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Short Communication

Responsivity to food stimuli in obese and lean binge eaters using functional MRI

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Abstract

Functional neuroimaging was employed to study 10 obese and 10 lean healthy young right-handed women, divided equally into binge and non-binge eaters. Subjects were presented with visual and auditory stimuli of binge type foods, non-binge type foods, and non-food stimuli in the fMRI scanner. Brain areas activated by both the visual and auditory stimuli across all individual subjects within a particular group was observed only for the binge food stimuli in the obese binge eaters, in the right premotor area, involved in planning of motor behavior. For four of the five obese binge eaters, the activation was in the ventral premotor cortex adjacent to the oral region, and may reflect past or concurrent motor planning about eating binge foods. Because a random effects group analysis has not yet been completed, this should be considered a preliminary report.

Keywords: Binge eating disorder; Brain imaging; Magnetic resonance imaging; Obesity; Psychological scales

Introduction

Functional brain imaging has been advancing rapidly from studies of sensation and cognition, to major psychiatric disorders, such as schizophrenia and depression, and more recently to eating disorders and obesity (Chowdhury & Lask, 2001). Using SPECT, Karhunen, Lappalainen, Vanninen, Kuikka, and Uusitupa, (1997) found increased activation in the right parietal and temporal lobe after visual food exposure in obese but not lean subjects. Wang et al. (2004) employing PET showed that food stimuli activated the orbitofrontal cortex (OFC) in lean individuals. In a recent fMRI study, healthy normal-weight women had activation of the medial and dorsolateral prefrontal cortex in response to high calorie food stimuli (Killgore, Young, Femia, Bogorodzki, Rogowska and Yurgelun-Todd, 2003). In the only imaging study in BED, Karhunen, Vanninen, Kuikka, Lappalainen, Tiihonen and Uusitupa (2000) using SPECT, observed greater left prefrontal and frontal activation following food exposure in BED than non-BED obese subjects. Hirsch, Moreno, and Kim (2001) developed an fMRI paradigm with multisensory stimuli to identify conjointly activated brain areas. We therefore employed fMRI, which has better spatial resolution than PET or SPECT, to examine conjoined brain activation to visual and auditory stimuli in obese and lean individuals, who were binge or non-binge eaters. We predicted that the obese binge eaters at the high end of both the weight and eating disorder spectrum would exhibit the most activation, especially in frontal and prefrontal cortical areas (involved in inhibition, decision making, ingestive behavior, and reward) in response to binge food stimuli.

Methods

Subjects

Ten obese (BMI = 29–41) and 10 lean (BMI 20–24) right-handed women participated. Exclusions included significant health problems, medications influencing body weight, smoking, alcohol >3 drinks/day or other substance dependence, suicidal ideation, psychotic disorder, claustrophobia, and presence of metallic implants, non-removable metallic

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dental retainers, or pacemakers. Subjects were weight stable for the past 3 months (±5%) and premenopausal, not pregnant or lactating, and not in treatment for obesity or binge eating. Candidates signed an IRB-approved consent form.

Binge eating status was assessed with the questionnaire on eating and weight patterns (QEWP) (Yanovski, 1993) and confirmed by interview. Binge eaters reported regular overeating with loss of control, without meeting full BED criteria (subthreshold BED), and non-binge eaters reported no regular overeating. Subjects also completed the binge eating scale (BES) (Gormally, Black, Daston, & Rardin, 1982), the Dutch eating behavior questionnaire (DEBQ) (Van Strien, Frijters, Bergers, & Defares, 1986), a depression scale (Zung, Richards, & Short, 1965), and a self-esteem scale (Rosenberg, 1965). Measurements were made of weight, height, and body fat (BIA; Tanita). Subjects had a 2090 kJ (650 kcal) meal of tuna, chicken, or egg salad sandwich, with juice or soda (no caffeine), and a fruit 3 h before the scan. The 45 min scan was performed between 1 and 3 pm. Subjects were told the purpose of the study afterwards.

