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Research report

Differences in attention to food and food intake between overweight/obese and normal-weight females under conditions of hunger and satiety

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ABSTRACT

Starting from an addiction model of obesity, the present study examined differences in attention for food-related stimuli and food intake between overweight/obese and normal-weight women under conditions of hunger and satiety. Twenty-six overweight/obese (BMI: 30.00 ± 4.62) and 40 normal-weight (BMI: 20.63 ± 1.14) females were randomly assigned to a condition of hunger or satiety. Three indexes of attention were employed, all including pictures of food items: an eye-tracking paradigm (gaze direction and duration), a visual probe task (reaction times), and a recording of electrophysiological brain activity (amplitude of the P300 event-related potential). In addition, the acute food intake of participants was assessed using a bogus taste task. In general, an attentional bias towards food pictures was found in all participants. No differences between groups or conditions were observed in the eye-tracking data. The visual probe task revealed an enhanced automatic orientation towards food cues in hungry versus satiated, and in overweight/obese versus normal-weight individuals, but no differences between groups or conditions in maintained attention. The P300 amplitude showed that only in normal-weight participants the intentional allocation of attention to food pictures was enhanced in hunger versus satiety. In hungry overweight/obese participants, the P300 bias for food pictures was not clearly present, although an increased food intake was observed especially in this group. In conclusion, various attention-related tasks yielded various results, suggesting that they measure different underlying processes. Strikingly, overweight/obese individuals appear to automatically direct their attention to food-related stimuli, to a greater extent than normal-weight individuals, particularly when food-deprived. Speculatively, hungry overweight/obese individuals also appear to use cognitive strategies to reduce a maintained attentional bias for food stimuli, perhaps in an attempt to prevent disinhibited food intake. However, in order to draw firm conclusions, replication studies are needed.

Introduction

Evidence from neuroimaging studies suggests that an altered functioning of the brain reward system plays a similar important role in the etiology and maintenance of addiction and obesity (Volkow & Wise, 2005; Wang et al., 2001). One addiction theory that seems particularly applicable to obesity is the incentive sensitization theory (Robinson & Berridge, 1993). In short, this theory assumes that a sensitization of the dopaminergic reward system serves to increase the salience of reward-related cues (such as drugs or food) in the environment and to make them more "attention-grabbing", thereby promoting craving and intake of the rewarding substance. Individuals with a high food cue-responsiveness (attentional bias, craving) are assumed to be more vulnerable to overeat and to become obese in the food-rich environment of today (Berridge, 2009; Polivy, Herman, & Coelho, 2008).

Starting from an incentive sensitization model of obesity, the present study primarily examines differences in the attentional processing of food-related stimuli between overweight/obese and normal-weight, hungry or satiated women. Whereas there is ample evidence that food-related attention is modulated by hunger and satiety in normal-weight individuals (Channon & Hayward, 1990; Lavy & van den Hout, 1993; Mogg, Bradley, Hyare, & Lee, 1998; Placanica, Faunce, & Soames Job, 2001; Stockburger, Hamm, Weike, & Schupp, 2008; Stockburger, Schmälzle, Flaisch, Bublatzky, & Schupp, 2009), surprisingly few studies have investigated this issue in overweight/obese persons, and even this evidence is inconclusive. For instance, Braet and Crombez (2003) found Stroop interference to food-related words in obese children, which was absent in their normal-weight peers. Using an imbedded word task, Soetens and Braet (2007), on the other hand, observed no preferential attentional processing of food-related words relative to neutral words, neither in normal-weight nor in

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overweight adolescents. Finally, Nijs, Franken, and Muris (2008) used event-related potentials (ERPs; i.e., stimulus-triggered electroencephalographic [EEG] brain activity) as indices of attention allocation, and found evidence for an enhanced attention towards food-related pictures relative to neutral pictures, in both obese and normal-weight adults, with no difference between both groups. In these three studies, participants were food-deprived for 2–3 h, and the modulation of food-related attention by hunger and satiety was not examined. In a recent study by Castellanos et al. (2009), a visual probe task was combined with the monitoring of eye movements to examine food-related attention in obese and normal-weight individuals under conditions of hunger and satiety. No between-group differences were found with regard to reaction time measures. However, obese individuals were found to demonstrate a similar bias in the initial orientation and maintenance of attention to food pictures, as assessed by means of gaze direction and duration, during conditions of hunger and satiety, whereas in normal-weight participants the food-related bias in attentional orientation and maintenance was clearly reduced (or even no longer existent) in a satiety as compared to a hunger state.

