Greater Reward-Related Neuronal Response to Hedonic Foods in Women Compared with Men
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Objective: The current study aimed to identify how sex influences neurobiological responses to food cues, particularly those related to hedonic eating, and how this relates to obesity propensity, using functional magnetic resonance imaging (fMRI).

Methods: Adult men and women who were either obesity resistant (OR) or obesity prone (OP) underwent fMRI while viewing visual food cues (hedonic foods, neutral foods, and nonfood objects) in both fasted and fed states.

Results: When fasted, a significant sex effect on the response to hedonic vs. neutral foods was observed, with greater responses in women than men in the nucleus accumbens ($P < 0.0002$) and insula ($P < 0.010$). Sex-based differences were not observed in the fed state. No significant group effects (OP vs. OR) or group-by-sex interactions were observed in fasted or fed states.

Conclusions: Greater fasted responses to hedonic food cues in reward-related brain regions were observed in women compared with men, suggesting that women may be more sensitive to the reward value of hedonic foods than men when fasted. This may indicate sex-dependent neurophysiology underlying eating behaviors.

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Introduction
Sex-based differences in eating behaviors are consistently observed. For example, studies suggest that women are more likely to diet than men, express greater concern about weight control, report more frequent consumption of fruits and vegetables, and attribute greater importance to healthy eating (1-3). Women also report more behaviors associated with eating disorders (4) and have higher rates of obesity, particularly severe obesity (5). Differences in eating behaviors and obesity rates between men and women involve several factors, such as gonadal hormones, social pressures and norms, and physical activity engagement (6). These factors also interact with neuronal processes involved in eating behaviors.

Multiple brain regions and networks are involved in eating-related processes, including those involved in sensory perception (e.g., primary visual cortex, fusiform gyrus), reward and interoceptive processing (e.g., insula, nucleus accumbens, anterior cingulate cortex [ACC]), and cognitive control (e.g., dorsalateral prefrontal cortex [dIPFC], parietal cortex) (7,8). Women consistently demonstrate a greater response to visual food cues than men in several regions related to eating behaviors, including the insula (9), ACC (10,11), dIPFC (12), and fusiform gyrus (10,12,13). Previous studies found sex-based differences when comparing neuronal responses to visual cues of foods vs. nonfood objects in normal-weight individuals in the fasted state (dIPFC, fusiform, parietal cortex: women > men [W > M]) (12) and across fasted and fed states (fusiform: W > M) (13). Sex-based differences have also been observed in neuronal responses in normal-weight participants to high-calorie visual food cues (fusiform: fasted > fed in women only) (10) and to high- vs. low-calorie food cues in a hunger-neutral (1 hour postprandial) state (insula, orbitofrontal cortex, middle/posterior cingulate gyrus: W > M) (9). Similar sex-based differences to high- vs. low-calorie food cues were also observed in participants with obesity in fasted (fusiform, caudate nucleus: W > M; parietal cortex: M > W) (11) and fed states (ACC: W > M; fusiform: M > W) (11).

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Hedonic eating, or eating beyond homeostatic needs, may be particularly associated with obesity (14). As such, the current study investigated sex-based differences in neuronal responses to hedonic foods. This was assessed in both fasted and fed states by using functional magnetic resonance imaging (fMRI). This study is the first to investigate whether sex-based differences in neuronal responses to food cues vary based on hedonic properties of foods, by comparing responses to foods with high vs. neutral hedonic value. This is also the first study to determine whether sex-based differences in neuronal responses to food cues vary based on the propensity to obesity, with the inclusion of both obesity-prone (OP) and obesity-resistant (OR) study groups. We hypothesized that women would show greater neuronal response to food cues than men, with OP women more responsive than OR women.

