Published in final edited form as:

Learn Motiv. 2011 May 1; 42(2): 165–172. doi:10.1016/j.lmot.2011.01.003.

Relationship between food habituation and reinforcing efficacy of food

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Abstract

Reinforcing value and habituation are two processes that have been used to study eating behaviors, but no research has examined their relationship, how they relate to energy intake, and whether they respond in a similar manner to food deprivation. Twenty-two female subjects were randomized to food deprived or non-deprived conditions, and assessed for food reinforcement, habituation to food and ad libitum eating. Results showed food reinforcement and habituation are correlated ($r = 0.62$, $p = 0.002$) and both independently predict energy intake. Hierarchical regression showed that the rate of habituation accounted for 30 percent of the variance in eating ($p = 0.008$), and adding food reinforcement increased the amount of variance accounted for up to 57.5 percent ($p < 0.05$). This suggests that both processes may influence energy intake in a meal.

Keywords

food reinforcement; habituation; ingestive behavior; deprivation

1. Introduction

Food reinforcement (Epstein, Leddy, Temple, & Faith, 2007) and habituation to food (Epstein, Temple, Roemmich, & Bouton, 2009) are constructs that have been related to energy intake and obesity. People high in food reinforcement consume more food (Epstein, Temple et al., 2007; Epstein et al., 2004), and are more likely to be obese (Epstein, Temple et al., 2007; Giesen, Havermans, Douven, Tekelenburg, & Jansen, 2010; Saelens & Epstein, 1996), and high food reinforcement predicts weight gain (Hill, Saxton, Webber, Blundell, & Wardle, 2009). Similarly, slow rates of habituation are related to greater energy intake (Epstein et al., 2008; Epstein, Robinson et al., 2009), obese persons have slower rates of habituation (Epstein, Paluch, & Coleman, 1996; Temple, Giacomelli, Roemmich, & Epstein, 2007) and slow rates of habituation are related to weight gain (Epstein, Robinson, Roemmich, & Marusewski, 2010). Theoretically, food reinforcement and habituation represent different processes that influence eating.

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The reinforcing value of food is related to the effectiveness of a reinforcer to initiate or maintain responding. This is a measure of how hard one will work for food on progressive ratio schedules of reinforcement (Epstein, Leidy et al., 2007). Relative reinforcing value is measured in a choice situation, in which subjects can choose to allocate time and effort among different reinforcers (Epstein, Leidy et al., 2007), which closely resembles a natural situation. Levels of reinforcing value correlate positively to energy intake and may be related to greater stimulation to initiate eating or increased food presentations to stimulate satiation to terminate a meal or eating bout.

Habituation is a general process in which responses to a repeatedly presented stimulus decrease over time, indicating that repeated presentations of food decrease physiological and behavioral responding for that food (Epstein, Temple et al., 2009). Research suggests that habituation is influenced by stimulus specificity, such that small differences in texture, color or shape may be sufficient to recover responding to a new food (Epstein, Robinson, Roemmich, Marusewski, & Roba, 2010) and to a previously habituated food (dishabituation; Groves & Thompson, 1970; McSweeney & Swindell, 1999). Habituation is thought to relate to the cessation of a meal or satiety, though there may be processes that increase responding for food, or sensitize, before habituation begins (Epstein et al., 2008; Epstein, Temple et al., 2009). McSweeney and colleagues provide strong support for the hypothesis that changes in operant responding for a reinforcer within a session can be attributed to habituation (McSweeney, Hinson, & Cannon, 1996; McSweeney, Murphy, & Kowal, 2005; McSweeney & Swindell, 1999).

While both food reinforcement and habituation to food are related to energy intake, obesity, the risk for weight gain, and may be theoretically linked (McSweeney et al., 1996; McSweeney et al., 2005; McSweeney & Swindell, 1999), there is no research on the relationship between food reinforcement and habituation including their independent or interactive influences on energy intake. One methodological approach to assess whether two processes are functionally related is to manipulate a factor known to influence one process and assess whether it has the same influence on both processes. If so, this supports the idea that they are functionally related, but if not, this would suggest that the two processes are regulated by different sets of variables. A reliable variable that influences food reinforcement is food deprivation (Epstein, Truesdale, Wojcik, Paluch, & Raynor, 2003; Raynor & Epstein, 2003), but to our knowledge there is no research on food deprivation and habituation in humans. The present study examined the relationship between habituation to food and reinforcing value of food under deprived or non-deprived (fed) conditions. Deprivation may not only increase the reinforcing value of food (Epstein et al., 2003; Raynor & Epstein, 2003), but also may slow down the rate of habituation as it may limit the ability of reinforcers to decrease responding. Subjects also participated in an ad libitum eating task to examine the relationship between the relative reinforcing value of food and habituation to food and energy intake.

