International Journal of Obesity (2009) 33, 1063–1073

0307-0565/09 $32.00
www.nature.com/ijo

ORIGINAL ARTICLE

Obese adults have visual attention bias for food cue images: evidence for altered reward system function

EH Castellanos[1,2], E Charboneau[1,2,3], MS Dietrich[1,2,4], S Park[1,5], BP Bradley[6], K Mogg[6] and RL Cowan[1,2,3,7,8]

[1]*Psychiatric Neuroimaging Program, Vanderbilt University School of Medicine, Nashville, TN, USA;* [2]*Department of Psychiatry, Vanderbilt University School of Medicine, Nashville, TN, USA;* [3]*Vanderbilt Addiction Center, Vanderbilt University School of Medicine, Nashville, TN, USA;* [4]*Department of Nursing, Vanderbilt University School of Medicine, Nashville, TN, USA;* [5]*Department of Psychology, Vanderbilt University, Nashville, TN, USA;* [6]*Emotion and Motivation Laboratory, Division of Clinical Neuroscience, School of Psychology, University of Southampton, Southampton, UK;* [7]*Department of Radiology, Vanderbilt University School of Medicine, Nashville, TN, USA and* [8]*Vanderbilt University Institute of Imaging Science, Vanderbilt University, Nashville, TN, USA*

Background*:* The major aim of this study was to investigate whether the motivational salience of food cues (as reflected by their attention-grabbing properties) differs between obese and normal-weight subjects in a manner consistent with altered reward system function in obesity.

Methodology/Principal Findings: A total of 18 obese and 18 normal-weight, otherwise healthy, adult women between the ages of 18 and 35 participated in an eye-tracking paradigm in combination with a visual probe task. Eye movements and reaction time to food and non-food images were recorded during both fasted and fed conditions in a counterbalanced design. Eating behavior and hunger level were assessed by self-report measures. Obese individuals had higher scores than normal-weight individuals on self-report measures of responsiveness to external food cues and vulnerability to disruptions in control of eating behavior. Both obese and normal-weight individuals demonstrated increased gaze duration for food compared to non-food images in the fasted condition. In the fed condition, however, despite reduced hunger in both groups, obese individuals maintained the increased attention to food images, whereas normal-weight individuals had similar gaze duration for food and non-food images. Additionally, obese individuals had preferential orienting toward food images at the onset of each image. Obese and normal-weight individuals did not differ in reaction time measures in the fasted or fed condition.

Conclusions/Significance: Food cue incentive salience is elevated equally in normal-weight and obese individuals during fasting. Obese individuals retain incentive salience for food cues despite feeding and decreased self-report of hunger. Sensitization to food cues in the environment and their dysregulation in obese individuals may play a role in the development and/or maintenance of obesity.

International Journal of Obesity (2009) **33,** 1063–1073; doi:10.1038/ijo.2009.138; published online 21 July 2009

Keywords: human obesity; incentive salience; eye tracking; visual probe; reward system

Introduction

Detecting and approaching food in the external environment is perhaps the most essential evolutionary adaptation for survival.[1] However, in the modern Western environment, this survival mechanism may contribute greatly to the obesity epidemic. Currently, over 30% of the US adult population is obese[2] with obesity-associated comorbidities reducing the life expectancy of severely obese persons by an estimated 5–20 years.[3]

Visual food cues arrive via many forms of media including television, the internet, and print. The ability of these ubiquitous visual stimuli to interact with the brain's reward system and trigger motivated behavior may play a significant role in excessive food intake and resultant obesity. Understanding how visual food cues interact with the brain's reward system to direct attention is of practical, ecological importance in determining the role of food cues in the development and maintenance of obesity. As visual food cue exposure is a potentially modifiable environmental variable,

Correspondence: Dr RL Cowan, Department of Psychiatry, Vanderbilt University School of Medicine, 1601 23rd Avenue South, Suite 3057, Nashville, TN 37212, USA.
E-mail: ronald.l.cowan@vanderbilt.edu or www.cowanlab.org
Received 26 November 2008; revised 7 May 2009; accepted 2 June 2009; published online 21 July 2009

better comprehension of food cue effects on attention is essential in advising the development of interventions to shape behavioral change.

The mesocorticolimbic dopamine system—most notably the ventral tegmental area (VTA), ventral striatum and the nucleus accumbens (NAc)—mediates the processing of reward and pleasure.[4] Endogenous opioids and dopamine play a key role in influencing communication between these structures. Both the VTA and NAc are primary targets for all drugs of addiction, and the ability of a drug to activate this system is the key component in determining its reward value and ability to motivate behavior.[5] Drugs of addiction are not the only substances which can activate this reward pathway. Palatable foods, especially those high in sugar and/or fat, have been shown to release brain opioids and dopamine in the VTA and NAc in a similar manner to addictive drugs.[6–13]

Alterations in brain function become relevant to human conditions when translated into altered patterns of behavior. The incentive-sensitization model of addiction postulates that addictive substances modify the dopaminergic mesolimbic system so that it becomes hyperresponsive to drug-related stimuli, allowing them to affect behavior by inducing a motivational state of craving.[14,15] This motivational state, mediated by increasing dopamine in the brain, serves to draw attention to events predictive of reward, including drug-related stimuli,[16,17] and can be measured as attentional bias. Exposure to drug cues has been shown to induce drug craving in addicts and can increase drug use.[18–20] Attentional bias for drug-related cues has been shown in tobacco,[21,22] alcohol,[23,24] caffeine,[25] opiates[26] and cannabis[27] users.

Attention bias for drug or food-related cues can be assayed using eye-tracking technology combined with a visual probe reaction time task. Eye-tracking technology, a noninvasive method for measuring gaze, provides a useful tool for gathering objective, quantitative information about visual attention to motivationally salient cues. Several factors contribute to the utility of eye tracking as a measure of visual attentional bias: (1) eye movements are important in targeting salient environmental cues; (2) cognition and perception depend on the process of obtaining information from the visual environment and (3) eye tracking provides a noninvasive, quantitative measurement of visual information processing.[28] Eye tracking has been used to demonstrate attentional bias for drug stimuli in tobacco[29–32] and cannabis users.[33] The visual probe response task measures the effects of stimulus attentional preference on reaction time.

Evidence from animal models and human neuroimaging studies supports the ability of palatable food to activate and alter the brain's reward circuitry similar to addictive drugs. However, it is not clear whether food has similar motivational properties as indexed by the ability to capture and hold attention, and whether attentional responses to food cues differ between obese and nonobese individuals. Most previous studies of attentional bias have examined biases for food-related words (rather than pictures) and have not examined obesity[34–36] but results have been inconsistent.[34] Studies of attentional processing of food cues in obesity have been limited, and have produced mixed findings. For example, in a study using a modified Stroop test, Braet and Crombez[37] found greater interference of food words in obese children than normal-weight children, whereas, using a different attentional task, Soetens and Braet[38] found no evidence of attentional bias to food cues in overweight adolescents. The latter studies also used words, rather than pictorial images of food, as stimuli. An advantage of using pictures is that they have greater ecological validity than word stimuli and thus may be more likely to reveal attentional biases. An event-related potential study compared obese and normal-weight individuals on their neural response to food images, and found no difference between the groups; however, this study did not specifically measure visuospatial attentional bias.[39] Thus, this study extended previous research by investigating attentional biases for food cues in obese and nonobese individuals, while using naturalistic visual stimuli (that is, images of food) and continuous monitoring of the focus of visual attention (eye tracking).