Methods

Participant characteristics
Fifty-six adults 25 to 40 years old were included in the study, drawn from a larger study investigating effects of obesity proneness on metabolism. Half the study participants were recruited as having a propensity to weight gain and obesity (OR; N = 28) and half were recruited as being prone to weight gain and obesity (OP; N = 28), as previously described (15-19). Briefly, OR participants had a BMI between 17 and 25 kg/m², responded to advertisements for “naturally thin people,” and reported no first-degree relatives with obesity, never having overweight themselves, having weight stability despite few to no attempts to lose weight, and not having high levels of physical activity. OP participants had a BMI between 20 and 30 kg/m², responded to advertisements for “people who struggle with their weight,” reported at least one first-degree relative with obesity, and had a history of weight fluctuations despite efforts to lose or maintain weight, but they were not actively attempting to lose weight and were weight stable for at least 3 months prior to participation. All participants were free of significant medical and psychiatric disease, including eating disorders, as assessed by medical history, physical examination, blood testing, and behavioral questionnaires (Eating Attitudes Test (20); Center for Epidemiologic Studies Depression Scale (21)). All participants were right-handed, with no contraindications to fMRI scanning, and reported being weight stable +/- 5 lb for the 3 months prior to the study. Data from three participants were excluded from the analyses because of technical problems (N = 2) or head movement >2 mm (N = 1) during fMRI scanning. Final analyses included 25 women (11 OR, 14 OP) and 28 men (14 OR, 14 OP). Participants provided written informed consent and all procedures were in accordance with and approved by the Colorado Multiple Institutional Review Board.

Study design
As previously described (16,18,19), body composition was assessed by dual-energy x-ray absorptiometry (DPX whole-body scanner, Lunar Radiation Corp., Madison, Wisconsin), and eating behaviors were assessed with the Three-Factor Eating Questionnaire (TFEQ (22)). One participant did not complete the TFEQ, resulting in a reduced sample size for the OR group for this measure (10 women, 14 men). Participants then completed a 4-day eucaloric run-in diet (50% carbohydrate, 30% fat, 20% protein; estimation of energy needs made using lean body mass plus an activity factor (23)) prior to fMRI scanning to ensure energy and macronutrient balance. Food was prepared by the Clinical Translational Research Center (CTRC) metabolic kitchen at the University of Colorado Anschutz Medical Campus. Participants presented to the CTRC every morning during the diet period, then were weighed, ate breakfast, and were given the remainder of their daily meals. Participants were asked to maintain usual patterns of physical activity and not to consume alcoholic or calorie-containing beverages. They were regularly questioned regarding activity and compliance. In women, study measures were performed in the follicular phase of their menstrual cycle.

On the study day, participants presented to the CTRC after an overnight fast of at least 10 hours. A visual analog scale (VAS) measured hunger (“how hungry are you?” from “not at all hungry” to “extremely hungry”), satiety (“how full do you feel right now?” from “not at all” to “extremely”), and prospective food consumption (“how much do you think you could eat right now?” from “nothing at all” to “a large amount”). Following this, participants were escorted to the Brain Imaging Center at the University of Colorado Anschutz Medical Campus. Following fasting fMRI measures (described below), participants consumed a liquid breakfast meal over 20 minutes, the caloric content of which was equal to 25% of the energy provided during run-in diet days, with identical macronutrient composition. Repeat fMRI measures were performed 30 minutes post meal. VAS measures were repeated 30, 90, 120, 150, and 180 minutes post meal (60-minute ratings omitted because participants were in the scanner).

fMRI data acquisition
As previously described (16,19), fMRI was performed by using a General Electric 3.0-T MR scanner. A high-resolution, T1-weighted, three-dimensional anatomical scan was acquired for each participant, after which functional images were acquired with an echo-planar gradient-echo T2*- blood oxygenation level dependent (BOLD) imaging contrast technique, with the following parameters: repetition time = 2,000 milliseconds, echo time = 30 milliseconds, 64² matrix, 240 mm² field of view, 27 axial slices angled parallel to the planum sphenoidal, 2.6 mm thick, 1.4 mm gap. An inversion-recovery echo-planar image (EPI) (inversion time = 505 milliseconds) volume was acquired to improve coregistration between the EPIs and gray matter templates used in preprocessing. Head motion was minimized with a VacFix head-conforming vacuum cushion (Par Scientific A/S, Odense, Denmark).

