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Eating-related Behaviors and Appetite During Energy Imbalance in Obese-Prone and Obese-Resistant Individuals

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Abstract

While the majority of Americans are now overweight, some individuals maintain their weight with minimal effort. This study investigated behavioral differences between 58 individuals recruited as either obese-resistant (OR) or obese-prone (OP) based on self-identification, BMI, and personal/family weight history. Subjects were studied during Eucaloric (EU), Overfed (OF), and Underfed (UF) phases which included a run-in diet, 1 day intervention diet, and a study day. At baseline, subjects completed the Three Factor Eating Questionnaire (TFEQ) and Power of Food Scale (PFS). On the study day, ratings of appetite, food appeal and desire, and food cravings were performed in response to a breakfast shake. OF resulted in reduced hunger and food desire while UF resulted in increased hunger and food appeal and desire. While hunger did not differ between groups, OP had higher scores for TFEQ measures (hunger, restraint and disinhibition), higher “hedonic hunger” as measured by the PFS, and greater food cravings and ratings of food appeal and desire. These results suggest that subjective hunger and desire for food change significantly after only one day of over- or underfeeding. Additionally, we found several behavioral differences between groups that are likely to promote weight gain over time in the OP.

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Disclosure statement

The authors declare no conflict of interest.

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Keywords

overfeeding; underfeeding; obesity prone; obesity resistant; hunger; satiety

Introduction

Despite efforts to promote healthy eating and physical activity behaviors in Americans, the prevalence of obesity and related metabolic disorders such as diabetes continue to increase. As of 2010, a majority of Americans were either overweight or obese (69%) leaving only a minority with a “normal” body mass index (BMI) (Flegal, Carroll, Kit, & Ogden, 2012). One of the most dramatic changes in the environment over the last 40 years has been the broad availability of relatively inexpensive, highly palatable foods leading to excessive energy intake. Most people in the United States experience at least brief periods of positive energy balance produced by the over-consumption of highly palatable food combined with periods of low levels of physical activity. Evidence that brief periods of positive energy balance are clinically relevant comes from a study of “holiday weight gain” (Yanovski, et al., 2000). In this study many individuals maintained their body weight over the holiday season, while others (largely the obese) tended to have large gains over a short period of time. Perhaps more importantly, weight gained over this brief period of time tended to remain. In addition, it has been shown that US adults consume significantly more energy over the weekend (Friday through Sunday) than they do during weekdays, again implying brief periods of over-nutrition (Haines, Hama, Guilkey, & Popkin, 2003).

While the rise in the prevalence of obesity is concerning from a health care perspective, it also begins to refocus attention on those who do not gain weight. Clearly some individuals maintain a healthy weight in the face of an environment that promotes weight gain in a majority of Americans. It is of great interest to determine what factors prevent these “obese resistant” individuals from gaining weight.

There is a great deal of prior work investigating behavioral differences between obese and normal weight individuals. It can be hypothesized that obese individuals might report food cravings that differ from normal weight individuals in quality or quantity. In fact, in developing the Food Craving Inventory as a tool to assess cravings, White et al found associations between food cravings and BMI (White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002). Additionally, in the Diabetes Prevention Program, frequency of food cravings was found to correlate positively with baseline BMI (Delahanty, et al., 2002). Eating behaviors have also been shown to have important relationships with the development of obesity. Three recognized eating behavior constructs are “disinhibition,” “restraint,” and “hunger,” which are commonly assessed using the Three Factor Eating Questionnaire (TFEQ) developed by Stunkard and Messick (Stunkard & Messick, 1985). Disinhibition was defined originally as “disinhibition of cognitive control of eating,” and has since been described as the tendency to overeat in response to different stimuli including emotional distress or situations in which an array of palatable foods is available (Lowe & Maycock, 1988; Stunkard & Messick, 1985). Disinhibition has been shown to be strongly associated with weight gain over time and obesity in adult life (Drapeau, et al., 2003; Hays, et al., 2002; Hays & Roberts, 2008). Given the increased prevalence of highly palatable food in the environment and its likely role in the increased rates of obesity, the Power of Food Scale has been developed to assess the psychological impact of living in food-abundant environments, as reflected in feelings of being controlled by food, independent of food consumption itself (Lowe, et al., 2009). Severely obese individuals have been shown to achieve higher Power of Food scores as compared with non-obese control subjects, interpreted as increased “hedonic hunger,” or drive to eat palatable foods in the absence of

energy need (Schultes, Ernst, Wilms, Thurnheer, & Hallschmid, 2010). While these differences have been observed in obese as compared to normal weight individuals, they have not been investigated in normal weight individuals who vary in their propensity to gain weight.