The above-mentioned studies illustrate some of the challenges attention research is dealing with, which may be the reason for the mixed results (for an overview, see e.g., Field & Cox, 2008). To study attentional processes, various behavioral and physiological, direct and indirect paradigms exist, which may measure different aspects of attention. In addition, results seem to depend on the type of stimuli, the duration of the stimulus presentation, and the choice of control stimuli. In the present study, different measures of attention, all including food-related and neutral control pictures, are employed. As direct behavioral measure, an eye-tracking procedure was applied: the eye movements of participants were directly monitored while they were exposed to pairs of food-related and neutral control pictures. By analogy with the study of Castellanos et al. (2009), a measure of gaze direction was employed as index of the automatic orientation of attention, and a measure of gaze duration was chosen as index of maintained attention. As an indirect behavioral measure, a visual probe task was chosen. During a visual probe task (Posner, Snyder, & Davidson, 1980), participants are exposed to pairs of target and neutral pictures, and requested to respond as fast as possible to a visual probe that appears on the location of one of the pictures after they disappear. Reaction times to the probes are assumed to be faster if the probe is located in the visual field where the attention is already drawn to, thereby reflecting attentional bias. In the paradigm as used in the present study, picture pairs were randomly presented for a short duration (100 ms) or a longer duration (500 ms), respectively reflecting the initial orientation of attention and maintained attention (Field & Cox, 2008). Finally, as an electrophysiological measure of attention, EEG was recorded during the exposure to pictures of food and neutral items to determine the P300 ERP. The P300 is a positive peak that appears at circa 300 ms after the presentation of a stimulus (Picton, 1992; Polich & Kok, 1995). The P300 amplitude reflects electrophysiological activity related to conscious attention allocation (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000), and is the most widely explored ERP index in selective attention paradigms (Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp, Flaisch, Stockburger, & Junghöfer, 2006).

Besides studying differences in food-related attention between overweight/obese and normal-weight women, the present study also aims to investigate the association between attention to food and direct measures of food motivation, i.e., subjective hunger level and food intake. The idea that the desire to eat and food intake are triggered by the exposure to external food cues is not new (Herman & Polivy, 2008; Sobik, Hutchison, & Craighead, 2005). In the 1960s, Schachter already proposed his externality theory, positing that the food intake of obese individuals was more determined by salient external food cues than the food intake of normal-weight individuals (Schachter, 1971). Support for this perspective has been provided by, for instance, Jansen et al. (2003), who demonstrated that overweight children had a stronger desire for food and ate more than normal-weight children after exposure to snack foods. Nowadays, with the growing obesity epidemic, which seems strongly related to the increased availability of rewarding food in Westernized environments, Schachter's theory seems to revive, forming the basis of new models, which integrate elements of incentive salience with new knowledge regarding the neural regulation of eating behavior and body weight.

To our knowledge, this is the first study that combines the elements of food-related attention, hunger/satiety state, body weight, subjective hunger levels, and also food intake, within one and the same study, in order to examine the relations among these variables. In line with an incentive sensitization model, the central hypotheses are as follows. First, it was expected that the attentional bias to food cues, subjective hunger level, and food intake would be enhanced during hunger as compared to a satiety state in both overweight/obese and normal-weight participants. Second, it was expected that overweight/obese individuals would demonstrate an enhanced attentional bias towards food stimuli, report more hunger, and eat more during a bogus taste task as compared to normal-weight participants. Third, positive correlations were expected between measures of food-related attentional bias, hunger levels, and food intake.

Rather than directly with obesity, enhanced food cue-reactivity has been more often associated with dietary restraint (Green & Rogers, 1993; Polivy, Coleman, & Herman, 2005; Polivy et al., 2008; Tapper, Pothos, Fadardi, & Ziori, 2008) and external eating (Brignell, Griffiths, Bradley, & Mogg, 2009; Johansson, Ghaderi, & Andersson, 2004; Newman, O'Connor, & Conner, 2008; Nijs et al., in press). For this reason, an additional purpose of the study was to explore the associations between various attention-related measures, indices of food motivation, and (over)eating styles (i.e., dietary restraint, emotional eating, and external eating) in both weight groups. In line with an incentive sensitization model of obesity, differences between overweight/obese and normal-weight participants were particularly expected with regard to the general tendency to (over)eat in response to food-related cues, i.e., external eating.