Functional imaging was performed while participants viewed visual stimuli using a projector and screen system. Previously validated visual stimuli consisted of three categories: nonfood-related objects (e.g., animals, trees, furniture), foods of high hedonic value (e.g., chocolate cake, eggs and bacon, pizza), and foods of neutral hedonic value (e.g., bagels, fruit, cereal). High vs. neutral hedonic value was determined in a previous study in which participants rated the images for “food appeal” (24). Those in the top food appeal tertile were selected as “high hedonic,” with those in the bottom tertile selected as “neutral.” To reduce habituation potential, different but similar images were used in each scanning session (fasted and fed). The primary analysis compared foods of high hedonic value with those of neutral hedonic value. A secondary analysis compared all foods (hedonic and neutral) with nonfood objects. Two runs were performed, each consisting of a pseudorandomized block design with six blocks of pictures of each category. Seven blocks of a low-level baseline (fixation cross) were also included in each run. Each
block consisted of four stimuli shown for 4 seconds each for a total of 16 seconds per block. Four additional scans were acquired at the beginning of each run to minimize saturation effects. Subjects were asked to lie quietly while viewing images.

Data analyses

fMRI data were preprocessed and analyzed by using SPM8 (Wellcome Department of Imaging Neuroscience, London, UK), as previously described (16,19). Functional data were realigned to the first EPI, normalized to the Montreal Neurological Institute EPI template, using the gray-matter-segmented inversion-recovery EPI as an intermediate to improve registration, and smoothed with a 6-mm, full width at half maximum Gaussian kernel. Movement parameters derived from the realignment procedure were included in the model to reduce effects of residual motion-related noise. The hemodynamic response was modeled with a double gamma function, without temporal derivatives, by using the general linear model in SPM8. A 128-second high-pass filter was applied to remove low-frequency fluctuation in the BOLD signal. To account for within-group and within-subject variance, a random-effects analysis was implemented. Parameter estimates for each individual’s first-level analysis (SPM contrast images) contrasting hedonic to neutral food cues were entered into second-level repeated-measures analysis of variance (ANOVA). For a secondary analysis, all food cues (hedonic and neutral) were contrasted to nonfood objects. The main group comparison was sex (women vs. men), with obesity-propensity group comparisons (OR vs. OP) as a secondary aim. These were evaluated by using directional contrasts (SPM t contrasts) in a full factorial model. A priori regions of interest (ROIs; insula, nucleus accumbens, dIPFC, ACC, and fusiform gyrus) were selected as those consistently observed to be involved in visual food cue processing (7,25-27) and based on previous findings of sex-based differences in neuronal response to visual food cues (9-13). ROIs were anatomically defined by using the Wake Forest University PickAtlas toolbox (http://fmri.wfubmc.edu/software/PickAtlas) and examined by using the MarsBar toolbox (http://marsbar.sourceforge.net/) in SPM. For each ROI, one value was extracted (mean across all values in the ROI). Results were corrected for multiple comparisons by increasing the statistical significance threshold to \( P = 0.01 \), reflecting a Bonferroni correction for \( x = 0.05 \) (five ROIs were examined).

Analyses of behavioral and body composition measures were performed with SPSS Statistics 24 (IBM Corp., Armonk, New York). Total area under the curve for appetite VAS ratings using all postmeal time points was used. A general linear model in SPSS assessed effects of sex (women vs. men), group (OR vs. OP), and sex-by-group interactions, with \( x = 0.05 \). For correlations between fMRI and behavioral/body composition data, regression analyses were performed in SPSS, using the peak fMRI signal extracted from each ROI.

