applesauce, red seedless grapes, or pineapple chunks. HED foods have an ED≥4.0 and included nacho cheese Doritos®, milk chocolate M&M's®, Chips Ahoy! cookies, Reese's® peanut butter cups, Hershey's® chocolate, mini Oreos®, Original Pringles® Chips, or Little Debbie® zebra cakes. The energy density cutoff is based on extensive work on the influence of ED on intake (Rolls, 2005; Rolls, Drewnowski, & Ledikwe, 2005).

Participants were instructed to make hypothetical purchases of 30 g serving of their chosen food for a typical day with the restrictions of the same income, no access to any other snack food, and food could not be saved. Prices were varied over 19 increasing price points: $0(free), $0.01, $0.05, $0.13, $0.25, $0.50, $1, $2, $3, $4, $5, $6, $11, $35, $70, $140, $280, $560, and $1120. Both LED and HED foods were assessed since research has shown that the reinforcing value of food can differ based on macronutrient composition (Epstein et al., 2011; Lappalainen & Epstein, 1990). The purchasing task has good test-retest reliability (Murphy, MacKillop, Skidmore, & Pederson, 2009) and has been shown to be related to energy intake of food (Epstein, Dearing, & Roba, 2010).

1.2.4. Behavioral demand dependent measures—Participants choices in the purchasing task resulted in the following facets of behavioral demand, (1) intensity (Q0): purchases made when the food was free or of very minimal price ($0.01), (2) Omax: maximum expenditure (maximum purchases * price) (3) Pmax: price point where maximum expenditure was observed, (4) breakpoint: first price where 0 purchases are made, (5) demand elasticity (α): quantitative non-linear relationship (decaying slope) between raw purchasing data and price with the following equation (Koffarnus, Franck, Stein, & Bickel, 2015; Yu, Liu, Collins, Vincent, & Epstein, 2014) modified from the exponential demand equation introduced by Hursh and Silberberg (Hursh & Silberberg, 2008) to allow analysis of zero values in consumption.:

$$Q = Q_0 * 10^{\mathrm{k}\left(e^{-\alpha Q0\mathrm{P}} - 1\right)}$$

Here, Q is consumption, P is price, k is a constant of span of minimum to maximum consumption across all participant data in log10 units, and Q0 and α served as dependent measures of demand intensity and elasticity, respectively. Measures were natural log-transformed and standardized prior to analysis to normalize skewed distributions. Relative values of each of the demand parameters was calculated to compare with relative reinforcing value in the choice paradigm. As an example, the relative demand PMAX for HED food would be calculated by the formula: $PMAX_{HED}$ / ($PMAX_{HED}$+$PMAX_{LED}$). The purchasing task is reliable and valid for alcohol (Murphy et al., 2009) has been used to study demand for a wide variety of substances, including alcohol (MacKillop et al., 2016), tobacco (Bidwell, MacKillop, Murphy, Tidey, & Colby, 2012; O'Connor et al., 2016), and cannabis (Aston, Farris, MacKillop, & Metrik, 2017).

1.2.5. Reinforcing value task—

The reinforcing value of LED and HED foods were assessed using a computer program, where subjects earned a point by pressing a response button to meet reinforcement schedule requirements (Epstein et al., 2007; Epstein et al., 2011). Schedules determine the amount of a response that is needed to earn a portion of food reward. The schedules for LED and HED foods were progressive fixed ratio schedules with response requirements of 4, 8, 16, 32, 64, 128, …,2048 and so forth for each point. Participants needed to earn five points in each schedule work requirements to receive a 30 g portion of their preferred LED or HED snack food sampled from the LED or HED foods used for the hypothetical purchase task. Thus, completing a fixed ratio of 4 required making 20 responses. The task was setup on separate computer stations for LED and HED foods, so participants could freely move between stations to earn as many portions as they wanted. Participants were instructed to perform one activity at a time (i.e., play the computer game or eat), and the session would end when they no longer wished to earn points toward portions of either type of food. Food portions were brought to the participant after they were earned and could be eaten right away or later during the task; however, the food could not be eaten once the task ended. Water was provided ad libitum. The reinforcing value of food has good test-retest reliability (Epstein, Temple, et al., 2007), and is related to BMI (Epstein et al., 2012; Giesen et al., 2010; Saelens & Epstein, 1996).