We used an eye-tracking paradigm in combination with a visual probe task, which had been modified from studies of addiction,[29–32] to assess attentional biases to food stimuli in healthy obese and normal-weight women. The primary objective of the study was to examine visual attention for food cues in obese versus normal-weight adults in hungry and sated conditions. We predicted that the fasting manipulation would increase both subjective hunger and attentional bias for food cues. Furthermore, we hypothesized that obese adults would show increased attentional bias for food cues compared with normal-weight individuals, and that satiety would have a reduced effect on their attentional bias for food cues as measured by gaze orientation, duration of gaze fixation, and manual reaction time to a visual probe. Confirmation of these hypotheses would be consistent with altered incentive salience for food cues, providing additional support for altered reward system function in obesity.

A secondary objective of the study was to examine relationships between attentional biases for food cues and personality and eating-style traits, which have been previously associated with dysfunction of the reward system and/or obesity. These measures included the Tridimensional Personality Questionnaire (TPQ),[40] Behavioral Inhibition/Activation System Scales (BIS/BAS),[41] Three Factor Eating Questionnaire (TFEQ)[42] and Dutch Eating Behavior Questionnaire (DEBQ).[43] The BIS/BAS scales were included following recent evidence indicating that BAS reward scores predict neural responses to palatable food cues in brain structures implicated in reward (for example, ventral striatum, VTA, amygdala).[44] The TFEQ has previously shown increased disinhibition and susceptibility to hunger in obese, relative to normal-weight, individuals,[45,46] whereas the TPQ includes a measure of reward dependence and has been previously used in studies of drug addiction.[47] The DEBQ assesses eating-style traits associated with overeating, including eating triggered by external food cues. We predicted that attentional bias for food cues would be associated with increased self-reported reward sensitivity and with eating-style traits associated with overeating, including external eating and disinhibition.

Methods

Participants

Study participants were recruited through the Vanderbilt Research Volunteer database, email advertisements, and flyers. Eligible participants were otherwise healthy women, aged 18–35 years and free of psychoactive or autonomically active medication. Potential participants were screened by telephone to verify inclusion criteria and to provisionally determine body mass index (BMI) for study group classification (BMI was verified at study enrollment). Subject BMI was calculated as the ratio of weight in kilograms to height in meters squared.[48] Subjects with BMI between 18.5 and 25 were classified as normal weight, and subjects with BMI equal to or greater than 30 were classified as obese. Exclusion criteria included a history of tobacco use, drug abuse or psychiatric or chronic medical illness as reported by study participants (subjects were not screened using laboratory measures). Forty subjects participated in the study, and data from 36 subjects are included in the analysis. Data from four subjects were excluded because two subjects did not return for the second study session, and two subjects failed eye-tracker calibration. Initial recruitment efforts did not target women exclusively; however, because study volunteers were predominantly women, the study was limited to women to improve homogeneity.

Ethics

Research participants provided written informed consent. The study was approved by the Vanderbilt University Institutional Review Board and conformed to the World Medical Association Declaration of Helsinki (http://www.wma.net/e/policy/b3.htm).

Design

See Figure 1 for a summary of the study design. To avoid order effect bias, subjects were randomly assigned to undergo the experimental task in the fasted or fed condition on the first study day and scheduled to return for the second study session at least 1 week later to minimize task habituation. For both fasted and fed conditions, subjects were instructed to fast at least 8 h before the study and refrain from alcohol use for at least 48 h before the study (subjects remained blind to randomization schema until arriving at the laboratory, at which point they were informed of the sequence of scheduled activities). Study sessions were scheduled in either the morning or afternoon according to the subjects' needs and effort was made to schedule the two sessions at the same time of day. Subject compliance was verified by interview before the experiment. On the day of the fasted condition, subjects completed the Hunger Scales[49] (described below), and then immediately took part in the experimental task (detailed below). On the day of the fed condition, subjects were asked to ingest to satiety a standardized liquid meal of vanilla-flavored Ensure-Plus (53% carbohydrate, 32% fat, 15% protein; 1.5 kcal ml^{-1}), which has been used in previous studies of adults.[50] The study meal was presented in an opaque glass, and participants were offered additional liquid meal until they declined further refills. Subjects then completed additional questionnaires (see below). Elapsed time between meal consumption and task initiation was ~30 min, and elapsed time between completing the Hunger Scales and task initiation was ~10 min. Pretask activities are further described below.

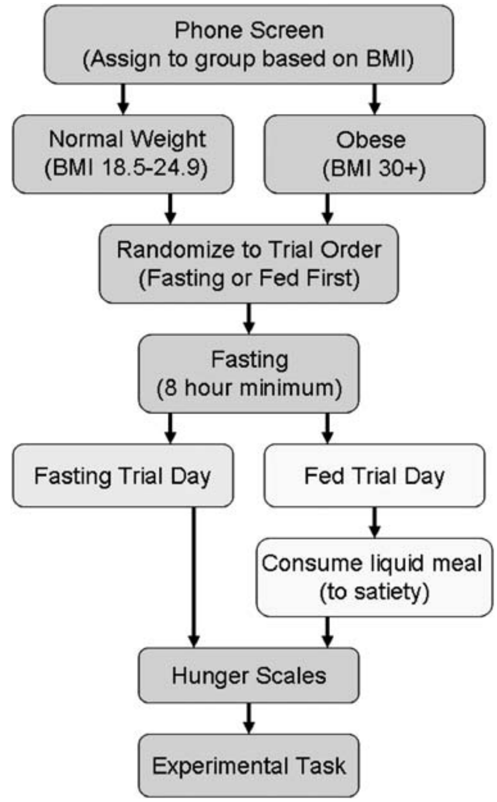

Figure 1 Study overview. After initial screening, obese and normal-weight groups were randomly assigned to complete either the fasted or fed condition first; these were a minimum of 1 week apart. Before each study day, subjects fasted for 8 h. In the fed condition, subjects consumed a standardized meal (Ensure-Plus) before the experimental task. The Hunger Scales were completed before the experimental task on both study days.

Procedures

Self-report measures. On the first study day, the subjects' BMI and visual acuity were measured. Personality and eating behavior data were collected using the TPQ,[40] BIS/BAS,[41] TFEQ[42] and DEBQ[43] to assess potential associations of personality and/or eating behavior traits with outcome variables.

BIS/BAS The BIS/BAS is a 24-item questionnaire that measures behavioral inhibition and three subscales of behavioral activation: Reward Responsiveness (5 items; score range 5–20), Drive (4 items; score range 4–16) and Fun-Seeking (4 items; score range 4–16). The BIS (Inhibition) scale is comprised of 7 items (score range 7–28). High measures of Drive using the BIS/BAS have been correlated with increased brain activation to food images in a fronto-striatal-amygdala-midbrain network.[44] Internal consistency values of the BIS/BAS scores in this study as measured by the Cronbach's Alpha statistic were 0.53 for the Drive scores, 0.69 for Fun-Seeking, 0.67 for Reward Responsiveness and 0.77 for the Inhibition scores.