2. Methods and Measures

2.1 Participants

Participants were 22 non-obese (BMI<30) females (18–50 years of age) recruited from posted flyers and web-based advertisements. Exclusionary criteria included: medications that may affect appetite or ability to taste/smell (e.g. methylphenidate, insulin, etc), previous/current diagnosis of a psychiatric or eating disorder, recent substance abuse, weight instability (a fluctuation of >10lbs over a 6 month period), allergies to study foods, and unfamiliarity for the study foods. Participants also were required to regularly eat breakfast, which was defined as a meal eaten within 2 hours of waking, at least 5 days per week and consisting of at least 200 calories. Females were studied since there are observed differences

in the reinforcing value of food between males and females (Epstein et al., 2004), and the reduction of individual variance that might be attributable to sex maximizes power to test study hypotheses.

2.2. Procedures

Participants were recruited through campus flyers and screened via telephone to ensure they met eligibility requirements. Eligible participants were scheduled for three appointments at least one week apart between the hours of 7:30AM–10:00AM and were randomized to groups (non-deprived/deprived). The order of food reinforcement and habituation tasks was counterbalanced (habituation/reinforcing value, reinforcing value/habituation), and an ad libitum eating session to measure energy intake in a non-task situation occurred on the third session. All participants were asked to abstain from eating and drinking for at least eight hours prior to their scheduled appointment, and deprivation status was manipulated by preloading the non-deprived group (240 calorie Clif Bar[®]; chocolate brownie (Fat 6g, CHO 42g, protein 9g) or banana nut bread (Fat 5g, CHO 44g, protein 10g), (ED = kcal/gram) = 3.5). Participants rated their favorite flavor Timbits[®] at the time of the phone screen and were assigned the highest rated flavor to be presented as the reinforcer during each task; old fashioned glazed (ED=kcal/grams) = 4.94, 80kcal/donut hole), cherry (ED=3.2, 60kcal/donut hole) or chocolate glazed (ED=3.7, 70kcal/donut hole) (see Table 1 for nutritional information). Timbits[®] are donut holes that are a popular breakfast item from Tim Horton's[®] restaurants. Participants were served all three donut hole flavors in the ad libitum eating session in addition to several other foods. All study procedures were approved by the Social and Behavioral Sciences Institutional Review board of the State University of New York at Buffalo.

In the initial visit, participants read and signed consent forms and completed demographics and a questionnaire assessing normal breakfast eating to ensure continued eligibility for the study. Each session included a multi-pass 24 hour dietary recall to ensure protocol compliance (see measures section) and end anchored hunger/fullness and food liking Likert scales. Participants were either asked to consume the preload or read a newspaper for approximately six minutes. After completing a second set of hunger/fullness and food preference scales, the participants were given verbal task instructions by the experimenter. There was an approximate 10–15 min delay between the consumption of the preload and the onset of the session task (habituation, reinforcing value, ad libitum eating). Participants earned 100 calorie portions of their preferred donut flavor in each computer task. The ad libitum eating session consisted of several different kinds of breakfast foods of both low and high energy density. Water was provided ad libitum in all sessions. At the end of session 2, participants completed eating behavior questionnaires. At the end of session 3, participants filled out a payment receipt, received a total of \$45 in Target gift cards and height and weight were measured.

2.3. Laboratory Environment

The laboratory environment consisted of a closed circuit television monitoring system and intercom with which to observe and communicate with participants. The laboratory rooms are connected to a closed duct system which circulates air ten times per hour, and a High Efficiency Particle Arresting (HEPA) filter (Honeywell International Inc, Morristown, NJ) that contains a Carbon Potassium Permanganate and Zeolite (CPZ) filter which removes air borne odorant from the laboratory rooms. A computer program, The Behavioral Choice Task, was used to administer both the food reinforcement and habituation tasks. This is a program in which reinforcement schedules can be programmed in a variety of configurations and responding can be presented in one of two ways; as a slot-machine type game (see the food reinforcement task) or as two flashing squares (see the habituation task).