1.2.6. Reinforcing value dependent measure—

The primary dependent measure was the RRV for LED or HED foods operationalized as breakpoint, or the maximal reinforcement schedule that the participant completed for LED and HED foods. The RRV was established by the formula: Breakpoint_{HED} / (Breakpoint_{HED}+Breakpoint_{LED}).

The dependent measures for the hypothetical purchase task and the reinforcing value task are presented in Table 1.

1.2.7. Three Factor Eating Questionnaire (TFEQ)—

The TFEQ is a validated instrument with subscales that assess dietary restraint, hunger, and disinhibition (Allison, Kalinsky, & Gorman, 1992; Laessle, Tuschl, Kotthaus, & Pirke, 1989). The TFEQ has excellent internal consistency, with Cronbach alpha values ranging between 0.78 and 0.94 on samples of almost 3000 adults of varying body weights (Cappelleri et al., 2009).

1.3. Analytic Plan

One hundred ninety-one participants had valid reinforcing value and behavioral demand data and met eligibility criteria. Since there was missing data for BMI, minority status, education and income, Little's test was run to assess whether the data were missing at random or not missing at random. Analysis showed that data was missing completely at random (MCAR) ($X2=72.95$, $df=165$, $p > 0.99$). When data are missing completely at random, ignoring missing data will not introduce bias, but may reduce power by a reduction in sample size (Dong & Peng, 2013). Following the guidelines set in Cheema (Cheema, 2014a, 2014b), listwise deletion is acceptable when the sample of complete data is representative of the target population, and the remaining sample has adequate power for tests of the hypothesis. The sample size is adequate to detect a medium effect size (r=0.300, power=0.987 alpha=0.05) and even ample power for smaller effects (r=0.205, power=0.801). Since imputation may wind up introducing addition error into the data (Cheema, 2014a, 2014b) when data are missing completely at random, we chose to use pairwise deletion, rather than listwise deletion, as pairwise deletion provides the largest dataset to test each of the correlations.

Pearson product-moment correlations were used to examine 1) the relationships among the reinforcing value and demand for LED and HED foods and 2) the relationships between measures of reinforcing value and demand and demographic variables of age, income, years of education, restraint, disinhibition and hunger (Allison et al., 1992; Laessle et al., 1989) and BMI. Statistical tests of differences between correlation coefficient effect sizes comparing RRV and behavioral demand measures were calculated using tests of dependent correlations (Bruning & Kintz, 1977). This was done because it is possible that the RRV or a behavioral demand measure was significantly related to an outcome, but it was not a significantly better predictor than a corresponding RRV or behavioral demand measure that was not a significant predictor. For example, RRV might be related to BMI while elasticity of demand was not related to BMI, but the correlation coefficients may not in fact be significantly different.

Regression models were used to examine whether measures of reinforcing value and demand both contribute to the prediction of BMI. Models included both reinforcing value and behavioral demand variables as independent predictors, as well as assessing whether the interaction of reinforcing value and demand variables was a significant predictor of BMI. Analyses were carried out in Systat 11 and SPSS19.

2. Results

Characteristics of the samples are shown in Table 2. Participants were the primary food purchasers for their family. For hypothetical food purchases on the behavioral demand task, 2.4% (5/208) of LED purchases were flagged as non-systematic with 2.9% (6/208) exceeding outlier cutoffs, and 1.9% (4/208) of HED purchases were flagged as non-systematic, with 2.4% (5/208) exceeding outlier cutoffs (Stein et al., 2015). Reinforcing value and behavioral demand data are shown in Table 3.

2.1. Relationships among demand and reinforcing value variables

Pmax, Omax, breakpoint and demand elasticity for LED and HED were all significantly related. Intensity was not related to Pmax for LED or HED foods (Table 4). When relative demand variables were considered, intensity was not related to Pmax. The other variables were significantly correlated.