DEBQ The DEBQ is a 33-item self-report which measures Emotional Eating (13 items; score range 0–5), which assesses eating in response to emotional arousal states (for example, anxiety), External Eating (10 items; score range 0–5), which assesses eating in response to external food cues, and Restraint (10 items; score range 0–5), which assesses the extent to which the individuals restrain food intake. Reliability of the scale scores in this study as measured using the Cronbach's Alpha statistic were 0.81 for the Emotional Eating subscale, 0.79 for the External Eating subscale and 0.77 for the Restraint subscale.

TFEQ The TFEQ is a 51-item questionnaire which measures Cognitive Restraint, Disinhibition and Susceptibility to Hunger.[42] Cognitive Restraint refers to the degree to which a person monitors and controls food intake (21 items; score range 0–21). Disinhibition assesses vulnerability to disruptions in eating control (16 items; score range 0–16). Susceptibility to Hunger measures awareness of and sensitivity to hunger (14 items; score range 0–14). Obese subjects have been reported to score higher on Disinhibition and Susceptibility to Hunger than normal-weight individuals.[45,46] Reliability of the scale scores in this study as measured using the Cronbach's Alpha statistic were 0.84 for the Cognitive Restraint subscale, 0.85 for the Disinhibition subscale and 0.79 for the Susceptibility to Hunger subscale.

TPQ The TPQ is a 100-item questionnaire that assesses three independent personality dimensions proposed in Cloninger's[40] biosocial theory of personality: Novelty Seeking (33 items; score range 0–33), Harm Avoidance (34 items; score range 0–34) and Reward Dependence (29 items; scores range 0–29). High scores on the Novelty Seeking subscale have been reported in substance use.[47] Reliability of the scale scores in this study as measured using the Cronbach's Alpha statistic were 0.78 for Novelty Seeking, 0.87 for Harm Avoidance and 0.41 for Reward Dependence.

Hunger Scales The Hunger Scales have been used in studies of selective attention to food in fasted and fed states in normal-weight individuals[36] and consist of four indices: (1) time since last meal, estimated to the nearest 15 min; (2) hunger rating, on a scale of 1–7, with 1 = not hungry at all and 7 = extremely hungry; (3) amount of favorite food subject could imagine eating at this time on a scale of 1–6, with 1 = none and 6 = as much as I could get; (4) time until next meal, estimated to the nearest 15 min. Because we controlled the duration of fasting and meal, questions 1 and 4 were not used for analysis.

For consistency of timing, subjects were administered specific questionnaires in specific sessions. Subjects completed the TPQ (administration time ~30 min) before the experimental task the day of the fasted condition. The day of the fed condition, subjects completed the BIS/BAS, TFEQ and DEBQ (total administration time ~30 min) after the standardized meal, an interval chosen to allow the postprandial hormonal response to peak by the time the experimental task took place (~40 min after eating).[51] As was previously mentioned, subjects completed the Hunger Scales[49] approximately 10 min before the experimental task in both sessions.

Experimental task. Eye-movement data were collected using a head-mounted ISCAN ETL-600 Eye Tracker (www.iscaninc.com, Burlington, MA, USA). Subjects' eye movements were calibrated with a five-point calibration procedure during which numbers were displayed to the top, right, left and bottom of a central cross. Participants then began the experimental task, modified from Mogg *et al*.[32] (see Figure 2 for an example). Each trial began with a central fixation cross for 1000 ms, followed by a pair of images, side by side, for

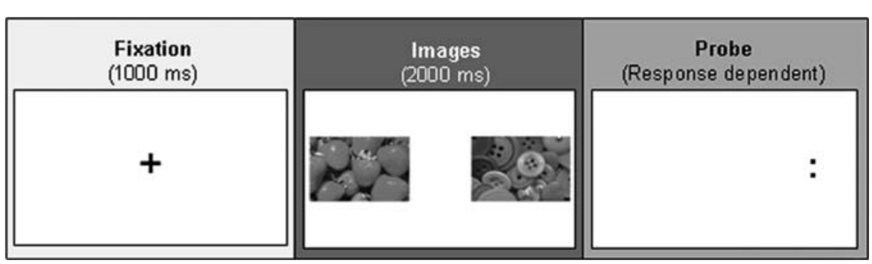

Figure 2 Example of trial events. Each trial displayed the fixation cross (1000 ms), followed by the paired images (2000 ms), and then the visual probe (until response).

2000 ms. In critical pairs, one image depicted food and the other a non-food item. After the image pair, a visual probe, consisting of a pair of dots (either ':' or '··') appeared in the position of one of the preceding images, remaining there until the subject gave a manual response. Although subjects were aware that their eye movements were being tracked, they were told that their primary goal was to correctly identify the visual probe. Subjects pressed one of two keyboard buttons to indicate the probe's identity. Subjects were instructed to look at the fixation cross at the start of each trial and respond to the visual probe as quickly and accurately as possible. The reaction time to the probe provides an index of attention at image offset; for example, if a subject is attending to the food image, she should be faster to respond to a probe which replaces it (that is, 'congruent' location), compared with a probe which replaces the non-food image (that is, 'incongruent' location).

The visual probe task was presented using Eprime software (Eprime 1.0; Psychology Software Tools Inc., Pittsburgh, PA, USA). Eye-movement data were recorded during food/non-food pairs trials. Gaze fixation measurements were sampled every 16 ms. Participants began with practice trials using colored shapes as the pictorial stimuli and were allowed to repeat practice trials until obtaining $\geqslant$85% accuracy. The pictorial stimuli used in the visual probe task consisted of 20 color images of high calorie food (for example, ice cream, pizza) and 20 color images of low calorie food (for example, apple, broccoli); each of these food images was individually matched as closely as possible for color, complexity and brightness to non-food images (for example, office supplies, tools). Additional 20 images of nature scenes, unrelated to food, were used as filler pairs. Filler pairs were randomly interspersed with food/non-food pairs to vary the task and reduce monotony. Each of the food/non-food image pairs was presented twice, with each food image appearing on the left and right equally. Visual probes appeared in the spatial location of the food and non-food images with equal frequency, and there was an equal number of probes of each type. All stimuli were constructed as 24-bit images with maximum dimensions of 300 pixels $\times$400 pixels and the distance between their inner edges corresponded to a minimum visual angle of 2.0° (at least one visual degree between the central fixation cross and inner edge of the picture). Images were presented on a 20-inch color computer monitor.

Data preparation

Eye-movement measures Data from practice and filler trials were discarded. Fixations were defined as occurring when (1) saccades remained stable within 1° for $\geqslant$100 ms, (2) the initial saccade occurred at least 100 ms after picture onset (fixations made before this time may reflect anticipatory eye movements) and (3) fixations were directed at either the left or right image (more than 1° wide of the central fixation position on the horizontal plane). Gaze fixations that were not on either image (that is, blank screen or off the screen) were not included in analysis of direction or duration bias. No fixation was recorded to either picture on 2% of trials; groups did not differ significantly in missing data ($P = 0.45$).