2.4. Measures

2.4.1. Dietary recalls—Dietary recalls were assessed using a 24 hour multi-pass method which includes four separate passes to ensure maximum food information is remembered. All passes are guided by the experimenter in an interview-like format and include a quick listing of all the foods eaten in the time period, a verbal review of the quick list and probing of large time gaps by the experimenter, detailed questions about the brand, flavor, and amounts of the foods listed and a verbal review of the detailed list by the experimenter. Participants were asked about food consumption over the previous 24 hours to ensure they were at least eight hours post-prandial and they had not consumed the study foods.

2.4.2 Food reinforcement task—The food reinforcement task measured the relative reinforcing value of the presented food and the reinforcing value of an alternate sedentary activity (reading a newspaper). The experimental room consisted of four stations, two computer stations at which the participant could earn reinforcers, one food station for consumption of the food portions and one station, the activity station, at which a newspaper was always present. Participants were allowed to freely switch between the two computer stations and the food station, but had to earn points for reading time to move to the activity station. The reinforcement task is presented on a computer screen and consists of a slot machine like game, in which subject responses (mouse button presses) cause the shapes to rotate and change. Three matching shapes earned the participant one point. Participants were required to earn 5 points per schedule to receive a 100 kcal portion of Timbits® or 2 min of reading time. Participants were instructed not to attempt to earn or consume both reinforcers at the same time. The schedules for both reinforcers were progressive fixed ratio (PR) schedules, in which the first schedule required four responses to earn one point, the second schedule required eight responses per point, the third required 16, etc; the response requirements doubled each time a schedule was completed, up to a fixed ratio of 2048 responses per point. Each reinforcer was available on a separate and independent PR schedule. Subjects were allowed to switch between computer tasks at any time and were not penalized for switching. Participants were not required to immediately consume either reinforcer, and when and how much was consumed was left to the participant's discretion. Participants verbally informed the experimenter over an intercom when they were using their earned reading time, and the experimenter informed the participants when their time was depleted. Responding was measured over 10-s intervals, and responding, time spent responding and rate were calculated for each schedule during which the participant responded for the reinforcer.

Reinforcing value for each reinforcer was established by calculating the PMAX or breakpoint, which is the highest fixed ratio schedule at which the participant earned a reinforcer. PMAX_{food} and PMAX_{reading} refer to the responding breakpoint for food and reading time reinforcers, respectively. Because the distribution of PMAX values was skewed, and the variability was larger than the mean, variables were log transformed prior to analysis.

2.4.3. Habituation task—The habituation task measured responding for food on a variable interval (VI) schedule. The task, presented on a computer screen, consisted of two squares, a red square that flashed when participants made a response (mouse button presses) and a green one that denoted a point had been earned. Participants were provided a 100 kcal portion of Timbits® after earning each point. The task was presented for 28 min and was programmed so that the reinforcer was available after intervals of 120 ± 36 s. An average of 14 food portions could be earned if responding was maintained for the entire task. An alternate sedentary activity (reading a daily newspaper), was available at a separate table and was not associated with any schedule of reinforcement. Food was served after each point

was earned, and the participant was able to both eat and continue to earn points at the same time. Participants were allowed to switch activities whenever they no longer wanted to earn points for food, and were not penalized if they chose to do so. Responding was assessed in 14 2-min time blocks. Trials (time blocks) to habituation was used as the measure of habituation and was calculated as the last 2-min interval before a participant stopped responding.

2.4.5. Ad libitum eating session—The ad libitum eating session was used to measure energy intake. The session lasted for a minimum of 20 min and participants were provided alternate activities including reading material (daily newspaper). Participants were served large portions of each type of food and were told there was more available. They were allowed to eat as much or as little as they chose and could stay longer than the minimum 20 min if they would like to continue eating. Foods were chosen to include high energy dense foods and a variety of low energy dense foods that may be eaten for breakfast and served in large portions. All foods were served in individual dishes. The foods served in the ad libitum task are presented in Table 1. The foods that were served included the three flavors of Timbits used in the food reinforcement and habituation tasks.

2.4.6. Demographics—Demographics were measured using a standardized questionnaire and assessed education, income, race and ethnic status.

2.4.7. Anthropometrics—Participant's height and weight were measured without shoes using a Digi-kit™ stadiometer (North Bend, WA), calibrated daily, and a Tanita™ BWB-800P digital weight scale (Arlington Heights, IL). These data were then used to calculate a body mass index ($BMI = kg/m^2$) score for each participant.