When the relationships between reinforcing value and behavioral demand variables were considered (Table 5), demand intensity and elasticity were related to reinforcing value breakpoint for LED, HED and relative reinforcing value comparisons. Demand Omax was related to reinforcing value breakpoint for LED foods as well as relative value breakpoint.

2.2. Reinforcing value and demand relationships with demographic, BMI and psychological variables

Table 6 shows the relationships between reinforcing value and behavioral demand and a variety of demographic, BMI and psychological outcomes. The significant relationships and their p values are in bold. In addition, significant variables that are different between the reinforcing value and behavioral demand measures are in italics. For example, for HED foods, three behavioral demand measures are related to participant age, Omax, Pmax and breakpoint, and each of these are significantly different from the relationship between reinforcing value and age. On the other hand, behavioral demand breakpoint was related to dietary restraint, but the correlation was not significantly different from the correlation between restraint and reinforcing value).

A number of similarities were observed between reinforcing value and demand measures. Reinforcing value and both intensity and elasticity for HED foods were related to BMI, and reinforcing value and intensity for relative food demand were related to BMI. Reinforcing value and demand breakpoint for LED foods were related to minority status.

However, some differences were observed. For example, as noted above, most demand variables for LED foods were related to age, in contrast to reinforcing value breakpoint. The Omax, Pmax and breakpoint correlations were significantly different from the reinforcing value correlation. Minority status was strongly related to reinforcing value and also related to demand breakpoint, but the relationship between reinforcing value breakpoint was significantly different from demand intensity, Pmax and elasticity. Education was significantly related to demand Pmax, which was significantly different from reinforcing value breakpoint. Finally, for LED foods, demand elasticity was significantly related to hunger, which was significantly greater than reinforcing value breakpoint.

When examining relationships among HED foods, income was related to reinforcing value breakpoint, which was significantly different from demand Pmax and demand elasticity. BMI was significantly positively related to reinforcing value (p=0.011), and negatively related to demand elasticity. Almost all the demand measures for HED foods were related to hunger in contrast to reinforcing value, but none of these significant correlations were different from the reinforcing value correlation with hunger. When considering relative reinforcing value and relative demand, correlations between income and Pmax and breakpoint were significantly different from the correlation between income and reinforcing value. Relative reinforcing value and relative intensity of demand predicted BMI, but relative reinforcing value was a better predictor than demand measures Pmax, breakpoint and demand elasticity.

2.3. Predictors of BMI

Regression models to predict BMI showed that when considering HED foods, reinforcing value (r=0.19, p=0.011) and demand intensity (r=0.15, p=0.041) were independent predictors of BMI. When reinforcing value and demand intensity were put into the same model with their interaction term, intensity (p=0.022), reinforcing value (p=0.005) and the interaction of intensity x reinforcing value were significant (p=0.050). The complete model accounted for 6.5% of the variance in BMI (F(3,181)=4.19, p=0.007). The graph of the interaction (Fig. 1) shows that reinforcing value moderates the influence of demand intensity for HED foods on BMI. If demand intensity is high, BMI is high, independent of reinforcing value. But if demand intensity is low, then reinforcing value differentially influences BMI. High reinforcing value results in high BMI even if demand intensity is low. When demand intensity and reinforcing value were both low, BMI was low.

When relative reinforcing value and relative demand variables were considered, relative reinforcing value (r=0.24, p=0.001) and relative intensity (r=0.23 p=0.002) were independent predictors of BMI, accounting for 6.7% of the variance (F(2,180)=8.60, p < 0.001). No other independent or interactive effects were observed.