Two dependent measures were derived from eye-movement data, as used in previous studies:[29] (1) Direction bias and (2) Duration bias. Direction bias scores (signifying initial orienting of attention) were calculated by computing the number of trials when the first fixation was directed onto the food image as a proportion of all trials in which the first fixation was made to either image (proportion scores >0.5 reflect an orienting bias toward food images; $0.5 =$ no bias; <0.5 reflect an orienting bias toward non-food images). Duration bias scores (signifying maintenance of attention) were calculated by computing the average time spent gazing at food (summed across each trial) as a percentage of the total amount of time looking at either image, that is, the sum of all gaze fixations to both images (proportion scores >0.5 reflect a bias to look longer at food than non-food images; $0.5 =$ no bias; <0.5 reflect a bias toward non-food images).

Probe reaction time measure Data from practice and filler trials were discarded. Consistent with previous studies,[36] reaction time outliers were excluded from analyses if less than 200 ms, greater than 1500 ms or greater than 2 standard deviations above each participant's mean. Three participants had excessive missing data ($\geqslant$25% reaction times missing) and were excluded; the remainder had $\leqslant$5% of data missing, without significant group difference. Reaction time bias scores were calculated by subtracting the mean reaction time on trials when the probe replaced the food image ('congruent' trials) from the mean reaction time on trials when the probe appeared opposite to the food image ('incongruent' trials). Positive values of reaction time bias scores signified attentional bias toward food, negative values a bias away from food.

Statistical methods

Eye-movement data were obtained during the experimental task using the ISCAN Raw Eye Movement Data Acquisition and Analysis Software program (DPQ Software; www.iscaninc.com, Burlington, MA, USA) and analyzed using the PRZ analysis software (ISCAN, 2007). Raw and processed data from the ISCAN system were transferred to a REDCap (Research Electronic Data Capture) system (GCRC Informatics Department, Vanderbilt University, Nashville, TN, USA) for statistical processing using the Statistical Package for the Social Sciences (SPSS, version 15.0; www.spss.com, Chicago, IL, USA). All data were blinded to group and fasting/fed condition before data entry and analysis. Descriptive and graphical methods were used to examine whether data were normally distributed; if not, nonparametric statistical methods were used and noted. Independent *t*-tests were used to compare continuous demographic variables (for example, age) between normal-weight and obese groups. The χ^2-test of independence was used to compare group racial composition using self-report of United States National Institute of Health (NIH)-defined categories of White, Black or Asian (the latter two categories were collapsed due to low expected frequencies).

To control study-wise Type I error rate, comparisons of eating measure subscales scores between study groups were initially conducted using multivariate analysis of variance (MANOVA) and were reported using Hotelling's trace statistic. If a multivariate statistically significant difference was found, *post hoc* comparisons of the individual subscale scores were conducted.

Hypothesis-driven analyses of subjective hunger and attentional bias scores were conducted using mixed-design analyses of variance (ANOVA) with group (normal weight versus obese) as the between-subjects variable, and satiety state (fasted versus fed) and food-calorific value (high calorie versus low calorie) as within-subjects variables. *Post hoc* examination of significant interaction effects was conducted using *t*-tests. Where significant ANOVA results were found for obesity or fasting, Spearman correlations were used to assess associations between eating measures and attentional bias scores. An α-level of 0.05 was used for determining statistical significance.

Results

Demographic characteristics

Subject characteristics are summarized in Table 1. No statistically significant differences in age or race existed between groups (age: $P=0.165$; race: $P=0.480$). The average age of participants was 28.56 years (s.d. = 4.05 years) and approximately 67% were Caucasian. The mean BMI was 38.69 for the obese group (min = 30.02, max = 52.32) and 21.73 for the normal-weight subjects (min = 19.05, max = 25.09). On average, obese subjects consumed 394.72 ± 25.12 calories and normal-weight subjects consumed 362.64 ± 96.75 calories ($P=0.272$).

Table 1 Baseline characteristics of groups

	Obese	*Normal weight*
Number of subjects	18	18
Age (years)	29.50 (4.48)	27.61 (3.45)
Race, % (N)		
White	61.1 (11)	72.2 (13)
Black	38.9 (7)	22.2 (4)
Asian	0.0 (0)	5.6 (1)
Height (cm)	164.32 (5.75)	163.05 (6.21)
Weight (lbs)*	229.66 (37.97)	127.46 (14.36)
BMI (kg/m^2)*	38.69 (6.87)	21.73 (1.85)
Duration of fast (min)	645.00 (132.28)	653.67 (220.47)
Study meal (calories)	394.72 (25.12)	362.64 (96.75)

Abbreviation: BMI, body mass index. Data are means (s.d.) unless otherwise noted. *$P<0.001$.

Personality and eating behavior

Personality and eating behavior measures are summarized in Table 2. Multivariate statistically significant differences were found on the DEBQ (Hotelling's trace = 0.821, $P=0.001$) between obese and normal-weight participants and TFEQ (Hotelling's trace = 0.640, $P=0.001$), but not on the TPQ (Hotelling's trace = 0.027, $P=0.885$) and the BIS/BAS (Hotelling's trace = 0.236, $P=0.258$). *Post hoc* univariate tests revealed that the multivariate difference for the DEBQ measure resulted from higher scores by the obese subjects than normal-weight subjects on the External Eating ($P<0.001$), Emotional Eating ($P<0.001$) and Restrained Eating ($P=0.004$) subscale scores. The multivariate difference for the TFEQ measure resulted from higher scores by the obese subjects than normal-weight subjects on the Disinhibition subscale ($P=0.001$). No statistically significant univariate differences were found for other subscale scores.

Pretask data

As predicted, analysis of subjective hunger ratings (using the Hunger Scales;[49] Table 3) showed a statistically significant main effect of condition, $F(1,34)=71.63$, $P<0.001$, with lower scores in the fed than the fasted condition (overall means were 2.33 (s.d. = 1.31) and 4.50 (s.d. = 1.42), respectively), demonstrating that feeding was effective in reducing hunger levels. In addition, the obese group tended to rate themselves as being more hungry than the normal-weight group regardless of condition (overall mean 3.78 vs 3.06),

Table 2 Summaries of eating and personality measures by weight group

	Obese *Mean (s.d.)*	*Normal weight* *Mean (s.d.)*
Behavioral inhibition/activation scale (BIS/BAS)[a]		
Drive	10.82 (1.32)	10.67 (1.65)
Fun Seeking	11.09 (2.12)	11.78 (1.73)
Reward Responsiveness	17.27 (1.62)	18.44 (1.62)
Inhibition	23.36 (3.14)	23.06 (2.71)
Dutch eating behavior questionnaire (DEBQ)[b]		
Emotional	3.18 (0.31)	2.57 (0.46)
External	3.37 (0.39)	2.60 (0.50)
Restrained	3.23 (0.56)	2.64 (0.46)
Three factor eating questionnaire (TFEQ)[c]		
Cognitive Restraint	9.22 (4.34)	11.56 (4.78)
Disinhibition	9.06 (3.99)	4.39 (3.26)
Susceptibility to Hunger	6.22 (3.57)	5.11 (3.20)
Tridimensional personality questionnaire (TPQ)[d]		
Novelty Seeking	14.83 (6.28)	14.25 (5.20)
Harm Avoidance	13.83 (7.26)	12.19 (5.79)
Reward Dependence	14.58 (3.34)	14.44 (2.87)

[a]BMI $\geqslant 30$: $N=11$, BMI $\leqslant 25$: $N=18$; Multivariate $P=0.258$. [b]BMI $\geqslant 30$: $N=15$, BMI $\leqslant 25$: $N=15$; Multivariate $P=0.001$; Post hoc: Emotional $P<0.001$, *External* $P<0.001$, *Restrained* $P=0.004$. [c]BMI $\geqslant 30$: $N=18$, BMI $\leqslant 25$: $N=18$; Multivariate $P<0.001$; Post hoc: Cognitive Restraint $P=0.135$, Disinhibition $P=0.001$, Hunger $P=0.333$. [d]BMI $\geqslant 30$: $N=12$ BMI $\leqslant 25$: $N=16$; Multivariate $P=0.885$.