2.4.8. Eating questionnaires—Several eating questionnaires were administered at the end of session 2 and included the Three Factor Eating Questionnaire (TFEQ), the Binge Eating scale (BES) and the Questionnaire on Eating and weight patterns (QEWP). Scores from the BES and QEWP were used for screening to assess potential eating disorders. No participants met exclusionary criteria.

2.4.9. Food liking, hunger and fullness—Food liking and hunger/fullness were assessed using end anchored 10-point Likert scales at three separate times in each session; immediately before the preload/waiting period, immediately after the preload/before task and after the task. Participants were asked 'how hungry are you right now' and the scale was anchored by extremely hungry (1) and extremely full (10). Participants were also asked how much they liked the study food, and the scale was anchored by do not like at all (1) and like very much (10).

2.5.1. Analytic Plan

Differences in participant characteristics by group (non-deprived versus deprived) were analyzed using one-way analysis of variance for continuous variables with group (deprived vs. non-deprived) as the between subject factors, and Chi square analysis was used for categorical variables. Mixed analyses of variance, with group (deprived vs. non-deprived) and session order (Habituation/reinforcement, reinforcement/habituation) as the between subject variables and time (before preload, after preload/before task, after task) as the within subject variables, were used to determine differences in food liking and hunger/fullness ratings for the reinforcement, habituation and ad-libitum eating tasks. Mixed analyses of variance with group (non-deprived versus deprived) and session order (Habituation/reinforcement, reinforcement/habituation) as the between subjects variables were used to assess differences in caloric consumption across tasks and differences in trials to

habituation, $PMAX_{food}$ and $PMAX_{reading}$. $PMAX_{food}$ and $PMAX_{reading}$, or breakpoint, is determined by the highest fixed ratio schedule a participant completed to earn a food or reading time reinforcer respectively.

Pearson correlation coefficients were used to examine the relationship between measurements of habituation, reinforcing value and energy intake. Hierarchical regression was used to assess whether adding food reinforcement to rates of habituation increased the prediction of energy intake by including rates of habituation in the first step and reinforcing value of food in step 2.

3. Results

3.1 Participant characteristics

The average participant was 25.4 ± 1.8 (Standard error of the mean, SEM) years of age with a BMI of 23.4 ± 0.6 SEM. The sample consisted of 23% ($n=5$) minority subjects with all participants completing high school and 36% ($n=8$) completing a post high school education. There were no differences in demographics by group (see Table 2).

3.2 Relationships between reinforcement, habituation and energy intake

Pearson product moment correlations (Figure 1) showed a significant relationship between trials to habituation and $PMAX_{food}$ ($r = 0.62$, $p = 0.002$), but not $PMAX_{reading}$ ($r = -0.06$, $p > 0.05$). Correlational analysis showed both trials to habituation ($r = 0.55$, $p = 0.008$) and $PMAX_{food}$ ($R = .74$, $p = 0.0001$) were related to ad libitum energy intake, as those slow to habituate or who found food more reinforcing consumed more calories, but $PMAX_{reading}$ was not significantly correlated with ad lib energy intake ($r = -0.03$, $p > 0.05$). Figure 2 illustrates the relationship between $PMAX_{food}$, $PMAX_{reading}$, trials to habituation and energy intake, with energy intake estimated for ± 1 SD values for the predictors. The hierarchical regression showed that trials to habituation accounted for 30 percent of the variance in energy intake ($p = 0.008$) in step 1, and that adding the reinforcing value of food increased the variance accounted for to 57.5 percent ($p = 0.003$), an increase of 27.5 in percent variance accounted for ($F_{inc} = 5.80$, $p < 0.05$).

3.3 Effects of deprivation on hunger, reinforcement, habituation and energy intake

Results show that hunger was successfully manipulated by the preload during the habituation ($F(1,18) = 60.57$, $p < 0.0001$), reinforcement ($F(1,18) = 50.48$, $p < 0.0001$), and ad libitum ($F(1,18) = 21.21$, $p = 0.0002$) sessions. In each case, hunger decreased after the preload in comparison to the no preload condition. There was no interaction of group by order of conditions in any analyses. There were no differences in liking for the experimental foods after preload in any session.