In order to assess these potential differences, we compared individuals who were resistant to weight gain (obese-resistant - OR) to other non-obese individuals who were likely to be at risk for weight gain (obese-prone - OP). Previously we found that thin, OR individuals quickly sensed changes in energy balance (short-term overfeeding) with significant decreases in subjective measures of hunger and increases in measures of satiety. In addition, these individuals appeared to also adapt by consuming less energy in the days following a period of overfeeding (Cornier, Grunwald, Johnson, & Bessesen, 2004). It is unclear whether differences in the ability to adapt energy intake to current energy status is related to differences in hormones and metabolites, differences in the nutrient sensing by the brain, or underlying behavioral differences between OP and OR individuals.

This study was designed to investigate behavioral qualities in OP and OR individuals and to assess the effects of short-term over- and under-feeding on appetitive response, food cravings, and ratings of food images. We hypothesized that the OP would exhibit baseline behavioral differences as compared to the OR, as well as differences in response to energy imbalance (over- and underfeeding) that would predispose them to weight gain over time.

Methods

Ethics Statement

This study was conducted according to the principles expressed in the Declaration of Helsinki. The study was approved by the Colorado Multiple Institutional Review Board. All patients provided written informed consent for the collection of samples and subsequent analysis.

Subjects

Subjects included healthy men and women, ages 25–35 years, without eating disorders or depression, who were empirically classified as either obese-resistant (OR) or obese-prone (OP) as described previously (Table 1) (Schmidt, Harmon, Sharp, Kealey, & Bessesen, 2012; Schmidt, Kealey, Horton, Vonkaenel, & Bessesen, 2012; Smucny, et al., 2012). Subjects who were OR had a BMI of 17–25 kg/m², self-reported no first degree relatives with a BMI >30 kg/m², and identified themselves as constitutionally thin based on their perception of difficulty gaining weight despite expending little effort to maintain their current weight. These individuals responded to advertisements asking “Have you always been thin?” and reported no history of ever being overweight. Individuals who were OP, in contrast, responded to the advertisement “Do you struggle with your weight?” They had a BMI of 20–30 kg/m², had at least one first degree relative with a BMI >30 kg/m², reported having to put effort into not gaining weight, reported previous attempts to lose weight, but were not actively attempting to lose weight. All subjects were weight stable for at least 3 months before being studied and reported that they did not engage in planned physical activity more than 3 hours per week. OR and OP subjects were matched for sex, age (+/- 2 years), and ethnicity/race.

Study Design and Measurements

Subjects first underwent baseline assessments, including completion of the TFEQ and the Power of Food Scale (Lowe, et al., 2009; Stunkard & Messick, 1985). They also underwent body composition measurement (lean body mass, fat mass, and fat-free mass) by dual-