Table 3 Mean subjective hunger and attentional bias measures as a function of group (obese versus normal weight) and satiety condition (fed versus fasted)

	Group			
	Obese		*Normal weight*	
	Mean	*s.d.*	*Mean*	*s.d.*
Subjective hunger rating				
Fed	2.83	1.34	1.83	1.10
Fasted	4.72	1.53	4.28	1.32
Gaze direction bias				
Fed hi-cal	0.640	0.098	0.471	0.124
Fed lo-cal	0.558	0.101	0.435	0.105
Fasted hi-cal	0.602	0.108	0.574	0.135
Fasted lo-cal	0.530	0.137	0.520	0.125
Gaze duration (ms)				
Fed hi-cal food	481.1	151.9	360.3	140.1
Fasted hi-cal food	480.5	139.4	522.1	233.3
Fed lo-cal food	421.2	144.4	330.1	117.0
Fasted lo-cal food	441.1	163.2	435.4	203.0
Fed hi-cal control	356.9	125.8	370.0	159.2
Fed lo-cal control	374.3	129.3	367.9	162.8
Fasted hi-cal control	378.0	170.7	355.3	125.6
Fasted lo-cal control	375.1	128.2	388.6	176.1
Gaze duration bias				
Fed hi-cal	0.578	0.098	0.496	0.070
Fed lo-cal	0.528	0.096	0.477	0.101
Fasted hi-cal	0.570	0.082	0.581	0.101
Fasted lo-cal	0.536	0.064	0.527	0.118
RT (ms)				
Fed hi-cal incongruent	772.0	95.6	738.4	123.0
Fed hi-cal congruent	803.6	108.8	749.9	144.4
Fed lo-cal incongruent	785.8	120.6	745.8	121.4
Fed lo-cal congruent	772.8	101.8	750.5	135.6
Fasted hi-cal incongruent	775.4	141.7	741.3	120.6
Fasted hi-cal congruent	790.3	149.7	730.5	105.8
Fasted lo-cal incongruent	763.3	127.7	745.0	111.1
Fasted lo-cal congruent	772.3	142.2	733.6	117.9
RT bias				
Fed hi-cal	−31.6	59.3	−11.5	47.1
Fed lo-cal	13.0	57.4	−4.7	45.2
Fasted hi-cal	−14.9	54.1	10.8	53.6
Fasted lo-cal	−9.1	52.7	11.4	40.6

Abbreviations: hi-cal, high calorie; lo-cal, low calorie; RT, reaction time.

$F(1,34)=3.99$, $P=0.054$. There was no statistically significant interaction between condition and group, $F(1,34)=1.18$, $P=0.286$.

Gaze direction bias

See Table 3 for summaries of gaze direction bias scores in each condition. There was a statistically significant main effect of group, $F(1,34)=8.92$, $P=0.005$, which was qualified by a statistically significant interaction effect of group-satiety condition, $F(1,34)=9.55$, $P=0.004$. As illustrated in Figure 3 (left), normal-weight individuals were more likely to look initially at food in the fasted than fed condition, $t(17)=2.84$, $P=0.011$; whereas the gaze direction bias in the obese group did not differ across conditions, $t(17)=1.35$, $P=0.194$. Thus, the direction bias scores significantly differed between groups only in the fed condition, $t(34)=4.70$, $P<0.001$. In the fed condition, obese individuals showed a significant bias to direct gaze at food, relative to non-food, images, as shown by a one-sample *t*-test which contrasted their mean direction bias score against a value of zero, $t(17)=4.75$, $P<0.001$; whereas normal-weight individuals showed a nonsignificant trend to direct their gaze away from food (one-sample $t(17)=2.04$, $P=0.057$). In contrast, in the fasted condition, the difference in direction bias between the groups was not statistically significant $t(17)=0.51$, $P=0.615$; with both groups showing a statistically significant bias for food relative to non-food images, one-sample $t(35)=3.06$, $P=0.004$ (see Figure 3).

There was also a statistically significant main effect of calorific value on direction bias scores, $F(1,34)=19.17$, $P<0.001$, as participants were more likely to look initially at high than low calorie foods (mean bias scores were 0.572 (s.d. = 0.097) and 0.511 (s.d. = 0.105), respectively). However, the calorific value of the food cues did not significantly influence the effects of group or satiety condition on direction bias scores.

Gaze duration bias

Mean gaze duration and bias scores under the various study conditions are summarized in Table 3. There was a significant main effect of calorific value on bias scores, $F(1,34)=10.07$, $P=0.003$, as participants looked longer at high calorie than low calorie foods; mean proportion scores were 0.556 (s.d. = 0.071) and 0.517 (s.d. = 0.077), respectively. There was also a significant main effect of satiety on bias scores, $F(1,34)=4.43$, $P=0.043$. The main effect of satiety was qualified by a statistically significant group-satiety interaction, $F(1,34)=4.42$, $P=0.043$, which was not significantly influenced by calorific value. As shown in the right panel of Figure 3, normal-weight individuals gazed longer at food in the fasted than fed condition, $t(17)=2.425$, $P=0.027$; whereas the obese group showed a similar bias in both conditions, $t(17)=0.002$, $P=0.998$. Thus, the groups differed significantly only in the fed condition, $t(34)=2.51$, $P=0.017$. After feeding, the obese group looked longer at food than non-food images, $t(17)=2.55$, $P=0.021$, whereas normal-weight individuals showed no bias, $t(17)=0.82$, $P=0.424$. In contrast, in the fasted condition, the groups did not differ significantly, $t(34)=0.05$, $P=0.958$, and both looked longer at food than non-food images, $t(35)=4.09$, $P<0.001$.