3. Discussion

The overarching purpose of the study was to assess whether reinforcing value as assessed by a behavioral task and behavioral demand as assessed by a hypothetical purchasing task are measuring the same aspects of food reinforcement. Based on previous research (Epstein, Dearing, & Roba, 2010) and the methodological and theoretical differences between the measures, we predicted that a moderate relationship would exist between the two types of measures. In addition, we predicted that the pattern of relationships with other variables would be different between the measures, and that both reinforcing value and behavioral demand for low and high energy foods predict BMI. Each hypothesis was supported by the results. A novel finding was that reinforcing value and behavioral demand were related to BMI only for high energy dense foods, or the relationship between low and high energy dense foods. The energy density of foods normally consumed is high rather than low in obese persons, and reduction in energy density of high energy dense foods can be an important tool in weight control (Ello-Martin, Roe, Ledikwe, Beach, & Rolls, 2007).

There are three differences we note between reinforcing value and behavioral economic demand measures. First, reinforcing value is based on actual responding for food, while behavioral demand is based on hypothetical purchasing of food. Research suggests correspondence between hypothetical and actual measures of demand (Amlung et al., 2012; Wilson et al., 2016). Responding and purchasing may be different processes, as money can be used to purchase different types of reinforcers, while reinforcing value is relevant only to obtain the specified reinforcer during the session. Determining how much money to spend on food may involve higher order decision making, as any money spent on food cannot be spent on alternative reinforcers.

Second, relative reinforcing value methodology focuses on a concurrent choice of one commodity versus another. We measured individual reinforcing value breakpoints for low and high energy dense foods, but the reinforcing value measures were determined in a concurrent choice context. Behavioral economic demand curves study each commodity separately. We constructed a relative value by relating demand parameters collected for choices of low and high energy dense foods. However, generating estimates of relative values when they are compared concurrently versus singly may be different. Research on concurrent choices of tobacco (Heckman et al., 2017; Murphy, Owens, Sweet, & MacKillop, 2016; Peters, Rosenberry, Schauer, O'Grady, & Johnson, 2017; Snider, Cummings, & Bickel, 2017) could be extended to food. For example, people could be asked how much money they would pay for option A (cheeseburger with fries) when the price of option A was varied, while the price of option B (grilled chicken with a side salad) stayed constant. The comparison of hypothetical purchases of two commodities, while the price of one is changing, can provide an index of how substitutable grilled chicken with side salad is for a cheeseburger with fries. Additionally, hypothetical demand curves could be created where the prices of both choices increase simultaneously to create behavioral demand in a choice paradigm for other reinforcers.

People make choices between eating versus non-eating activities, or between different types of food. Seldom are people forced to eat only one food. Consistent with the importance of choice, food is more reinforcing than alternative behaviors for obese youth, while alternatives to food are more reinforcing than food for leaner peers (Temple et al., 2008). It is relevant to study what behaviors are substitutes for food reinforcement (Goldfield & Epstein, 2002), or what behaviors can reduce food reinforcement when provided concurrently (Carr & Epstein, 2017).

Finally, only the reinforcing value task involves an active motoric response to obtain food, which may be important for multiple reasons related to the neurobiology of reinforcement. Dopamine is commonly thought of as one of the most important neurotransmitters responsible for responding for any type of reinforcer, including food (Wise, 2006; Wise & Bozarth, 1987). Salamone has developed a theory that focuses on how dopamine is related to effort (Salamone, 2009; Salamone, Correa, Farrar, Nunes, & Pardo, 2009; Salamone, Correa, Mingote, & Weber, 2005). Salamone relates dopamine and effort to elasticity of rewards, as both nucleus accumbens dopamine depletion and dopamine antagonists impact how hard animals will work for food. In a series of creative experiments, Salamone and colleagues (Salamone, 2009; Salamone et al., 2005; Salamone et al., 2009) provided animals free access to chow or access to palatable food that animals had to work for. Animals normally chose to work for the more palatable food, but when dopamine levels were reduced, they switched to the lower effort chow. The same pattern can be observed in a T-maze that provided free access to chow versus access to palatable food that required getting over a barrier.