Results

Behavioral and body composition measures

Main effects of sex were observed for BMI, lean body mass, and percent body fat, with BMI and lean body mass greater in men and percent body fat greater in women (Table 1). As previously reported, group effects were observed for BMI, fat mass, and percent body fat, such that all were significantly greater in OP compared with OR (16,28). OP also had significantly greater lean body mass compared with OR.

No significant effects of sex were observed for appetite or food-related measures (Table 2). As previously reported, significant effects of group on all TFEQ subscales were observed, with greater restraint, disinhibition, and hunger ratings in OP compared with OR (28).

fMRI

In the fasted state, a significant effect of sex on the response to hedonic compared with neutral foods was observed, with a greater response in women than men in the nucleus accumbens (\( P = 0.0002 \)) and insula (\( P = 0.010 \), (Figure 1). A trend in this direction was observed in the ACC (\( P = 0.039 \)) but did not survive multiple comparison correction. Sex differences in response to hedonic vs. neutral foods were not observed in the fed state. No significant group effects (OP vs. OR) or sex-by-group interactions were observed when comparing hedonic with neutral foods in fasted or fed states.

When comparing all foods (hedonic plus neutral foods) with nonfood objects, no significant sex effects were observed in either fasted or fed states. No significant effects of group were observed in the fasted state, but in the fed state, the response to foods vs. nonfood objects was greater in OP compared with OR in the dIPFC (\( P < 0.001 \)), ACC (\( P = 0.005 \)), and insula (\( P = 0.008 \)). A significant

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**TABLE 1 Participant characteristics**

|               | Women                  |          | Men                  |          | Sex effect | Group effect | Sex by group |
|---------------|------------------------|----------|----------------------|----------|------------|--------------|--------------|
| Age (y)       | 31.7 ± 2.7             | 30.5 ± 3.9 | 31.2 ± 3.9           | 29.9 ± 3.9 | 0.595      | 0.221        | 0.977        |
| BMI (kg/m²)   | 19.4 ± 0.8             | 25.9 ± 3.3 | 22.0 ± 2.0           | 26.5 ± 2.5 | 0.022      | < 0.001      | 0.140        |
| Lean body mass (kg) | 40.7 ± 3.6          | 46.6 ± 6.7 | 56.5 ± 9.1           | 62.7 ± 7.0 | < 0.001    | 0.003        | 0.930        |
| Fat mass (kg) | 11.6 ± 1.9             | 24.0 ± 7.7 | 17.2 ± 18.2          | 23.6 ± 14.3 | 0.461      | 0.010        | 0.396        |
| Body fat (%)  | 21.5 ± 3.0             | 32.9 ± 6.7 | 16.4 ± 4.4           | 24.2 ± 7.3 | < 0.001    | < 0.001      | 0.268        |

Data given as mean ± SEM. 

*Significant \( P \) values in bold.

OP, obesity-prone; OR, obesity-resistant.
interaction between group and sex in the nucleus accumbens (P = 0.005) in the foods vs. objects comparison during the fed state was also observed, such that although there were no OP vs. OR differences in women, greater nucleus accumbens response was observed in OP vs. OR men (P = 0.009). Although there was no significant sex-by-group interaction in these regions (P > 0.05), a greater OP vs. OR response was also observed in men only for ACC (P = 0.009) and marginally for insula (P = 0.018). A greater dlPFC response in OP vs. OR was observed for men (P = 0.008) and marginally for women (P = 0.017).

**Correlations between fMRI and behavioral/body composition measures**

A significant correlation between percent body fat and nucleus accumbens response to hedonic > neutral foods in the fasted state was observed, with a greater response associated with a greater percent body fat (r = 0.40, P = 0.003). However, when sex was included as a covariate, the correlation between response and body fat was no longer observed. Similarly, significant correlations were observed between insula response to hedonic > neutral foods in the fasted state and both percent body fat (r = 0.30, P = 0.030) and lean body mass (r = −0.29, P = 0.035). As in the nucleus accumbens, these associations were not observed when sex was included as a covariate, suggesting that the observed correlations between brain response and body fat/lean body mass were driven by sex-based differences.