energy x-ray absorptiometry (DEXA) (DPX whole-body scanner, Lunar Radiation Corp., Madison, WI). Each subject participated in 3 study phases in a randomized counterbalanced manner, with each phase consisting of a 3 day baseline eucaloric run-in diet period (50% carbohydrate, 30% fat, and 20% protein), followed by an intervention diet on day 4, then a study day on day 5. The three study phases consisted of one of the following on day 4: Eucaloric (EU) diet, Overfeeding (OF) by 40% above estimated energy needs, or Underfeeding (UF) by 40% of baseline caloric intake. During all three study periods, the diets were made up of the same macronutrient composition (50% carbohydrate, 30% fat, and 20% protein). Estimates of daily energy needs were made using lean body mass (as determined by DEXA) in the following equation: Resting Metabolic Rate (RMR) = (fat free mass • 23.9) + 372. The estimates were confirmed using RMR as assessed by indirect calorimetry, multiplied by an activity factor of 1.3. This method has been used successfully by our group in a number of prior studies (Adochio, Leitner, Gray, Draznin, & Cornier, 2009; Cornier, Bergman, & Bessesen, 2006; Cornier, et al., 2004; Cornier, et al., 2009; Cornier, Von Kaenel, Bessesen, & Tregellas, 2007; Tregellas, et al.) All food was prepared and provided by the Clinical Translational Research Center (CTRC) metabolic kitchen. Subjects presented to the CTRC every morning, ate breakfast, and picked up the remainder of their daily meals which were packed in coolers. Subjects were asked to maintain their usual pattern of physical activity and were regularly questioned regarding activity and compliance. Subjects were asked to not consume any alcoholic or calorie-containing beverages during the study period. In women, study days were scheduled during the follicular phase of their menstrual cycle. In order to assess weight maintenance, all subjects were asked to weigh in on the first day of each study phase, at the time when they picked up the food for the 3-day eucaloric run-in diet. This weight was compared to the weight obtained at their screening visit, and if the weights differed by more than 3 pounds, the subject would not continue with that study phase. None of the subjects were excluded based on weight changes during the 1 month interval between study phases. Additionally, the subjects were weighed on the study day (day 5). Weights from day 1 and day 5 of the Eucaloric phase were analyzed and were not found to be significantly different.

Study Day

Subjects presented to the outpatient clinic of the CTRC in the morning after an overnight fast of at least 10 hours. They were weighed and completed subjective appetite ratings measured by visual analog scale (VAS). These included ratings of hunger, prospective food consumption, and satiety. Hunger was rated on a 100-mm line preceded by the question, “How hungry do you feel right now?” and anchored by “not at all hungry” and “extremely hungry” on the right. Prospective food consumption was rated using the question, “How much food do you think you could eat right now?” anchored by “nothing at all” and “a large amount.” Satiety was rated by the question, “How full do you feel right now?” with the anchors “not at all” and “extremely” (Cornier, et al., 2004). Subjects also completed the Food Craving Inventory (FCI), a tool for assessing food cravings which contains questions such as “I have an intense desire to eat one of my favorite foods” (White, et al., 2002). The FCI was given in a subset of subjects, as it was added after the study was underway.

Subjects then consumed a liquid breakfast meal within 20 minutes. The energy content of this meal was equal to 25% of the energy provided by the intervention diet (EU, OF or UF) and had an identical macronutrient composition. Subjects were asked to repeat the FCI again in the fed condition, at 60 minutes following the meal. Repeat appetite ratings by VAS were also performed 30, 90, 120, 150, and 180 minutes after the meal, and the area under the curve (AUC) was calculated using the trapezoid method (Allison, Paultre, Maggio, Mezzitis, & Pi-Sunyer, 1995). Additionally, at 60 minutes post-meal, subjects were asked to rate visual stimuli consisting of images of foods of high appeal, as previously described (Burger,

Cornier, Ingebrigtsen, & Johnson, 2011). Examples of visual stimuli included images of fruit, ice cream, cakes, steak, pasta and pizza. Visual stimuli were presented on a computer screen and subjects were asked to rate them for appeal (“How appealing is this food?”) and desire (“How much do you desire to eat this food?”) on a scale from 0 to 100.

Statistical Analyses

Data were analyzed using SigmaPlot version 12 (San Jose, CA). All results are reported as means and standard errors unless otherwise noted. Scores for the TFEQ and Power of Food Scale, as well as mean change in cravings (pre-meal cravings compared to post-meal cravings) were analyzed using a two-tailed t-test, with tests for differences in group (OR vs. OP) as well as sex (M vs. F). A two-way repeated measures ANOVA was used to examine the effects of overfeeding and underfeeding on appetite ratings (fasting and total AUC); food cravings (pre- and post-meal, as well as absolute change from pre- to post-meal); and image ratings (mean for each feeding condition), with p values identified for interactions and main effects of obesity (OP and OR) and study phase (EU, OF and UF).