Consistent with the importance of effort in determining food reinforcement, single cell recordings from rodents show activation of the nucleus accumbens is more strongly activated when cocaine reinforcers are delivered based on responding than if they are delivered independent of responding (Carelli, 2002). Similarly, with humans, activation of the ventral striatum is strongest when reinforcers are presented contingent upon button presses than independent of button presses (Knutson, Fong, Adams, Varner, & Hommer, 2001; O'Doherty et al., 2004; Pagnoni, Zink, Montague, & Berns, 2002).

The absence of making an effortful response may be a major difference between the two approaches to measuring food reinforcement. The absence of an effortful response in the purchasing task is not just a function of hypothetical versus actual purchasing, as even in an actual purchasing task, a participant would not necessarily need to make effortful responses to obtain food. An important implication may be that to assess motivational processes that involve effort to obtain food, it may be necessary to arrange for the participant to engage in a response to gain access to a reinforcer. A questionnaire indicating how important a commodity is, or how much it is liked, may have less activation of motivational processes related to effort and more activation of decision making processes.

The present study is not without limitations. One issue is that the data for a small number of men were excluded, limiting the analysis to women, so that results may not generalize to men. Previous research has shown sex differences in food reinforcement (Epstein et al., 2004), so that replication with men may provide a different picture. Given that only a limited set of outcome variables were studied, how the two measures are related to common or unique outcomes is unclear. If both measures tapped into the same constructs, then parsimony would be supported by both theory and empirical observations. Nonetheless, we hope that identifying reinforcing value and hypothetical behavioral demand as separate measures of food reinforcement can lead to new and innovative approaches to obesity treatment and prevention. The pattern of results suggests that while there is a moderate relationship between reinforcing value and hypothetical behavioral demand, reinforcing value measures something different than behavioral demand. Finally, while the present study focused on food reinforcement, whether the same differentiation applies to other consumable reinforcers would be interesting to discern. Hypothetical behavioral demand has shown similarities in the factor structure of the constructs across reinforcers (Bidwell et al., 2012; MacKillop et al., 2009). Comparison research is needed to assess if reinforcing value provides an independent predictor for other reinforcers, such as alcohol or smoking.

The observation that the reinforcing value and behavioral demand approaches to reinforcement are different, but both predict BMI, should be considered an opportunity that may provide new ideas to understanding how reinforcement processes are related to BMI. Perhaps reinforcing value and behavioral demand should be considered two relatively orthogonal processes, so that people could be low or high in reinforcing value and low or high in demand for high energy dense foods. The interaction observed showed that a high intensity of demand is associated with high BMI, but the relationship between low intensity of demand and BMI depends on reinforcing value. BMI was higher for those low in demand if their reinforcing value was high than if their reinforcing value was low.

We present two approaches to food reinforcement that could be used in treatment or prevention of obesity that may differ based on which is the stronger predictor of BMI or BMI change. If reinforcing value is the stronger predictor, than one approach may be to provide an enriched array of alternative reinforcers to food that can compete with food reinforcement (Carr & Epstein, 2017; Goldfield & Epstein, 2002). Providing reinforcing alternatives to food would reduce the desire to consume the food. Attempts to reduce access to food, either by environmental control or by increasing pricing, could increase the probability of people making the choice of not eating that food. The idea of shifting choices is based on identifying substitutes to reinforcers so that people will choose the substitute rather than the reinforcer that is targeted for reduction.

An approach to modify demand is episodic future thinking, which teaches people to think about the future as they are making decisions about current reinforcers. Episodic future thinking was developed to modify delay discounting (Daniel, Said, Stanton, & Epstein, 2015; Daniel, Stanton, & Epstein, 2013a, 2013b), but it has recently been shown to also modify demand as assessed by the hypothetical purchase task (Sze, Stein, Bickel, Paluch, & Epstein, 2017). The cognitively oriented episodic future thinking intervention activates the prefrontal cortex and it is consistent with the decision making aspects of neurocognitive models of choice (Bickel, Jarmolowicz, Mueller, & Gatchalian, 2011; Bickel, Moody, Quisenberry, Ramey, & Sheffer, 2014).