**Discussion**

Sex-based differences in neuronal responses to hedonic compared with neutral foods were observed in the fasted state, with greater responses in women compared with men in the nucleus accumbens.
and insula. Given the prominent roles of these regions in reward processing related to food (8,29,30), study results could indicate that women are more sensitive to salient and rewarding aspects of hedonic foods than men when fasted, potentially indicating sex-dependent neurophysiology underlying eating behaviors. Previous studies have found that nucleus accumbens response to visual food cues relates to subsequent snack food consumption (31). Greater nucleus accumbens response to food cues has also been associated with subsequent weight gain in women (32) and less success in a weight loss program (27). Greater insula response to food cues has also been found to predict reduced weight loss success (27).

In the fed state, sex differences were not observed, suggesting that this hyper-responsivity is specific to the fasted state. This corresponds to previous findings that fasting enhances food image valence for women but not for men (33). It has been suggested that this may reflect greater sensitivity to the hunger state in women, with men having greater internal food representation stability (33). Furthermore, although fasted sex-based differences (W > M) were observed when comparing hedonic with neutral foods, this was not observed for the foods vs. objects comparison; that is, this was specific to the more distinct comparison of hedonic to neutral foods, rather than foods as a whole. This may suggest that although both men and women are similarly responsive to foods vs. objects in general, when fasted, women may find hedonic foods specifically to be more rewarding than men. Hormonal differences between men and women may relate to these effects, as gonadal hormones have been implicated in nucleus accumbens activity modulation (34). For example, estrogen signaling at beta estrogen receptors in the brain is thought to be relevant to hedonic eating, with studies finding evidence of dense beta estrogen receptor distribution in the nucleus accumbens (30). However, behavioral effects of centrally acting gonadal hormones, and how they relate to obesity propensity, are not yet fully understood. For example, estrogen plays an important role in the central regulation of food intake, energy expenditure, and fat distribution and is thought to be associated with weight gain, particularly during menopause, but the underlying mechanisms are still unclear (35,36). No OP vs. OR differences in the response to hedonic vs. neutral foods were observed, nor were interactions between group and sex, suggesting that women as a whole may be more sensitive to rewarding aspects of food in the fasted state, regardless of weight gain propensity.

These findings are consistent with previous observations of greater insula response to visual food cues in a neutral hunger state (1 hour postprandial) in women compared with men (9). Previous studies have also found greater fasted response to visual food cues in women compared with men in other ROIs included in the current study, specifically the dLPFC (12) and fusiform gyrus (10-12). Additionally, studies have observed greater fed state responses in women compared with men in the ACC (11) and in men compared with women in the fusiform gyrus (11), whereas others have observed no sex-based differences in neuronal response to food cues (37,38). Several factors may contribute to differences between previous and current findings. An important consideration is menstrual cycle phase, which was controlled in the current study. To the best of our knowledge, our previous investigation of sex-based differences in fasted normal-weight individuals is the only other study of sex-based differences in visual food cue responses that has held menstrual cycle phase constant (12). Differences in neuronal response to visual food cues have been demonstrated in different cycle phases, so this may considerably impact results (39-41). Other differences between previous and current findings may be explained by different MR field strengths (11,13,37), which can impact signal-to-noise ratio; inclusion of only lean participants or only participants with overweight/obesity (11-13,37); lack of controlled meal composition and size prior to fed state measurements (13); different meal administration timing (9,11,13,37); and lack of a prestudy run-in diet (9,11,13,37,38). The current findings may relate to differences in obesity propensity.