To determine whether weight as measured by BMI or fat mass had significant effects on the main outcomes, a statistical analysis considering these variables was also performed within the R Statistical Computing Environment, version 2.15.0 (R Foundation for Statistical Computing, Vienna, Austria). Results for scores on the TFEQ (hunger, restraint and disinhibition) and for score on the Power of Food Scale were initially evaluated by generating simple linear regression models both with and without BMI, and with and without fat mass. For food cravings and image ratings, mixed effect linear regression models both with and without BMI, and with and without fat mass were developed. For each outcome the model was run using study phase and BMI or fat mass as the fixed effects with a random intercept for each subject. Next, we split the population into two groups based on OR/OP status and again ran the simple linear or mixed effect linear regression models for each outcome as listed above. The significance of BMI was calculated from a general linear hypothesis test using the multcomp package (Hothorn, Bretz, & Westfall, 2008). The null hypothesis was that BMI had no effect on the model. This process was then repeated for fat mass in the place of BMI. Significance was established at the .05 level.

Results

Subjects and baseline characteristics

A total of 58 subjects were studied, equally divided between male and female. OP subjects had greater BMI, fat mass and percent body fat than OR, but lean body mass and fat free mass were not significantly different between groups. At baseline, the OP group reported significantly higher scores than the OR group on all three components of the Three Factor Eating Questionnaire (hunger, restraint and disinhibition). Additionally, they reported significantly higher scores on the Power of Food Scale (Table 1).

Appetite Ratings

Overfeeding and underfeeding produced a number of significant differences in the fasting ratings for hunger, prospective food consumption and satiety (Figure 1). One day of OF as compared to EU resulted in significant reductions in fasting ratings of hunger (67.8 ± 2.9 vs. 51.5 ± 2.9 mm, $p < 0.001$) and prospective food consumption (66.0 ± 2.4 vs. 51.7 ± 2.3 mm, $p < 0.001$) and higher ratings of satiety (33.6 ± 2.4 vs. 19.3 ± 2.5 mm, $p < 0.001$). One day of UF was associated with reduced fasting ratings of satiety (11.6 ± 2.4 vs. 19.3 ± 2.5 mm, $p = 0.027$) but did not impact fasting ratings of hunger or prospective food consumption. The total AUC (in response to a test breakfast meal) for ratings of hunger, prospective food consumption and satiety also differed by feeding phase for the entire sample (Figure 1) as

well as across OR-OP groups (Table 2). Hunger AUC was higher in the UF ($p<0.001$) and lower in the OF ($p<0.001$) phase compared to the EU phase. Prospective food consumption AUC was also higher in the UF compared to EU ($p=0.004$) and lower in the OF phase ($p<0.001$). Compared to EU, satiety AUC was lower in the UF ($p<0.001$) and higher in the OF ($p<0.001$) phases. The incremental AUC for hunger, prospective food consumption and satiety ratings, however, did not differ by group or feeding phase, suggesting that the differences in total AUC were driven by the differences in fasting ratings. There were no differences in AUC between the groups (OR vs. OP) and no differences in the change in AUC from EU to OF or EU to UF between groups.

Cravings

Overall, food cravings were reduced in the fed as compared to the fasted state (Table 3). Cravings in the fasted state were rated higher in the UF compared to OF ($p<0.001$) and EU conditions ($p=0.012$) for both groups combined. Cravings in the fed state were rated higher in UF as compared to OF ($p<0.001$) or EU ($p<0.001$), and lower in the OF as compared to EU ($p=0.005$) for both groups combined. When analyzed by group, cravings (for all feeding phases combined) were greater in the OP as compared to the OR group in the fasted ($p=0.023$) as well as the fed state ($p=0.008$). However, no difference was found for group or phase for the absolute change between fasted and fed cravings.