In conclusion, the results suggest that reinforcing value and behavioral demand assess related, but different aspects of food reinforcement. The differences between the two types of measures may be due, in part, to methodological differences that arise due to direct measures of behavior instead of subjective reports of how someone would purchase food. The two types of measures may also differ due to different conceptual approaches to reinforcement. The present paper only tested one important prediction of food reinforcement, how they are related to body mass. It is also important to test whether the two approaches differ in prediction of who would become obese, or predictions of who will lose more weight in behavioral treatment programs. Modifying reinforcement processes is not a common element of most obesity treatment programs, so incorporating ideas about how food reinforcement is related to obesity may provide novel approaches to the prevention or treatment of obesity.

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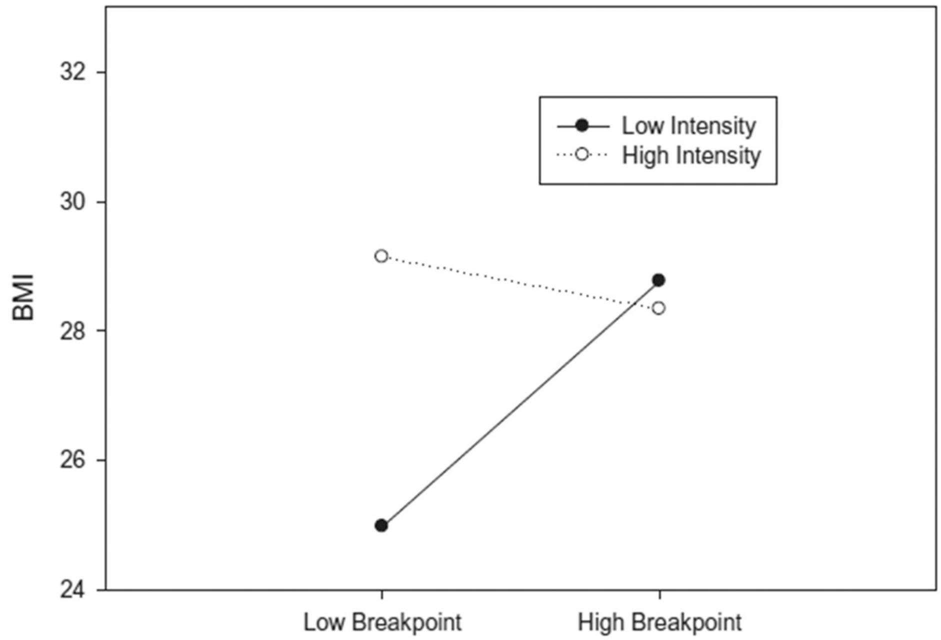

Figure. 1.

Interaction of reinforcing value breakpoint and demand intensity for high energy dense foods predicting BMI. Individuals with high intensity have higher BMI irrespective of breakpoint, but individuals with low intensity only have higher BMI if they have higher breakpoint.

Table 1.

Measures of demand for food and reinforcing value

Measure	Definition
Demand for food	
Intensity	Number of purchases made when food was free or minimal price (e.g. $0.01)
P_{max}	Price point for maximal expenditure
O_{max}	Maximal expenditure (maximum purchases * price)
Breakpoint	First price where no purchases were made
Demand Elasticity	Quantitative non-linear relationship (decaying slope) between purchasing and price
Relative Demand	$Demand_{HED}$ / ($Demand_{HED}$ + $Demand_{LED}$)
Reinforcing value of food	
Breakpoint	Final reinforcement schedule completed
Relative Reinforcing value	$Breakpoint_{HED}$ / ($Breakpoint_{HED}$ + $Breakpoint_{LED}$)

Table 2.

Participant Characteristics

Characteristic	
Sex (male/female)	0/185
Ethnic/Racial status (n)	
Non-Hispanic White	147
Hispanic	2
African American	25
Native American	1
Asian	8
Other	2
Age (years)	42.64 ± 7.22
Height (cm)	164.22 ± 6.48
Weight (kg)	74.15 ± 20.15
Body Mass Index (BMI)	27.47 ± 7.12
Income (US$)	63,319 ± 29,975
Years of education	16.07 ± 2.97
Three factor eating questionnaire	
Dietary restraint	9.51 ± 5.00
Disinhibition	5.71 ± 3.75
Hunger	4.72 ± 3.33

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Table 3.