The secondary aim of the current study was to assess the impact of obesity propensity on sex-based differences in neuronal response to food cues. Although OP vs. OR differences, across sex, were not observed when comparing hedonic with neutral foods, in either fasted or fed states, greater ACC, dLPFC, and insula responses were observed in OP vs. OR when comparing foods with objects while fed. This suggests a continued reward response to foods in OP post satiation, not observed in OR. A sex-by-group interaction observed in the nucleus accumbens (fed state, foods > objects) suggests that this group difference was driven by the men in the sample, with greater OP vs. OR response in men but not in women. Similar results were observed in the ACC and insula, with greater OP response in men but not in women. This further supports that weight propensity may play a lesser role in food responses in women than in men. Although women in the sample had greater percent body fat than men, this does not appear to drive the observed sex-based differences in neuronal responses (i.e., W > M to hedonic foods in nucleus accumbens and insula), as associations between neuronal response and percent body fat were not observed when accounting for sex.

A potential limitation of the current study is that although women were scanned in the same menstrual cycle phase, we did not assess variations in sex-based differences across different menstrual cycle phases. In future studies, assessing women during multiple phases would allow for investigation of how menstrual cycle phase affects sex-based differences in response to food cues. It could also be useful to include gonadal hormone measures to determine how estrogen and testosterone impact food cue responses and how this interacts with sex-based differences. Order of hunger state was not counterbalanced in the current study, which may also be a limitation. Sample sizes in the current study are another potential limitation. As they were not large enough to provide appropriate power for a whole-brain analysis, it is possible that additional regions with sex differences could have been missed with the ROI approach used in the current study. Sample sizes for testing interactions may also have been too small. Also, although the secondary analysis of obesity proneness aimed to assess effects independent of obesity that make an individual prone to obesity, the multivariate nature of this construct makes it difficult to parse which aspects of obesity proneness (e.g., BMI, genetic propensity, frequency of past dieting behavior, history of weight instability) drive differences in brain response. Additionally, although sex-based differences in dietary restraint were not observed in the current study, this has been observed in previous studies (42). Given that higher levels of dietary restraint may relate to hyperactive response to food cues in reward-related brain regions (43), it is possible that sex-based differences in neuronal response to food cues may relate to differences in dietary restraint. Future studies with larger sample sizes can investigate this further.
Conclusion

The current study found sex-based differences (W > M) in the response to hedonic foods while participants were in the fasted state but not in the fed state. These differences were specific to the more nuanced comparison of hedonic vs. neutral foods and were not present when simply comparing all foods with nonfood objects. These results suggest that women may be more sensitive than men to salient and rewarding aspects of food when fasted. The current findings also suggest that reward and homeostatic responses may have less to do with weight gain propensity. Additional research is warranted to further delineate the relationships between sex and neuronal responses to food cues, such as studies with larger sample sizes, which would allow for whole-brain analyses, and studies that can examine neuronal responses in different menstrual cycle phases.