Procedure

Subjects were positioned in a 1.5-Tesla twin-speed scanner (GE) with quadrature RF head coil. The obese subjects fit easily into the scanner (bore diam. = 60 cm). Functional T2*-weighted images with a gradient echo pulse sequence (echo time = 60 ms, repetition time = 4 s, flip angle = 60°) were obtained with matched anatomic high resolution T_1*-weighted scans. During each run, 36 whole brain scans were made, each consisting of 25 contiguous slices (4 mm thick), parallel to the AC/PC line (19×19 cm field of view, 128×128 matrix size, 1.5×1.5 mm in plane resolution).

Subjects were presented with visual and auditory stimuli (transmitted through goggles and a headset) representative of binge type foods, non-binge type foods, and neutral non-food stimuli. The stimuli were presented in runs of 10 consecutive 4 s epochs, with pre- and post- 40-s baseline epochs. Subjects were asked to attend to the stimuli and queried afterwards. A Latin-Square paradigm employed two similar, but not identical, nonconsecutive stimuli runs for binge foods (desserts and high fat salty snacks), non-binge foods (fruits and vegetables), and non-food items (office supplies). The auditory stimuli (similar to the visual stimuli) were recorded two-word names (e.g. chocolate brownie) repeated twice to fill the 4-s epoch. While still in the scanner after each run, subjects verbally rated hunger and desire to eat on a scale from 0 to 10. After leaving the scanner, they rated color printed individual binge and non-binge food stimuli on likeability and binge eating likelihood (−100 to +100). These ratings allowed analysis of potential subjective factors and helped ensure subject alertness.

Because of the high variability in anatomical structure for regions associated with food and reward, such as the OFC (Rolls, 2000), and their proximity to the sinuses, introducing artifactual errors, individual brain analysis was given priority over group analysis. Specific brain activation areas in each brain were labeled with anatomical names and Brodmann's areas (BA) based on the Tailarach & Tournox (1988) atlas and compared across brains within a group (Kim, Relkin, Lee, & Hirsch, 1997; Hirsch et al., 2001), blind to the particular group category. Conservation was defined as activation of the same brain area in all individual subjects within a group, 5/5 (strict), or in 4/5 (lenient).

Images for each subject were computationally aligned, and spatially smoothed with a two-dimensional Gaussian filter (2–3 voxels at half-height). Significant signal changes with a voxel-by-voxel analysis for each run were identified by subtraction of mean baselines from stimulation epochs, and subjected to *t*-test with $P < .0001$ to correct for multiple comparisons (Hirsch et al., 2001). Brain activation areas across the two sensory modalities were conjoined to obtain unique activated areas, with clusters of >2 adjacent voxels.

Statistics

Subject characteristics and psychological scores were analyzed with MANOVA. Ratings during and after the scans were analyzed with repeated ANOVA followed by post-hoc tests. Weight and binge eating categories were entered as fixed factors. Two tailed $\alpha = 0.05$ was required for significance (SPSS 12.0).

Results

The obese subjects had a higher body weight ($P < 0.0001$), BMI ($P < 0.0002$) and percentage body fat ($P < 0.001$) than the lean subjects, without interactions by binge eating category (Table 1). There were no group differences in age or in depression and self-esteem. The binge eaters had higher scores on the BES ($P < 0.01$), the total DEBQ ($P < 0.006$) and all three subscales ($P < 0.02$), without a weight-group interaction.

Conserved activation (strict) was seen only following binge food stimuli for the obese binge eaters in the right precentral gyrus (GPrC) in the premotor area (BA 6) (Table 2). For four of these five subjects, the conserved area was in the lower premotor area or ventral premotor cortex. Conserved activation (lenient) following binge food stimuli was observed bilaterally in the GPrC and inferior frontal gyrus (GFi), and in the left lingual (GL) and fusiform gyrus (GF) in the obese binge eaters as well as in the left inferior occipital gyrus (GOi) and the right GL in the lean non-binge eaters. For the non-binge food stimuli, the right GFi and the right GF were activated in the obese binge eaters, and the right lingual gyrus (GL) as well as the left middle occipital (GOm) and left middle temporal gyrus (GTm) in the lean non-binge eaters. For the non-food stimuli, no conserved areas were activated in any group (Fig. 1).

During the scan, following the stimuli runs, across all subject groups, hunger ratings and desire to eat were highest following binge food stimuli ($P < 0.001$), without group interactions. After the scan, on likeability and binge eating likelihood, the binge foods were rated higher than the non-binge foods ($P < 0.002$) across subject groups without interactions.