$PMAX_{food}$ was increased by food deprivation ($F(1,18) = 19.33$, $p = 0.0003$), but $PMAX_{reading}$ ($F(1,18) = 1.74$, $p > 0.05$) and trials to habituation ($F(1,18) = 1.10$, $p > 0.05$) were not. Energy intake was greater for those who experienced food deprivation for the reinforcement task ($F(1,18) = 15.22$, $p = 0.001$), but not for the habituation task ($F(1,18) = 3.59$, $p > 0.05$). Energy intake was also increased after food deprivation in the ad libitum eating task ($F(1,18) = 4.68$, $p = 0.04$). Order did not interact with group to influence energy intake in analyses.

4. Discussion

The results indicate that habituation to food and reinforcing value of food are related, such that those who habituate slowly find food more reinforcing. In addition, reinforcing value of

food adds to the prediction of energy intake in a laboratory setting beyond habituation to food, suggesting that both processes lead to a more complete understanding of factors that influence energy intake.

McSweeney and colleagues have integrated habituation theory and reinforcement theory together in their theoretical argument that the within sessions reductions in motivated responding for food (McSweeney et al., 1996; McSweeney & Swindell, 1999) or drugs (McSweeney et al., 2005) reliably observed in operant and self-administration paradigms is due to habituation. These studies are characterized by demonstrations that the changes observed in responding for reinforcers are consistent with habituation theory (McSweeney et al., 1996; McSweeney & Swindell, 1999), but none of these studies took the step of directly observing the relationships between patterns of responding in both paradigms for the same reinforcer. However, a recent paper on habituation did test whether the reductions in eating are consistent with changes in reinforcing value of food. Morewedge, Eun Huh, and Vosgerau (2010) asked people to imagine eating a food 3 or 30 times, with the prediction that imagining eating the food repeatedly would lead to habituation, and a reduction in eating, just as actually tasting the food multiple times would lead to habituation and a reduction in eating (Epstein, Temple et al., 2009). The investigators showed stimulus specificity for the reduced eating, consistent with habituation theory (Epstein, Temple et al., 2009), and they also showed that the habituation related reductions in eating were due to a decrease in reinforcing value of food (Morewedge et al., 2010). This clearly ties the processes together, just as we have done in the present study, though using a different methodological approach.

The idea that habituation may be an explanation for the within session pattern decline in responding is consistent with previous ideas (McSweeney et al., 1996; McSweeney & Swindell, 1999), but habituation only shares some variance with food reinforcement. The usual pattern of responding for food involves an increase in responding prior to the reduction, and this increase may represent the incentive salience or 'wanting' component of responding (Robinson & Berridge, 2000). Habituation does provide for the initial increase in responding, or sensitization, prior to the decelerating limb of the habituation curve. Because we have observed that subjects who sensitize habituate slower and consume more food than those who do not sensitize (Epstein, Robinson, Roemmich, Marusewski et al., 2010; Epstein et al., 2008), it is possible that procedures that enhance sensitization may explain more variance in energy intake than procedures that do not enhance sensitization.

Habituation may account for the decelerating limb of the reinforcement curve after responding for a reinforcer has been initiated, the additional variance explained by reinforcing value may be due to factors that influence the initiation of responding. One important construct that may motivate people to respond for food is food craving, which is an important component of the incentive salience model for drug addiction (Robinson & Berridge, 1993; Robinson & Berridge, 2000), and which may be generalized to food (Kelley & Berridge, 2002). Cravings arise from the reliable pairings of stimuli with palatable food, so that after associational learning the cues can elicit responding for food, with the possibility that the reactivity to food cues leads to overeating (Jansen et al., 2003; Nederkoorn & Jansen, 2002). The reinforcing value of food may be different for different types of foods, with sugar being a major component associated with food reward (Avena, Rada, & Hoebel, 2008).

There is shared variance and procedural overlap in the measures of relative reinforcing value and habituation used in this study. Both tasks involve responding for food, and while the specifics of the task are different, there are similarities between the tasks. However, both

tasks were differentially affected by the deprivation manipulation, and the tasks made independent contributions to predicting energy intake.