Reinforcing value and hypothetical behavioral demand values (mean ± standard deviation) of high and low energy dense snack foods.

	HED	LED	RRV
Measure			
Reinforcing value			
Breakpoint	29.92 ± 81.75	53.54 ± 75.99	−1.39+1.45
Demand			RD
Intensity (Q_0)	2.63 ± 2.51	3.52 ± 2.26	0.41 ± 0.15
O_{max}	1.72 ± 2.10	2.57 ± 2.80	0.41 ± 0.18
P_{max}	1.30 ± 1.34	1.62 ± 1.54	0.45 ± 0.18
Breakpoint	2.39 ± 2.97	3.29 ± 5.03	0.45 ± 0.16
Elasticity	0.17 ± 0.24	0.10 ± 0.09	0.59 ± 0.18

Note- HED and LED = high and low energy dense foods; RRV = Relative reinforcing value, RD = relative demand, Relative=HED/HED + LED.

Table 4.

Relationships among measures of behavioral demand for low and high energy dense snack foods

	Intensity		O_{max}		P_{max}		Breakpoint	
	r	***p***	***r***	***p***	***r***	***p***	***r***	***p***
LED								
O_{max}	0.40	< 0.001						
P_{max}	0.09	0.20	0.80	< 0.001				
Breakpoint	0.22	0.003	0.85	< 0.001	0.90	< 0.001		
Elasticity	−0.48	< 0.001	−0.89	< 0.001	0.66	< 0.001	−0.74	< 0.001
HED								
O_{max}	0.42	< 0.001						
P_{max}	0.09	0.20	0.82	< 0.001				
Breakpoint	0.21	0.005	0.91	< 0.001	0.93	< 0.001		
Elasticity	−0.52	< 0.001	−0.96	< 0.001	−0.75	< 0.001	−0.85	< 0.001
Relative Demand								
O_{max}	0.43	< 0.001						
P_{max}	0.10	0.18	0.70	< 0.001				
Breakpoint	0.20	0.007	0.81	< 0.001	0.82	< 0.001		
Elasticity	−0.45	< 0.001	−0.67	< 0.001	−0.42	< 0.001	−0.55	< 0.001

Note - LED and HED=low and high energy dense snack foods, Analyses represent Pearson product-moment correlation coefficients and p values.

Table 5.

Relationships between reinforcing value and behavioral demand for low and high energy dense snack foods

Measures of Behavioral Demand	Intensity		O_{max}		P_{max}		Breakpoint		Elasticity	
	r	***p***	***r***	***p***	***r***	***p***	***r***	***p***	***r***	***p***
Reinforcing Value										
LED										
Breakpoint	0.20	0.006	0.18	0.015	0.07	0.353	0.12	0.112	−0.22	0.003
HED										
Breakpoint	0.30	< 0.001	0.13	0.081	0.08	0.253	0.12	0.094	0.14	0.018
Relative Value										
Breakpoint	0.23	0.001	0.15	0.046	0.10	0.174	0.14	0.059	−0.17	0.024

Table 6.

Relationship between reinforcing value, behavioral demand and demographic, BMI and restraint, disinhibition and hunger for low and high energy dense snack foods.