Image ratings

For both groups combined, there were feeding effects for both food appeal and desire to eat. Overall, food appeal was rated higher in the UF as compared to the OF phase (67.4 ± 0.8 vs. 64.5 ± 0.8 , $p<0.001$). Desire was rated higher in the UF as compared to OF (61.9 ± 1.5 vs. 50.5 ± 1.5 , $p<0.001$) or EU (61.9 ± 1.5 vs. 56.5 ± 1.5 , $p<0.001$) phase. Desire to eat was also rated lower in OF as compared to the EU phase (50.5 ± 1.5 vs. 56.5 ± 1.5 , $p=0.019$). The OP subjects rated the food images as having higher appeal (How appealing is this food?) for all phases combined, as compared to OR ($p=0.039$) (Table 4). When analyzed by phase, the difference between OR and OP was only significant in the OF phase ($p=0.002$). Within OP, there was no significant difference in food appeal ratings between phases (EU, OF and UF). However, within the OR group, food appeal was rated lower in the OF as compared to UF condition ($p<0.001$). The OP subjects rated the images for desire to eat (How much do you desire to eat this food?) more highly for all phases combined, as compared to OR ($p=0.026$). When analyzed by phase, the difference between OP and OR was only significant in the OF phase ($p=0.012$). There were significant differences depending on phase within both OP and OR: For OP, desire was rated higher in the UF vs. OF ($p=0.015$). For OR, desire was rated higher in the UF vs. OF ($p<0.001$), and higher in EU vs. OF ($p=0.028$).

Effects of Fat Mass and BMI

Because there were differences in fat mass and BMI between groups, simple linear or mixed effect linear regression models were performed for each of the main outcomes. For all outcomes, BMI and fat mass were either statistically insignificant or caused drastic fluctuations in coefficients and standard errors, so it was determined that they should not be included in the analyses when OR/OP status is included. Subsequently, we repeated the linear regression models for each outcome for each group (OR and OP) separately. These models indicated that, when each group was analyzed separately, neither fat mass nor BMI had a significant effect on any of the outcomes (score for each measure on the TFEQ, score on the Power of Food Scale, food cravings and image ratings).

Discussion

The present study was carried out to examine differences in “appetite” and eating behaviors in response to energy imbalance in obese-prone and obese-resistant individuals. Overall, we did not find differences between the two groups in subjective appetite ratings, but we found that both groups sensed 24-hour energy imbalance more accurately than they did a single meal of greater or lesser caloric content. Additionally, we found that the OP group reported higher hunger, restraint and disinhibition; higher “hedonic hunger” as measured by the Power of Food Scale; greater food cravings both in the fasted and fed state, and higher ratings of food images for appeal and desire to eat.

Interestingly, the results of this study indicate that the fasting ratings of hunger, prospective food consumption and satiety differed as a result of one day of energy imbalance, while acute over- or underfeeding (a breakfast test meal of differing caloric content) did not affect these subjective ratings of appetite. We did not find any differences in subjective appetite ratings in the OP as compared to the OR. In contrast, we previously reported that short-term overfeeding resulted in significant decreases in subjective measures of hunger and increases in measures of satiety in OR individuals as compared to the reduced obese (Cornier, et al., 2004). This may be explained in part by the difference in comparison group, as reduced obese individuals may exhibit differences in appetitive response as a result of changes in body weight. In the present study, even though the test breakfast meal provided 40% above or 40% below baseline caloric needs (for the OF and UF phases, respectively), the AUC for hunger, prospective food consumption and satiety did not differ by phase after accounting for the fasting differences. Thus, both OR and OP individuals appeared to sense 24-hour energy balance more accurately than they sensed the energy content of a single meal. The day-to-day variability in caloric content of a given meal can vary widely (it has been shown that the intra-individual coefficients of variation of daily food intake averaged $\pm 23\%$ (Bingham, et al., 1994)), so it is possible that the overall caloric intake of a 24-hour period contributes more to subjective feelings of appetite than does a single meal. However, the fact that there were no significant differences between groups suggests that variability of appetite does not appear to be a primary determinant of proneness or resistance to obesity.