While the results provide strong support for the idea that habituation to food and reinforcing value for food are related, and that both may contribute to eating behaviors, there are limitations to the study. The sample included only lean females; obese persons may have responded differently. Research has shown obese persons find food more reinforcing than leaner peers (Giesen et al., 2010; Saelens & Epstein, 1996; Temple, Leigerski, Giacomelli, Salvy, & Epstein, 2008), and obese persons will habituate at a slower rate to food than leaner peers (Epstein et al., 1996; Temple, Giacomelli, Roemmich et al., 2007). It is possible that the relationship between habituation and reinforcing value may break down as the reinforcing value goes up and rate of habituation gets slower for obese participants. It is also possible that this increased reinforcing value of food may be sufficiently high such that differences in motivational status would not be apparent in obese individuals. It is also possible that there could be differences by sex. While differences in the rate of habituation have not been observed by sex, the reinforcing value of food is stronger for men than women (Epstein et al., 2004; Perkins, Epstein, Fonte, Mitchell, & Grobe, 1995), which could influence the relationship between how the two processes influence intake. Finally, participants were not required to consume the food after earning it, so there may have been some differences in the pattern of consumption during the task that could have influenced the results. The largest potential difference would be for participants who accumulated all food until the end, rather than consuming the food as it was earned. Further research should be done using obese participants and males and females.

4.1 Conclusion

Both the reinforcing value of food and habituation are related to energy intake (Epstein et al., 2008; Epstein, Robinson et al., 2009; Epstein, Temple et al., 2007; Epstein et al., 2004) and body mass index (Epstein et al., 1996; Epstein, Temple et al., 2007; Giesen et al., 2010; Saelens & Epstein, 1996; Temple, Giacomelli, Roemmich et al., 2007) such that a high reinforcing value or slow habituation predicts increased energy intake and higher BMI, and both processes independently predict energy intake. The development of interventions to reduce food reinforcement as well as speed up the rate of habituation has implications for the prevention or treatment of obesity. It may be particularly important to identify interventions that impact both the reinforcing value of food as well as habituation to food to have the most powerful effects on reducing food intake. It may be that interventions that only influence one of these processes may have less impact on eating over time, leading to relapse and reinstatement of unhealthy eating behaviors. Translating basic research on habituation and reinforcing value may represent new approaches to obesity treatment and prevention.

Acknowledgments

Appreciation is expressed to Tinuke Oluyomi for assisting in the data collection. Dr. Epstein is a consultant to Kraft foods and NuVal/ONQI. The other authors do not have any potential conflict of interests. This research was funded in part by a grant from the National Institute of Drug Abuse, R01 HD 39778, and the National Institute of Diabetes and Digestive Diseases 1U01 DK088380.

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Figure 1.

Relationships between reinforcing value of food and trials to habituation (A), reinforcing value of food and energy intake (B), trials to habituation and energy intake (C), and reinforcing value of reading and energy intake (D). Correlation coefficients and probability levels for each correlation are provided.

Table 1

Serving size and macronutrient composition of study foods.

	Calories Served	Grams Served	Energy Density	Fat	Carbohydrates	Protein
Old Fashioned Glazed Timbit®	300	60.7	4.9	3.8	30	18.8
Cherry Timbit®	300	93.8	3.2	5	50	12.5
Chocolate Glazed Timbit®	300	81.1	3.7	4.3	42.9	10.7
Strawberry Yogurt	150	150.0	1.0	4.4	29.9	1.3
Empire Apple	110	193.0	.57	.85	28.9	0
Blueberry Mini Muffins	180	47.0	3.8	2	25	8
Green Seedless Grapes	100	140.8	.71	0	25.5	0

Table 2Participant Characteristics (mean $\pm$ SD)

	Non-deprived	Deprived	Total
N (minority)	11 (3)	11 (2)	22 (5)
Age (years)	22.3 $\pm$ 4.5	28.5 $\pm$ 10.1	25.4 $\pm$ 8.2
BMI (kg/m ²)	23.0 $\pm$ 2.7	23.8 $\pm$ 3.1	23.4 $\pm$ 2.4
Three Factor Eating Questionnaire			
Restraint	8.5 $\pm$ 7.2	9.1 $\pm$ 4.3	8.8 $\pm$ 4.2
Disinhibition	6.6 $\pm$ 2.7	6.5 $\pm$ 3.5	6.5 $\pm$ 3.0
Hunger	6.2 $\pm$ 3.4	5.5 $\pm$ 1.9	5.8 $\pm$ 2.7
Education (n)			
Some college or less	8	6	14
Completed college	3	5	8
Income (n)			
Less than \$50,000	9	9	18
Equal to or greater than \$50,000	2	2	4