Table 1
Categorical and demographic characteristics and psychological scores of the subjects (mean±SD)

Weight category	Binge eat	*n*	Age	Wt (kg)	BMI	Body fat (%)[a]	Zung[b]	RSE[c]	BES[d]	DEBQ[e] emotional	DEBQ[e] restraint	DEBQ[e] external	DEBQ[e] Total
Obese	Yes	5	23.4±2.5	80.4[a]±10.9	32.3[a]±4.6	42.5[a]±6.9	46.0±12.6	16.6±5.5	14.7[a]±12.7	27.6[a]±14.2	20.8[a]±7.6	23.0[a]±6.7	71.4[a]±24.4
	No	5	21.4±0.5	86.3[a]±14.1	33.5[a]±6.5	40.2[a]±8.2	43.2±6.9	16.0±3.7	5.2[b]±3.2	19.6[b]±9.6	13.0[b]±8.9	18.6[b]±1.1	53.2[b]±21.8
Lean	Yes	5	20.8±1.6	61.8[b]±5.3	22.4[b]±1.0	30.3[b]±6.7	41.8±4.1	18.2±1.3	12.0[a]±6.0	26.8[a]±12.7	10.1[a]±4.5	30.0[a]±6.0	74.2[a]±25.5
	No	5	21.2±0.8	61.7[b]±7.2	21.9[b]±1.3	26.1[b]±5.9	38.5±8.2	15.2±3.1	3.0[b]±2.2	6.6[b]±2.9	4.1[b]±1.8	20.0[b]±2.5	35.6[b]±9.0

[a] BIA.
[b] Zung depression.
[c] Rosenberg self-esteem.
[d] Gormally binge eating scale.
[e] Dutch eating behavior questionnaire (subscales: Emotional, Restraint, External).
Note: Different superscripts within a given column indicate significant differences.

Discussion

As predicted, brain activation areas were greatest for the obese binge eaters. Only they showed conserved activation (5/5) in response to binge food stimuli in the frontal precentral area, involved in planning of motor behavior (Chung, Han, & Kim, 2000), primarily in the ventral premotor cortex adjacent to the mouth region of the motor homunculus. This may reflect encoded or concurrent motor planning (Bischoff-Grethe, Goedert, Willingham, & Grafton, 2004) about eating such foods, including mouth movement preparation. It is unlikely that actual mouth movements occurred because the primary motor cortex was not conserved.

A more complex picture emerges using a lenient (4/5) conservation criterion, with the obese binge eaters, in response to binge food stimuli, still exhibiting the most activation areas, now bilaterally in the GPrC and GFi. The GFi is in the dorsolateral prefrontal cortex and OFC (BA 44 and 45, 46, 47) and has verbal (mainly left side) and spatial processing functions and is a convergence zone for taste and food-related stimuli (Rolls, 2000; Kringelbach, O'Doherty, Rolls, & Andrews, 2003). Activation was also seen in the left GL and left GF, visual areas for object recognition (Nakamura, Kawashima, Sato, Nakamura, Sugiura and Kato, 2000), which may reflect the salience of these stimuli in this group. The only other group showing conserved activated areas, although fewer, was at the opposite end of the spectrum, the lean non-binge eaters. However, unlike the obese binge eaters, most activated areas were in response to non-binge food stimuli, which may have more salience for them. This group additionally showed activation in the left inferior occipital gyrus (secondary visual area) in response to binge food stimuli, in the GOm (secondary visual area) and GTi (secondary visual and auditory area) in response to non-binge food stimuli. This activation pattern, mainly in secondary sensory areas, differs as well from the cognitive and motor planning areas in the obese binge eaters.

The lack of conserved subcortical activation observed, especially in the hypothalamus, known to be involved in food intake (Hellström, Geliebter, Näslund, Schmidt, Yahav and Hashim, 2004) should not be viewed as negative evidence. The fMRI scan was designed to be global, thus favoring detection of activation from the large cortical areas. Moreover, lack of substantive activation in the OFC may be due to artifactual signal drop. Lastly, because the individual fMRI analysis was calculated for a very large number of voxels, it is possible, even with quite strong statistical corrections, to obtain significant results in some brain areas in individual subjects. Since a random effects group analysis has not yet been completed, the results should be considered preliminary. Individual and group analyses can be used to complement each other (St. Onge et at., 2005).