Reaction time bias data

Reaction time and reaction time bias values are summarized in Table 3. No statistically significant main effects of group,

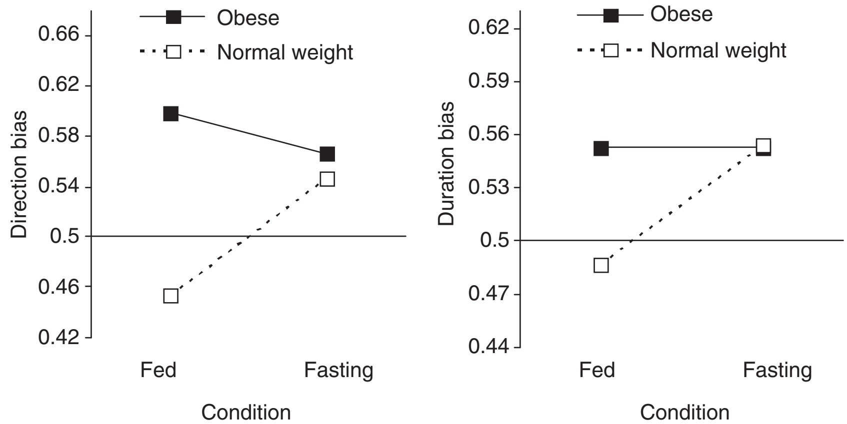

Figure 3 Mean gaze direction and duration bias scores as a function of group (obese versus normal weight) and satiety condition (fed versus fasting).

condition or calorific value, as well as interaction effects, were observed ($P>0.05$). We also examined the relationship of self-reported hunger scores to reaction time and reaction time bias scores, irrespective of group (obese or normal weight) and condition (fasted or fed). There was no statistically significant main effect of self-reported hunger score on reaction time or reaction time bias ($P>0.05$).

Correlations
Across the whole sample, the gaze direction bias in the fed condition correlated significantly with subjective hunger ratings ($r=0.58$), each DEBQ score (External, $r=0.46$; Emotional, $r=0.36$; Restraint, $r=0.37$) and TFEQ Disinhibition ($r=0.39$), Ps<0.05. The gaze duration bias in the fed condition correlated positively with subjective hunger ratings ($r=0.47$) and negatively with TPQ harm avoidance ($r=$-0.38), Ps<0.05.

Discussion

Results indicated that normal-weight subjects were more likely to shift their gaze toward food images rather than non-food images when they were in a state of hunger (fasted state) rather than satiety (fed state). In contrast to the normal-weight subjects, obese subjects focused greater visual attention on food images compared with non-food images regardless of whether they were in a state of hunger (fasted state) or satiety (fed state).

To measure visual attention in this study, we examined both the initial orientation and maintenance of gaze in response to visual food cues. Both obese and normal-weight individuals demonstrated a gaze direction bias for food cues in the fasted state, indicating an orienting bias toward food images. However, in the fed state, obese individuals retained the direction bias for food cues whereas normal-weight individuals lost the orienting bias toward food and even had a trend toward orienting to non-food images.

Attentional bias for food cues was also present in the maintenance phase of attention, as measured by gaze duration. Both obese and normal-weight individuals demonstrated longer gaze duration for food images than non-food images in the fasting condition. However, in the fed condition, obese individuals maintained an attentional bias for food images, whereas normal-weight individuals lost this attentional bias for food images.

The results from the eye-movement data for normal-weight subjects are compatible with the view, indicated by previous research, that the motivational state of hunger is associated with an attentional bias toward food-related stimuli.[36] Furthermore, our results for obese subjects suggest that there is reward system dysregulation in this group that is manifested as altered attentional salience. Growing evidence from both animal and human neuroimaging studies suggests that reward system dysregulation, comparable to that seen in drug addiction, may occur with exposure to palatable foods.

Our finding that obese individuals have an attentional bias for food cues after eating (whereas normal-weight individuals do not) suggests that this aspect of incentive salience for food cues in obese individuals may be related to reward system dysregulation, which is further supported by scores on the personality and eating behavior questionnaires. On the TFEQ, obese subjects had higher scores on Disinhibition, which measures susceptibility to disruptions in eating control. This is potentially consistent with a relapse model of drug addiction in terms of loss of control in the context of external disruptions. Obese subjects also had higher scores on each of the DEBQ scales, which assess self-reported behavioral styles associated with overeating, including External Eating, which measures hyperresponsiveness to external food cues. This latter finding is consistent with a conditioned salience for food cues. BIS/BAS scores in our obese group did not differ from those of controls. We included this questionnaire because of general relevance to reward system function and because BAS reward scores have previously been shown to predict neural activation in reward regions in response to viewing highly palatable foods.[44] It is possible that BAS scores did not differ by group because the BAS measures general aspects of sensitivity to reward, and is not specific for food rewards. Another possibility is that the relationship between sensitivity to reward and obesity is complex. Others have reported that BMI correlates positively with sensitivity to reward in normal-weight and overweight subjects but that BMI correlates inversely with reward sensitivity in obese subjects.[52] Our obese subjects did not show increased novelty seeking as measured by the TPQ. Increased novelty seeking has been associated with increased risk for substance abuse and dependence[53,54] and with reduced midbrain dopamine receptor availability.[55] It is possible that novelty seeking may not be a strong risk factor for obesity because, unlike drugs of abuse, humans are exposed to food on a daily basis.

According to the incentive-sensitization model of addiction, neural modification of the dopaminergic mesolimbic system by exposure to addictive drugs leads to hypersensitization of the reward system to drug-related stimuli.[14,15] The present findings suggest that food cues may have the ability to elicit attentional bias in obese individuals in a model consistent with the incentive-salience model of addiction. However, altered visual attention for food cues measures only one component of the incentive-salience model and additional study is necessary to examine other measures of altered incentive salience in obesity. Recent studies in humans[56] and rodent models[57] have suggested that obesity may be associated with dysregulation in brain regions involved in processing the rewarding properties of food. In our study, obese individuals exhibited both gaze orientation and duration biases toward food stimuli, which supports the possibility that enhanced sensitivity to food reward in obesity may be measurable as attentional bias. Recent animal studies in rats[58] have provided evidence that obesity-prone rats have an attenuated dopamine response to feeding before obesity develops, causing them to develop compensatory hyperphagia and resultant obesity, and that differences in dopamine receptor binding between obese and lean rats increases with continued exposure to unrestricted food, rather than a restricted diet.[57] These findings are consistent with the hypothesis that obese individuals may have a genetic predisposition to develop attentional bias for food cues, and that chronic exposure to palatable food further sensitizes the brain's reward system to food stimuli.

The attentional bias in gaze for food cues was greater for high calorie than low calorie foods. High calorie foods are generally higher in sugar and fat, both of which have been shown to activate the brain's reward system,[59,60] which in turn may account for their attention-grabbing properties. However, the attentional biases in gaze, which were associated with food deprivation and obesity, were not significantly influenced by the calorific value of the food, suggesting that such biases operate for food cues in general. Although the gaze direction and duration measures showed a similar pattern of attentional bias, the reaction time measure showed no significant results. The latter provides only a snapshot view of attentional bias (that is, at the offset of the pictures), at which point an attentional bias for food cues might be susceptible to task-related strategic influences, for example, shifting attention away from the pictures back to the central position in anticipation of the probe onset. Also, the time point at which the attentional bias is assessed has varied across studies, for example, 500[35,36] versus 2000 ms here, which may possibly contribute to variation in findings. Thus, eye-movement measures, which sample data continuously, are likely to be a more sensitive index of attention allocation than reaction time. Another methodological variable which may have contributed to the null results in the reaction time data is the relatively complex nature of the probe task (that is, probe discrimination task with indirect stimulus-response mapping), which was similar to that previously used in eye-tracking research into attentional biases in nicotine dependence in college students.[30] However, using this complex task, reaction times were relatively longer and more variable than seen with less complex probe tasks (for example, probe localization task), where participants indicate the position of a single dot probe,[36] and it may be helpful to use a simpler version of this task in future research.