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References

1. Courtenay WH, McCrea DR, Meriggi JR. Gender and ethnic differences in health beliefs and behaviors. J Health Psychol 2002;7:219-231.
2. Baker AH, Wardle J. Sex differences in fruit and vegetable intake in older adults. Appetite 2003;40:269-275.
3. Wardle J, Haase AM, Steptoe A, Nillapun M, Jormuttiwes K, Bellsile F. Gender differences in food choice: the contribution of health beliefs and dieting. Ann Behav Med 2004;27:107-116.
4. Streigel-Moore RH, Rosselli F, Perrin N, et al. Gender difference in the prevalence of eating disorder symptoms. Int J Eat Disord 2009;42:471-474.
5. Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. JAMA 2010;303:235-241.
6. Lovejoy JC, Sainsbury A. Sex differences in obesity and the regulation of energy homeostasis. Obes Rev 2009;10:154-167.
7. Schur EA, Kleinmans NM, Goldberg J, Buchwald D, Schwartz MW, Maravilla K. fMRI differences in obese humans in response to high vs. low energy food. Neuroimage 2004;23:1486-1493.
8. Mehta S, Melhorn SJ, Smeraglio A, et al. Regional brain response to visual food cues in men and women: relation to fasting and feeding. Am J Clin Nutr 2011;93:377-383.
9. Schur EA, Kleiman MS, Goldberg J, Buchwald D, Schwartz MW. Human brain response to the anticipation of weight loss and maintenance strategies. Pub Health Nutr 2012;15:133-140.
10. Murdang DL, Cox JE, Cook EW, 3rd, Weller RE. fMRI reactivity to high-calorie food pictures predicts short- and long-term outcome in a weight-loss program. Neuroimage 2012;59:2709-2721.
11. Cornier MA, McFadden KL, Thomas EA, Bechtell JR, Tregellas JR. Propensity to obesity impacts the neuronal response to energy imbalance. Front Behav Neurosci 2013;7:92.
12. Stoeckel LE, Cox JE, Cook EW, 3rd, Weller RE. Motivational state modulates the hedonic value of food images differently in men and women. Appetite 2007;48:139-147.
13. Becker JB, Grunwald GK, Melanson EL, Forster JE, Seagle HM, Sharp TA, Hill JO. Differences in food choice: the contribution of health beliefs and dieting. Appetite 2003;40:269-275.
14. Bailer KA, Sharp TA, Kealey EH, Besseden H. The effects of overeating on spontaneous physical activity in obesity prone and obesity resistant humans. Obesity (Silver Spring) 2012;20:2186-2193.
15. Schmidt SL, Harmount KA, Sharp TA, Kealey EH, Besseden H. The effects of overeating on spontaneous physical activity in obesity prone and obesity resistant humans. Obesity (Silver Spring) 2012;20:2186-2193.
16. Cornier MA, McFadden KL, Thomas EA, et al. Differences in the neuronal response to food in obesity-resistant as compared to obesity-prone individuals. Physiol Behav 2013;110:111-118.
17. Schmidt SL, Kealey EH, Horton TJ, VonKnaul S, Besseden H. The effects of short-term overeating on energy expenditure and nutrient oxidation in obesity-prone and obesity-resistant individuals. Int J Obes (Lond) 2013;37:1192-1197.
18. Thomas EA, Bechtell JL, Vestal BE, et al. Eating-related behaviors and appetite during energy imbalance in obese-prone and obese-resistant individuals. Appetite 2013;65:96-102.
19. Cornier MA, Shott ME, Thomas EA, et al. The effects of energy balance, obesity-proneness and sex on the neuronal response to sweet taste. Behav Brain Res 2015;278:446-452.
20. Garner DM, Olmsted MP, Bohr Y, Garfinkel PE. The Eating Attitudes Test: psychometric features and clinical correlates. Psychol Med 1982;12:871-878.
21. Radloff LS. The CES-D scale: a self-report depression scale for research in the general population. Appl Psychol Measurement 1977;1:385-401.
22. Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. J Psychosom Res 1985;29:71-83.
23. Grunwald GK, Melanson EL, Forster JE, Seagle HM, Sharp TA, Hill JO. Comparison of methods for achieving 24-hour energy balance in a whole-room indirect calorimeter. Obes Res 2003;11:752-759.