We hypothesized that the OP would exhibit behavioral differences (as compared to the OR) that might put them at risk for weight gain over time. Indeed, the present study demonstrated differences between groups in scores on the Power of Food Scale, TFEQ, food cravings, and the hedonic response to food images. The OP group had a higher mean score on the Power of Food Scale, interpreted as increased “hedonic hunger,” or drive to eat palatable foods in the absence of energy need. Although this scale is a relatively new construct, one study has reported increased scores in obese as compared to normal-weight individuals (Schultes, et al., 2010). Given the common theory that the increasing prevalence of obesity relates to increased availability of highly palatable, energy-dense foods, the difference in propensity to eat these foods could play a strong role in determining weight trajectory over time. In addition, OP individuals reported higher scores for all three constructs measured on the TFEQ: hunger, restraint and disinhibition. A number of prior studies (Drapeau, et al., 2003; Hays, et al., 2002; Hays & Roberts, 2008) have demonstrated an association between disinhibition and BMI as well as with weight gain over time. Although our OP subjects were not obese, they did have higher mean BMI and fat mass than OR subjects, and we hypothesize that they will be likely to gain more weight over time. Thus, our findings that these individuals report higher disinhibition suggest that the tendency to overeat in response to a variety of stimuli could predispose the OP individuals to weight gain and obesity. Perceived hunger, as measured by the TFEQ, reflects feelings of hunger and its behavioral consequences. We found that OP individuals had higher hunger scores, which could potentially put them at higher risk for weight gain due to increased food intake in response

to feelings of hunger. In general, hunger has not been found to correlate with obesity, but in a recent study of 1,000 men and women in France, higher hunger scores measured with the TFEQ were found to correlate with increased BMI (although disinhibition was the factor most strongly associated with BMI) (Aurelie, et al., 2012). Restraint is defined as the conscious restriction of food intake to prevent weight gain or promote weight loss. Previous research has yielded conflicting results regarding the relationship between the restraint and the development of obesity. While some studies have shown higher restraint to correlate with higher BMI (Hill, Weaver, & Blundell, 1991; Tuschl, Platte, Laessle, Stichler, & Pirke, 1990), others have shown an inverse relationship (Foster, et al., 1998; Williamson, et al., 1995), and still others showed no significant association at all (Drapeau, et al., 2003; Lawson, et al., 1995; Provencher, Drapeau, Tremblay, Despres, & Lemieux, 2003). In the present study, OP individuals reported significantly higher levels of dietary restraint.

While relationships between factors on the TFEQ and the development of obesity have been explored extensively in the literature, weight gain as it relates to the experience of food cravings or responses to images of food have been less well-defined. We hypothesized that the OP would report higher cravings for food, which could later influence food choices and energy intake. Our findings indicate that the OP, in fact, report higher cravings for food than the OR, both in the fasted and fed state. Previous research has shown that food cravings are significantly related to food intake, with specific food cravings correlating with the types of foods consumed (Martin, O'Neil, Tollefson, Greenway, & White, 2008). Thus, increased cravings for food in OP individuals could contribute to increased energy intake and weight gain over time.

Visual food cues are abundant in the current environment, with images of food appearing in print media, on screen, and in the environment when others are eating. Previous research has investigated the effects of visual food cues on both brain activation in response to food pictures, and on ratings of appeal and desire to eat the food presented. These studies have shown that brain activation in reward and attention related areas is increased when individuals are shown pictures of energy dense, highly palatable foods, and that activation resulting from high calorie foods is positively associated with BMI (Killgore, et al., 2003; Rothenmund, et al., 2007; Stoeckel, et al., 2008). In constructing and validating the set of images employed in this study, Burger et al found that BMI was positively correlated to desire to eat, but not food appeal (Burger, et al., 2011). In this study, the OP rated the food images with higher appeal and desire to eat as compared to the OR. When analyzed by feeding condition, a significant effect was seen only in the OF phase. Additionally, the OR group was found to have significant differences in ratings of food appeal among feeding phases, whereas there were no such differences in ratings of food appeal in the OP group. This would suggest that despite being in a state of positive energy balance, the OP continue to find images of food appealing and desirable, which could lead to continued consumption of the foods and subsequent weight gain.