A limitation in this study concerns the use of a standardized liquid meal. This approach offers advantages in terms of easy standardization of nutrient content and measure of calorie content. However, it is possible that the palatability or the method of administration (by offering multiple glasses) of the liquid meal may limit consumption in otherwise hungry individuals. Although both normal-weight and overweight subjects reported reduced hunger after eating, it is possible that subjects did not eat to satiety because of meal palatability or because they were conscious of the amount ingested. It is also possible that attention salience for food remains higher following a meal that the individual perceives as unsatisfactory either because it is too low in calories or because of palatability. Subjects were told whether they would receive the liquid meal or whether they would continue fasting before completing questionnaires. It is possible that anticipation of receiving a meal may have differentially influenced responses in obese individuals. Additionally, two of our questionnaires (the BIS/BAS and the TPQ) were added to the study protocol after several subjects had already completed both sessions, so that the sample size from these questionnaires is relatively small. Another methodological limitation is that the food images formed a homogeneous category, whereas non-food images depicted items from various categories (for example, office supplies, tools). Thus, it is possible that more attention may be paid to food stimuli because they were of the same category, or, alternatively, that more attention may be paid to control items because of their greater variety. However, an overriding consideration in selecting the stimuli was that, within each picture pair, the food and non-food images were matched as closely as possible for color, complexity and brightness, which required the use of a variety of items. In the future, however, it would seem desirable to select non-food images from a single category, although also ensuring close matching within each picture pair of other perceptual variables. Finally, subjects were excluded from the study if they reported a history of tobacco use, drug abuse or psychiatric or chronic medical illness; however, we did not independently verify these reports through urine or blood screening.

As visual food cues are particularly prominent in society, understanding the implications of exposure to visual food cues in obesity is of great importance in developing potential behavioral therapies, environmental alterations and public health measures. The pathogenesis of obesity is an inarguably complex process involving genetic, hormonal, behavioral, environmental and even cultural factors. Further study of the neural correlates of attentional bias to food cues in obesity through other modalities such as neuroimaging may lead to a better understanding of when and how hypersensitization to food reward may occur. In addition, eye tracking may provide a useful research tool in investigating the efficacy of treatments for obesity, for example, in assessing the extent to which psychological or pharmacological interventions are effective in removing enhanced attentional biases for food cues. Understanding the contribution of visual attention and food cues to obesity will open an untapped perspective in both studying and treating this important public health concern.

Acknowledgements

We thank two anonymous reviewers for their contributions to improving this article.

References

1 Denton D. *The Primordial Emotions: The Dawning of Consciousness*. Oxford University Press: New York, NY, 2005.
2 Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA* 2006; **295**: 1549–1555.
3 Fontaine KR, Redden DT, Wang C, Westfall AO, Allison DB. Years of life lost due to obesity. *JAMA* 2003; **289**: 187–193.
4 Kelley AE, Berridge KC. The neuroscience of natural rewards: relevance to addictive drugs. *J Neurosci* 2002; **22**: 3306–3311.
5 Wise RA. Drug-activation of brain reward pathways. *Drug Alcohol Depend* 1998; **51**: 13–22.
6 Rada P, Avena NM, Hoebel BG. Daily bingeing on sugar repeatedly releases dopamine in the accumbens shell. *Neuroscience* 2005; **134**: 737–744.
7 Avena NM, Rada P, Hoebel BG. Evidence for sugar addiction: behavioral and neurochemical effects of intermittent, excessive sugar intake. *Neurosci Biobehav Rev* 2008; **32**: 20–39.
8 Spangler R, Wittkowski KM, Goddard NL, Avena NM, Hoebel BG, Leibowitz SF. Opiate-like effects of sugar on gene expression in reward areas of the rat brain. *Brain Res Mol Brain Res* 2004; **124**: 134–142.
9 Kelley AE, Bakshi VP, Fleming S, Holahan MR. A pharmacological analysis of the substrates underlying conditioned feeding induced by repeated opioid stimulation of the nucleus accumbens. *Neuropsychopharmacology* 2000; **23**: 455–467.
10 Avena NM, Long KA, Hoebel BG. Sugar-dependent rats show enhanced responding for sugar after abstinence: evidence of a sugar deprivation effect. *Physiol Behav* 2005; **84**: 359–362.
11 South T, Huang XF. High-fat diet exposure increases dopamine D2 receptor and decreases dopamine transporter receptor binding density in the nucleus accumbens and caudate putamen of mice. *Neurochem Res* 2008; **33**: 598–605.
12 Davis JF, Tracy AL, Schurdak JD, Tschop MH, Lipton JW, Clegg DJ *et al.* Exposure to elevated levels of dietary fat attenuates psychostimulant reward and mesolimbic dopamine turnover in the rat. *Behav Neurosci* 2008; **122**: 1257–1263.
13 Huang XF, Yu Y, Zavitsanou K, Han M, Storlien L. Differential expression of dopamine D2 and D4 receptor and tyrosine hydroxylase mRNA in mice prone, or resistant, to chronic high-fat diet-induced obesity. *Brain Res Mol Brain Res* 2005; **135**: 150–161.
14 Robinson TE, Berridge KC. Addiction. *Annu Rev Psychol* 2003; **54**: 25–53.
15 Robinson TE, Berridge KC. Incentive-sensitization and addiction. *Addiction* 2001; **96**: 103–114.
16 Schultz W, Dayan P, Montague PR. A neural substrate of prediction and reward. *Science* 1997; **275**: 1593–1599.
17 Wickelgren I. Getting the brain's attention. *Science* 1997; **278**: 35–37.
18 Franken IH. Drug craving and addiction: integrating psychological and neuropsychopharmacological approaches. *Prog Neuropsychopharmacol Biol Psychiatry* 2003; **27**: 563–579.
19 Carter BL, Tiffany ST. Cue-reactivity and the future of addiction research. *Addiction* 1999; **94**: 349–351.
20 Garavan H, Pankiewicz J, Bloom A, Cho JK, Sperry L, Ross TJ *et al.* Cue-induced cocaine craving: neuroanatomical specificity for drug users and drug stimuli. *Am J Psychiatry* 2000; **157**: 1789–1798.
21 Bradley BP, Mogg K, Wright T, Field M. Attentional bias in drug dependence: vigilance for cigarette-related cues in smokers. *Psychol Addict Behav* 2003; **17**: 66–72.
22 Waters AJ, Shiffman S, Bradley BP, Mogg K. Attentional shifts to smoking cues in smokers. *Addiction* 2003; **98**: 1409–1417.
23 Field M, Mogg K, Zetteler J, Bradley BP. Attentional biases for alcohol cues in heavy and light social drinkers: the roles of initial orienting and maintained attention. *Psychopharmacology (Berl)* 2004; **176**: 88–93.
24 Townshend JM, Duka T. Attentional bias associated with alcohol cues: differences between heavy and occasional social drinkers. *Psychopharmacology (Berl)* 2001; **157**: 67–74.
25 Yeomans MR, Javaherian S, Tovey HM, Stafford LD. Attentional bias for caffeine-related stimuli in high but not moderate or non-caffeine consumers. *Psychopharmacology (Berl)* 2005; **181**: 477–485.
26 Lubman DI, Peters LA, Mogg K, Bradley BP, Deakin JF. Attentional bias for drug cues in opiate dependence. *Psychol Med* 2000; **30**: 169–175.
27 Field M, Mogg K, Bradley BP. Cognitive bias and drug craving in recreational cannabis users. *Drug Alcohol Depend* 2004; **74**: 105–111.
28 Henderson JM, Hollingworth A. Eye movements during scene viewing: an overview. In: Underwood G (ed). *Eye Guidance in Reading and Scene Perception*. Elsevier Science Ltd: Oxford, UK, 1998, pp 269–293.
29 Bradley BP, Garner M, Hudson L, Mogg K. Influence of negative affect on selective attention to smoking-related cues and urge to smoke in cigarette smokers. *Behav Pharmacol* 2007; **18**: 255–263.