Method

Participants

Because gender differences have been reported with regard to food craving and (over)eating styles (e.g., Braet et al., 2008; Burton, Smit, & Lightowler, 2007), only female participants were recruited to participate in the present study. Through campus flyers and e-mail, female students of Erasmus University Rotterdam were informed about the present study and asked to contact us by telephone if they were interested in participation. A short telephonic screening interview was conducted during which students received information about the study and inclusion and exclusion criteria were checked. Participants were excluded from participation if they reported (1) the presence of a psychiatric, neurological or physical illness, or the use of any medication, within the past month, that might influence eating behavior, body weight, or EEG activity, or that would not allow a 17-h fast; (2) any participation, within the past three months, in an intervention aimed at losing weight, such as a low calorie diet; and (3) the presence of a food intolerance. Eventually, 66 eligible females agreed to participate: 40 of them had a healthy body weight (mean BMI = 20.63, SD = 1.14), whereas 26 were overweight or obese (mean BMI = 30.00, SD = 4.62). The study protocol was approved by a local ethical committee. All participants provided written informed consent. In return for their participation, they received either course credits or a financial reward.

Procedure

After an appointment had been made, participants were sent a written information brochure by post, accompanied by a questionnaire concerning eating styles, i.e., the Dutch Eating Behavior Questionnaire (DEBQ; Strien van, Frijters, Bergers, & Defares, 1986, for a description, see Section 'Questionnaires'), which was completed at home. Participants were asked to fast for 17 h before the start of the experiment. More specifically, they were required to have dinner before 7 p.m. or 8 p.m. the evening before the day of testing, and subsequently to abstain from foods and caloric drinks until the end of the experiment, which took place at lunch time, i.e., at 12 o'clock or 1 p.m. Participants were randomly assigned to a hunger or satiety condition. This means that half of the normal-weight ($N = 20$) and half of the overweight/obese participants ($N = 13$) were satiated upon arrival at the university's laboratory by giving them a milk shake, which they had to finish within 15 minutes. The milk shake consisted of 500 cc whole milk, 4 scoops of milkshake powder (Weight Care®, 4 flavors), and a tablespoon of sugar. The energy content of the milk shake was circa 600 kcal. Each participant conducted a series of attention-related tasks (respectively, an eye-tracking task, a visual probe task, and an EEG/ERP task), and, hereafter, a bogus taste task to assess food intake. Before and after each task, participants rated their hunger level on a visual analogue scale (VAS). Finally, their weight and height were measured, after which they received the course credits or the financial reward.

Questionnaires

The Dutch Eating Behavior Questionnaire (DEBQ; Strien van et al., 1986) consists of 33 items that assess external eating (10 items; i.e., the tendency to eat in response to the exposure to food-related cues), emotional eating (13 items; i.e., the tendency to eat in response to emotions), and dietary restraint (10 items; i.e., the tendency to restrict food intake). Participants have to indicate on a Likert scale how often each item is applicable to them (1 = never; 5 = very often). The DEBQ has adequate psychometric properties (Strien van et al., 1986).

As a fast and spontaneous index of the subjective level of hunger before and after each task, a 100-mm VAS (0 = no hunger at all, 100 = extreme hunger) was used. More precisely, subjects had to answer the question "To what degree do you experience hunger at this moment?" by placing a mark on the VAS.

Eye-tracking

The eye movements of participants were recorded, while they were exposed to pairs of pictures. Fifteen pairs of pictures of high-calorie snack food (e.g., chocolate, donut) and neutral (office-related) items (e.g., stapler, paperclips) were used. The pictures of each pair were shown side by side and matched as closely as possible with regard to shape, color, and position of the photographed object as well as background color. Ten additional pairs of pictures of neutral items (tools) were used as fillers. The pictures were made by the authors, they were found on the internet, or selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005). Each picture pair was shown for 2000 ms, and presented twice in a semi-random order on a computer monitor with a resolution of 1600×1200 pixels. Within a pair, each picture appeared once on the left side and once on the right side of the screen.

Eye movements were recorded using the remote Tobii Eye Tracker 2150 (Tobii, Stockholm, Sweden). Participants were seated in front of the Tobii monitor at a distance of approximately 60 cm. After calibration, they were instructed to keep their head still and just look attentively at the pictures. Every 20 ms (50 Hz), the position of gaze was recorded.

Eye movement data were analyzed using ClearView software (Tobii, Stockholm, Sweden). Data of filler trials were discarded. No eye movement data were collected for 3 subjects (all normal-weight, of which 2 were satiated) because of calibration difficulties. No fixation data were found in 1 (satiated normal-weight) subject. Eye fixations were defined as saccades that remained stable within a radius of 30 pixels for $\geq$100 ms, and that were initiated at least 100 ms after picture onset (eye fixations before this time may reflect anticipatory eye movements, Bradley, Garner, Hudson, & Mogg, 2007). The variables of interest for this measure were a direction bias score and a duration bias score (also see Castellanos et al., 2009). The direction bias is regarded as an index of initial attentional orientation and was computed as the number of trials in which the first fixation was directed to the food picture as a proportion of the total number of trials in which eye fixations were observed. A proportion score $>$.50, = .50, and $<$.50 is assumed to reflect respectively an orientation bias towards food pictures, no bias, and an orientation bias towards control pictures. The duration bias is regarded as an index of maintained attention and was computed as the average gaze duration to the food picture per trial as a proportion of the average gaze duration to both the food and neutral control pictures per trial (whereby gaze duration was the sum of eye fixation durations within one trial). Again, a duration bias $>$.50, = .50, and $<$.50 is assumed to reflect respectively a bias in maintained attention to food pictures, no bias, and a bias in maintained attention to non-food-related control pictures.