While prior research has investigated differences between obese and normal weight individuals, there has been less attention to behavioral differences among individuals who are not yet obese but who may be predicted to be at greater risk of weight gain over time. It would be hypothesized that the OP would gain excess weight based on their family history and prior reports of struggling with their weight. Our findings indicate that these individuals do, in fact, exhibit behavioral differences that predispose them to increased intake of food and subsequent development of obesity.

There are some limitations of this study that should be discussed. While there are inherent problems with classifying individuals as being prone or resistant to obesity before its development, we believe that the most important factor in this categorization is self-

identification. The method of recruitment for the study involved advertisements directed at individuals who perceived that they either had a tendency to gain weight or a tendency to remain thin. Other criteria such as attempts to control weight or diet and family history of obesity were used in addition to help enrich the sample for propensity to gain weight or not. These groups have been previously studied as defined here, with the hope of determining predictors of weight gain over time (Schmidt, Harmon, et al., 2012; Schmidt, Kealey, et al., 2012). Ultimately, however, it will be the longitudinal weight data which is currently being collected that will determine whether or not these categories are valid. The fact that the two groups differed with respect to BMI and fat mass at baseline likely reflects the fact that individuals who report struggling with their weight and who perceive a tendency to gain weight are more likely to have already gained weight during their twenties and early thirties. It is difficult to determine the extent to which current body weight affects responses to items on questionnaires relating to food behaviors, and even more difficult to determine causal relationships (i.e., the extent to which attitudes and behaviors toward food influence body weight vs. the extent to which body weight affects and potentially changes eating behaviors). Nevertheless, we examined the impact of BMI and fat mass on these variables using linear regressions and did not find that current BMI or fat mass were significant predictors of the main outcomes. In addition, it could be argued that the presentation of food images during the time encompassed by the AUC for subjective appetite ratings could affect a subject's ratings of hunger and satiety. However, the visual stimuli and appetite ratings were not done concurrently, as images were presented at 60 minutes, while appetite ratings had been done at 30 minutes and were done next at 90 minutes. Moreover, these measurements tested different constructs: the subjective appetite ratings tested the physiologic sensation of hunger, while the questions asked following the visual stimuli tested the desire for and appeal (i.e., wanting and liking) of the food presented.

In conclusion, our results indicate significant measurable behavioral differences between OP and OR individuals. OP individuals report higher hunger, restraint and disinhibition, higher scores on the Power of Food Scale, increased food cravings (in both the fasted and fed states), and higher ratings of food images for appeal and desire, most notably in the overfed state. These differences may predispose these OP individuals to increased energy intake over time, even during periods of positive energy balance, leading to weight gain and the development of obesity.

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Highlights

Subjective appetite ratings depend upon energy balance within the previous 24 hours

Obese-prone individuals report higher hunger, restraint and disinhibition

Food cravings, food appeal, and desire to eat are rated higher in the obese-prone

Obesity proneness does not impact appetite ratings

Figure 1. Subjective Appetite Ratings in Response to Energy Imbalance

Ratings of hunger (A), prospective food consumption (B), and satiety (C) in response to a test meal are shown for the Eucaloric (EU), Overfed (OF) and Underfed (UF) conditions. For each time point for OF and UF, $a=p<0.05$ for comparison to EU. The total Area Under the Curve (AUC) for hunger was higher in the UF ($p<0.001$) and lower in the OF ($p<0.001$) conditions compared to the EU condition. Prospective food consumption AUC was also higher in the UF compared to EU ($p=0.004$) and lower in the OF condition ($p<0.001$). Compared to EU, satiety AUC was lower in the UF ($p<0.001$) and higher in the OF ($p<0.001$) conditions.

Table 1

Baseline characteristics.