Consistent with the SPECT study by Karhunen et al. (2000), there were more activation areas in the prefrontal cortex of obese binge eaters compared to obese non-binge eaters in response to food stimuli, especially binge food stimuli. Prior imaging studies comparing lean and obese subjects, which did not identify subjects with binge eating, more common in the obese (Yanovski, 1993), may have misattributed the contribution of binge eating to obesity.

Table 2
Conserved brain hemisphere activation areas for three categories of stimuli: there was no activation in any group by the non-food stimuli

Weight	Binge eat	*n*	Binge foods			Non-binge foods		
				Right	Left		Right	Left
Obese	Yes	5	GPrC (6)[a]	5[b]	4[b]			
			GFi (44)	4	4	GFi (44)	4	
			GL (17,18)	4				
			GF (18,19)	4		GF (18,19,37)	4	
	No	5	–	–				
Lean	Yes	5	–	–				
	No	5	GL (17,18)	4		GL (17,18)	4	
			GOi (18,19)	4				
						GOm (19)		4
						GTm (21,39)		4

GFi, Inferior frontal gyrus; GPrC, Precentral gyrus (premotor area); GL, Lingual gyrus; GF, fusiform gyrus; GOi, Inferior occipital gyrus; GOm, Middle occipital gyrus; GTm, Middle temporal gyrus.
[a] Numbers in parentheses indicate predominant Brodmann areas.
[b] Conserved per group of five subjects.

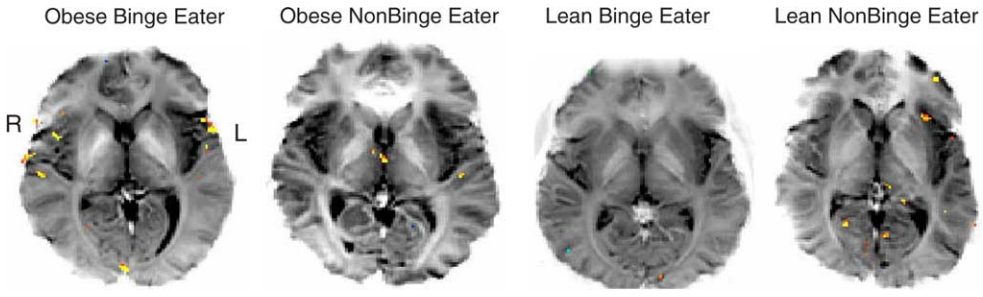

Fig. 1. Conjoined activation areas for visual and auditory stimuli in an axial brain slice (11th of 25) for a representative subject per group in response to binge food stimuli. Activation (>2 adjacent voxels) were observed for: obese binge eater—right (R) and left (L) GPrC (6), R superior temporal gyrus (22,42), R cuneus (17*), L GFi* (45,46). Obese non-binge eater—R thalamus, R fornix, L superior temporal gyrus (22). Lean binge eater—R cuneus (17). Lean non-binge eater—L GFi (45,46), L cingulate gyrus (29,30), L cuneus (31), R cuneus (31). Note: Brodmann areas are in parentheses. Areas conserved across >4/5 within a group are italicized above.

Surprisingly, there was no conserved activation in the obese non-binge eaters or the lean binge eaters, suggesting that both obesity and binge eating had to be present (or absent). BMI or percentage body fat did not differ between the obese non-binge eaters and the obese binge eaters, or between the lean binge eaters and the lean non-binge eaters, ruling out a potential contributing factor. Likewise, scores on the BES and DEBQ were higher for the binge eaters regardless of weight category. Also, ratings of hunger and desire to eat were higher for the binge foods regardless of subject group as were ratings for liking of the binge foods and likelihood to binge eat, making these unlikely mediating factors.

In conclusion, fMRI revealed the greater number of brain activation areas in the obese binge eaters, particularly in the frontal premotor area, in response to binge food stimuli, which may reflect past encoded or concurrent motor planning about ingesting such foods.

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