	RV		Behavioral Demand									
	Bkpnt		Intensity		Omax		Pmax		Bkpnt		Elasticity	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
LED												
Age	0.04	0.601	−0.10	0.184	−0.20	**0.007** *0.009*	−0.19	**0.010** *0.014*	−0.21	**0.004** *0.006*	**0.17**	**0.020**
Minority	**0.27**	**<0.001**	0.00	0.988 *0.002*	0.12	0.114	0.08	0.265 *0.014*	**0.15**	**0.036**	−0.05	0.460 *< 0.001*
Income	−0.04	0.651	−0.10	0.204	0.02	0.814	−0.03	0.700	−0.06	0.415	−0.03	0.728
Education	0.04	0.620	−0.01	0.842	−0.12	0.104	−0.14	0.062	**−0.15**	**0.043** *0.046*	0.09	0.233
BMI	−0.06	0.390	−0.10	0.174	0.02	0.915	0.04	0.622	0.03	0.643	0.00	0.999
Restraint	−0.11	0.130	−0.10	0.186	−0.12	0.097	−0.13	0.079	**−0.16**	**0.034**	0.13	0.078
Disinhibition	−0.02	0.775	0.10	0.157	0.09	0.227	0.05	0.525	−0.01	0.939	−0.13	0.067
Hunger	0.02	0.769	0.11	0.137	**0.16**	**0.029**	0.13	0.073	−0.13	0.076	**−0.18**	**0.012** *0.031*
HED												
Age	0.03	0.690	−0.07	0.330	−0.17	0.023	−0.09	0.231	−0.10	0.185	0.13	0.067
Minority	0.14	0.063	**0.17**	**0.022**	0.08	0.264	0.04	0.613	0.01	0.182	−0.06	0.432
Income	**−0.17**	**0.030**	**−0.21**	**0.007**	−0.03	0.729	0.03	0.728 *0.048*	0.01	0.904	0.03	0.739 *0.046*
Education	−0.11	0.154	−0.01	0.882	−0.10	0.193	−0.14	0.055	−0.13	0.088	0.09	0.202 *0.034*
BMI	**0.19**	**0.011**	**0.15**	**0.041**	0.10	0.169	0.03	0.640	0.05	0.513	**−0.14**	**0.050**
Restraint	−0.13	0.089	**−0.25**	**0.001**	−0.15	0.041	−0.08	0.272	−0.10	0.198	0.15	0.036
Disinhibition	0.14	0.064	**0.19**	**0.009**	0.15	0.039	0.11	0.142	0.11	0.120	0.22	0.003
Hunger	0.13	0.075	**0.26**	**< 0.001**	0.20	0.005	0.12	0.096	−0.14	0.051	0.27	< 0.001
Relative												
Age	0.07	0.335	0.02	0.748	0.03	0.653	0.09	0.234	0.10	0.186	0.01	0.949
Minority	−0.01	0.904	0.09	0.243	−0.07	0.373	**−0.17**	**0.018**	**−0.16**	**0.026**	−0.03	0.663

	RV		Behavioral Demand									
	Bkpnt		**Intensity**		**Omax**		**Pmax**		**Bkpnt**		**Elasticity**	
	r	***p***	***r***	***p***	***r***	***p***	***r***	***p***	***r***	***p***	***r***	***p***
Income	**−0.16**	**0.042**	−0.09	0.257	−0.05	0.495	0.05	0.513 *0.037*	0.06	0.428 *0.028*	0.10	0.930
Education	−0.14	0.059	0.02	0.748	−0.01	0.888	−0.01	0.886	0.00	0.952	−0.03	0.653
BMI	**0.24**	**0.001**	**0.23**	**0.002**	0.11	0.132	0.02	0.768 *0.017*	0.02	0.765 *0.017*	−0.10	0.194 *< 0.001*
Restraint	−0.13	0.089	**−0.16**	**0.027**	−0.02	0.821	0.03	0.727	0.05	0.500	0.02	0.799
Disinhibition	**0.16**	**0.029**	0.14	0.062	0.09	0.215	0.09	0.201	0.14	0.063	−0.02	0.813
Hunger	0.13	0.072	**0.19**	**0.011**	0.06	0.382	0.00	0.956	0.01	0.860	−0.04	0.569

Note - LED and HED=low and high energy dense snack foods, RV refers to reinforcing value, Bkpnt refers to breakpoint, Relative=HED / HED+LED. r and p values that are bolded are significantly related to reinforcing value or demand task values. Italicized p values denote the probability that the dependent correlation coefficients for reinforcing value or behavioral demand measures were different from alternative measure of food reinforcement.