	OR	OP
Total n (male/female)	29 (15/14)	29 (14/15)
Age (years)	30.7 ± 3.4	30.4 ± 3.9
BMI (kg/m ²)	20.9 ± 1.9	26.1 ± 2.8 ^a
Lean Body Mass (kg)	48.5 ± 10.3	53.4 ± 10.4
Fat Mass (kg)	10.7 ± 3.6	22.7 ± 8.0 ^a
Percent Body Fat	18.8 ± 4.6	28.7 ± 8.0 ^a
Hunger	4.5 ± 2.4	6.3 ± 2.9 ^b
Restraint	4.6 ± 3.0	9.4 ± 4.4 ^a
Disinhibition	3.1 ± 2.2	7.7 ± 3.5 ^a
Power of Foods Scale	39.2 ± 10.2	49.5 ± 14.1 ^b

Mean ± standard deviation for Obese-Resistant (OR) and Obese-Prone (OP)

^a
p<0.001^b
p<0.05

Table 2

Appetite Ratings.

	Hunger			Prospective Food Consumption			Satiety		
	All	OR	OP	All	OR	OP	All	OR	OP
EU	8380 ± 349	8104 ± 494	8656 ± 494	9830 ± 335	10344 ± 474	9318 ± 474	8289 ± 340	8109 ± 481	8469 ± 481
UF	10196 ± 340 ^a	9801 ± 481 ^b	10593 ± 481 ^b	11216 ± 326 ^b	11335 ± 462	11098 ± 462 ^b	6362 ± 331 ^a	6460 ± 468 ^b	6264 ± 468 ^b
OF	5882 ± 345 ^a	5515 ± 481 ^a	6250 ± 481 ^b	6870 ± 331 ^a	6554 ± 462 ^a	7187 ± 474 ^b	10298 ± 336 ^a	10113 ± 468 ^b	10484 ± 481 ^b

Mean total AUC (mm x 180min) ± SEM for Eucaloric (EU), Underfed (UF) and Overfed (OF) conditions, for Obese-Resistant (OR) and Obese-Prone (OP)

^a p<0.001 for comparison to EU^b p<0.05 for comparison to EU

Table 3

Food Cravings As Measured by the Food Craving Inventory (FCI).

		All subjects (n=46)	OR (n=23)	OP (n=23)
All phases	Fasted	39.8 ± 1.0	37.2 ± 1.7	43.0 ± 1.8 ^c
	Fed	35.5 ± 1.1	31.8 ± 2.0	39.5 ± 2.0 ^c
EU	Fasted	39.4 ± 1.4	36.9 ± 1.9	41.9 ± 1.9
	Fed	35.2 ± 1.3	32.1 ± 1.8	38.3 ± 1.8
UF	Fasted	44.8 ± 1.4 ^b	41.1 ± 1.9	48.4 ± 1.9 ^{b,c}
	Fed	41.7 ± 1.3 ^a	36.9 ± 1.8	46.5 ± 1.8 ^{b,c}
OF	Fasted	36.2 ± 1.4	33.6 ± 1.9	38.7 ± 2.0
	Fed	30.0 ± 1.3 ^b	26.4 ± 1.8	33.5 ± 1.8 ^c

Mean ± SEM for Obese-Resistant (OR) and Obese-Prone (OP) in Eucaloric (EU), Underfed (UF) and Overfed (OF) conditions

^a p<0.001 for comparison to EU^b p<0.05 for comparison to EU^c p<0.05 for comparison to OR

Table 4

Ratings of Appealing Food Images.

	Appeal		Desire	
	OR	OP	OR	OP
All phases	63.4 ± 1.9	69.3 ± 2.0 ^b	54.4 ± 2.5	62.4 ± 2.4 ^b
EU	62.4 ± 1.1	67.2 ± 1.1	52.9 ± 2.2	60.0 ± 2.1
UF	65.6 ± 1.1	69.3 ± 1.1	58.6 ± 2.2	65.2 ± 2.1
OF	59.3 ± 1.1	69.7 ± 1.1 ^b	44.9 ± 2.2 ^a	56.2 ± 2.2 ^b

Mean ± SEM for Obese-Resistant (OR) and Obese-Prone (OP) in Eucaloric (EU), Underfed (UF) and Overfed (OF) conditions

^a p<0.05 for comparison to EU^b p<0.05 for comparison to OR