30 Mogg K, Field M, Bradley BP. Attentional and approach biases for smoking cues in smokers: an investigation of competing theoretical views of addiction. *Psychopharmacology (Berl)* 2005; **180**: 333–341.
31 Field M, Mogg K, Bradley BP. Eye movements to smoking-related cues: effects of nicotine deprivation. *Psychopharmacology (Berl)* 2004; **173**: 116–123.
32 Mogg K, Bradley BP, Field M, De HJ. Eye movements to smoking-related pictures in smokers: relationship between attentional biases and implicit and explicit measures of stimulus valence. *Addiction* 2003; **98**: 825–836.
33 Field M, Eastwood B, Bradley BP, Mogg K. Selective processing of cannabis cues in regular cannabis users. *Drug Alcohol Depend* 2006; **85**: 75–82.
34 Leland DS, Pineda JA. Effects of food-related stimuli on visual spatial attention in fasting and nonfasting normal subjects: Behavior and electrophysiology. *Clin Neurophysiol* 2006; **117**: 67–84.
35 Placanica JL, Faunce GJ, Soames Job RF. The effect of fasting on attentional biases for food and body shape/weight words in high and low Eating Disorder Inventory scorers. *Int J Eat Disord* 2002; **32**: 79–90.
36 Mogg K, Bradley BP, Hyare H, Lee S. Selective attention to food-related stimuli in hunger: are attentional biases specific to emotional and psychopathological states, or are they also found in normal drive states? *Behav Res Ther* 1998; **36**: 227–237.
37 Braet C, Crombez G. Cognitive interference due to food cues in childhood obesity. *J Clin Child Adolesc Psychol* 2003; **32**: 32–39.
38 Soetens B, Braet C. Information processing of food cues in overweight and normal weight adolescents. *Br J Health Psychol* 2007; **12** (Part 2): 285–304.
39 Nijs IM, Franken IH, Muris P. Food cue-elicited brain potentials in obese and healthy-weight individuals. *Eat Behav* 2008; **9**: 462–470.
40 Cloninger CR, Przybeck TR, Syrakic DM, Wetzel RD. *The Temperament and Character Inventory (TCI): A Guide to Its Development and Use*. Center for Psychobiology of Personality, Washington University: St Louis, MO, 1994.
41 Carver CS, White TL. Behavioral-inhibition, behavioral activation, and affective responses to impending reward and punishment—the Bis Bas scales. *J Pers Soc Psychol* 1994; **67**: 319–333.
42 Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *J Psychosom Res* 1985; **29**: 71–83.
43 van Strien T, Frijters JER, Bergers GPA, Defares PB. The dutch eating behavior questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. *Int J Eat Disord* 1986; **5**: 295–315.
44 Beaver JD, Lawrence AD, van DJ, Davis MH, Woods A, Calder AJ. Individual differences in reward drive predict neural responses to images of food. *J Neurosci* 2006; **26**: 5160–5166.
45 Lindroos AK, Lissner L, Mathiassen ME, Karlsson J, Sullivan M, Bengtsson C *et al*. Dietary intake in relation to restrained eating, disinhibition, and hunger in obese and nonobese Swedish women. *Obes Res* 1997; **5**: 175–182.
46 Provencher V, Drapeau V, Tremblay A, Despres JP, Lemieux S. Eating behaviors and indexes of body composition in men and women from the Quebec family study. *Obes Res* 2003; **11**: 783–792.
47 Gerra G, Zaimovic A, Timpano M, Zambelli U, Begarani M, Marzocchi GF *et al*. Neuroendocrine correlates of temperament traits in abstinent opiate addicts. *J Subst Abuse* 2000; **11**: 337–354.
48 NIH. *Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults*. NIH: Bethesda, MD, 1998.
49 Grand S. Color-word interference. II. An investigation of the role of vocal conflict and hunger in associative priming. *J Exp Psychol* 1968; **77**: 31–40.
50 Gautier JF, Chen K, Salbe AD, Bandy D, Pratley RE, Heiman M *et al*. Differential brain responses to satiation in obese and lean men. *Diabetes* 2000; **49**: 838–846.
51 Carroll JF, Kaiser KA, Franks SF, Deere C, Caffrey JL. Influence of BMI and gender on postprandial hormone responses. *Obesity (Silver Spring)* 2007; **15**: 2974–2983.
52 Davis C, Fox J. Sensitivity to reward and body mass index (BMI): evidence for a non-linear relationship. *Appetite* 2008; **50**: 43–49.
53 Kampov-Polevoy AB, Eick C, Boland G, Khalitov E, Crews FT. Sweet liking, novelty seeking, and gender predict alcoholic status. *Alcohol Clin Exp Res* 2004; **28**: 1291–1298.
54 Hale RL, Whiteman S, Muehl K, Faynberg E. Tridimensional personality traits of college student marijuana users. *Psychol Rep* 2003; **92**: 661–666.
55 Zald DH, Cowan RL, Riccardi P, Baldwin RM, Ansari MS, Li R *et al*. Midbrain dopamine receptor availability is inversely associated with novelty-seeking traits in humans. *J Neurosci* 2008; **28**: 14372–14378.
56 Wang GJ, Volkow ND, Felder C, Fowler JS, Levy AV, Pappas NR *et al*. Enhanced resting activity of the oral somatosensory cortex in obese subjects. *Neuroreport* 2002; **13**: 1151–1155.
57 Thanos PK, Michaelides M, Piyis YK, Wang GJ, Volkow ND. Food restriction markedly increases dopamine D2 receptor (D2R) in a rat model of obesity as assessed with *in-vivo* muPET imaging ([11C] raclopride) and *in-vitro* ([3H] spiperone) autoradiography. *Synapse* 2008; **62**: 50–61.
58 Geiger BM, Behr GG, Frank LE, Caldera-Siu AD, Beinfeld MC, Kokkotou EG *et al*. Evidence for defective mesolimbic dopamine exocytosis in obesity-prone rats. *FASEB J* 2008; **22**: 2740–2746.
59 Volkow ND, Wise RA. How can drug addiction help us understand obesity? *Nat Neurosci* 2005; **8**: 555–560.
60 Kelley AE, Bakshi VP, Haber SN, Steininger TL, Will MJ, Zhang M. Opioid modulation of taste hedonics within the ventral striatum. *Physiol Behav* 2002; **76**: 365–377.