24. Burger KS, Cornier MA, Ingebrigtsen J, Johnson SL. Assessing food appeal and desire to eat: the effects of portion size & energy density. Int J Behav Nutr Phys Act 2010;7:8.101.
25. Pelchat ML, Johnson A, Chan R, Valdez J, Ragland JD. Images of desire: food-craving activation during fMRI. Neuroimage 2004;23:1486-1493.
26. Carnell S, Gibson C, Benson L, Ochner CN, Geliebter A. Neuroimaging and obesity: current knowledge and future directions. Obes Rev 2012;13:43-56.
27. Murdang DL, Cox JE, Cook EW, 3rd, Weller RE. fMRI reactivity to high-calorie food pictures predicts short- and long-term outcome in a weight-loss program. Neuroimage 2012;59:2709-2721.
28. Cornier MA, McFadden KL, Thomas EA, Bechtell JL, Tregellas JR. Propensity to obesity impacts the neuronal response to energy imbalance. Front Behav Neurosci 2013;5:9.52.
29. Kelley AE, Baldo BA, Pratt WE, Will MJ. Corticostriatal-hypothalamic circuitry and food motivation: integration of energy, action and reward. Physiol Behav 2005;86:773-795.
30. Van Vugt DA. Brain imaging studies of appetite in the context of obesity and the menstrual cycle. Hum Reprod Update 2010;16:276-292.
31. Lawrence NS, Hinton EC, Parkinson JA, Lawrence AD. Nucleus accumbens response to food cues predicts subsequent snack consumption in women and increased body mass index in those with reduced self-control. Neuroimage 2012;63:415-422.
32. Demos KE, Heatherton TF, Kelley WM. Individual differences in nucleus accumbens activity to food and sexual images predict weight gain and sexual behavior. J Neurosci 2012;32:5549-5552.
33. Stoeckel LE, Cox JE, Cook EW, 3rd, Weller RE. Motivational state modulates the hedonic value of food images differently in men and women. Appetite 2007;48:139-147.
34. Becker JB, Grunwald GK, Melanson EL, Forster JE, Seagle HM, Sharp TA, Hill JO. Differences in food choice: the contribution of health beliefs and dieting. Appetite 2003;40:269-275.
35. Lawrence NS, Hinton EC, Parkinson JA, Lawrence AD. Nucleus accumbens response to food cues predicts subsequent snack consumption in women and increased body mass index in those with reduced self-control. Neuroimage 2012;63:415-422.
36. Demos KE, Heatherton TF, Kelley WM. Individual differences in nucleus accumbens activity to food and sexual images predict weight gain and sexual behavior. J Neurosci 2012;32:5549-5552.
37. Kelley AE, Baldo BA, Pratt WE, Will MJ. Corticostriatal-hypothalamic circuitry and food motivation: integration of energy, action and reward. Physiol Behav 2005;86:773-795.
38. Van Vugt DA. Brain imaging studies of appetite in the context of obesity and the menstrual cycle. Hum Reprod Update 2010;16:276-292.
39. Lawrence NS, Hinton EC, Parkinson JA, Lawrence AD. Nucleus accumbens response to food cues predicts subsequent snack consumption in women and increased body mass index in those with reduced self-control. Neuroimage 2012;63:415-422.
40. Demos KE, Heatherton TF, Kelley WM. Individual differences in nucleus accumbens activity to food and sexual images predict weight gain and sexual behavior. J Neurosci 2012;32:5549-5552.
41. Becker JB, Grunwald GK, Melanson EL, Forster JE, Seagle HM, Sharp TA, Hill JO. Differences in food choice: the contribution of health beliefs and dieting. Appetite 2003;40:269-275.
42. Stoeckel LE, Cox JE, Cook EW, 3rd, Weller RE. Motivational state modulates the hedonic value of food images differently in men and women. Appetite 2007;48:139-147.
43. Becker JB, Grunwald GK, Melanson EL, Forster JE, Seagle HM, Sharp TA, Hill JO. Differences in food choice: the contribution of health beliefs and dieting. Appetite 2003;40:269-275.
44. Stoeckel LE, Cox JE, Cook EW, 3rd, Weller RE. Motivational state modulates the hedonic value of food images differently in men and women. Appetite 2007;48:139-147.
45. Becker JB, Grunwald GK, Melanson EL, Forster JE, Seagle HM, Sharp TA, Hill JO. Differences in food choice: the contribution of health beliefs and dieting. Appetite 2003;40:269-275.