Visual probe task

The picture pairs of the eye-tracking task were also used for the visual probe task. The visual probe task consisted of 10 practice trials and 4 blocks that each consisted of 100 experimental trials, of which 60 were target trials (food–neutral picture pairs) and 40 were filler trials (neutral–neutral picture pairs). Each trial started with a central fixation cross (1000 ms), followed by the appearance of a pair of pictures, displayed side by side for 100 ms (orienting attention) or 500 ms (maintained attention), with a resolution of 1024×768 pixels. Immediately after the pictures disappeared, a probe (a square) appeared at the location of one of the pictures. The participant was instructed to look attentively at the fixation cross in each trial and to respond as quickly as possible to the probe by pressing the z-(left) or m-(right) button of the computer keyboard. If the participant did not respond, the probe disappeared after 2000 ms. The inter-trial interval was 500 ms. In half of the target trials the food picture was displayed at the left side of the screen, in the other half at the right side. In half of the target trials the probe appeared at the position of the food-related picture (food-relevant trials), in the other half at the position of the neutral picture (office-relevant trials). Half of the trials were displayed for 100 ms, the other half for 500 ms. Filler trials were also equalized regarding the position of the pictures and the probe, and the presentation duration. The order of trials was random.

Reaction times in food-relevant and office-relevant trials were recorded. Consistent with previous studies (e.g., Castellanos et al., 2009; Mogg et al., 1998), reaction times of incorrect responses were excluded from the data, and so were reaction time outliers, which were defined as reaction times less than 200 ms, greater than 1500 ms, or exceeding the mean individual reaction time of the participant plus/minus 3 standard deviations. The data of one (hungry overweight/obese) participant had to be excluded from further analyses because more than 50% of trials were lost.

EEG counting task

While EEG was recorded, participants were again exposed to the same pictures of food and office items, supplemented with 15 emotionally pleasant pictures (of babies) as an additional control category. The pictures were shown in a random order for 800 ms with a varying inter-stimulus interval between 300 and 500 ms. There were 3 blocks, and in each block the participant was instructed to count the number of pictures of one category (food, office items, or babies). The order of the category that had to be counted was counterbalanced within each group and condition. In each block, each picture was shown for 4 times. On 3 semi-random moments during each block the task stopped for 10 s and the participant was asked to write down the number of (food, office or baby) pictures she had counted.

To be able to compare the data of the counting task with the data of the other attention-related tasks, only the P300s (see Section 'EEG recording, ERP analyses and definition of P300') in response to food-related and neutral pictures are further analyzed and discussed. To limit the number of variables and statistical analyses, only the data of the actively attended (i.e., counted) stimuli were included in statistical analyses.

EEG recording, ERP analyses and definition of P300

EEG signals were recorded over 32 scalp sites (positioned following the 10–20 International System), using an Active-Two amplifier system (Biosemi, Amsterdam, the Netherlands) with active Ag/AgCl electrodes mounted into an elastic cap. Two additional scalp electrodes were used as reference and ground electrodes. Furthermore, additional electrodes were attached to the left and right mastoids, to the supraorbital and suborbital position of the left eye (VEOG), and to the outer canthi of both eyes (HEOG). Online, signals were recorded with a low pass filter of 134 Hz. All signals were digitized with a sample rate of 512 Hz and 24-bit A/D conversion.

Data were referenced off-line to the mathematically linked mastoids. EEG and EOG activity was filtered with a bandpass of .10–30 Hz (phase shift-free Butterworth filters; 24 dB/octave slope). After ocular correction (Gratton, Coles, & Donchin, 1983), epochs (segments from 200 ms prestimulus to 800 ms poststimulus) that included an EEG signal exceeding $\pm 75\ \mu V$ were eliminated. Data of 2 subjects (both normal-weight, of which 1 was hungry and 1 was satiated) were excluded from further analyses, because more than 50% of the epochs contained artifacts. The mean 200 ms prestimulus period served as baseline. After baseline correction, average ERP waves were determined for each participant, at each scalp site, for the two stimulus conditions. Based on visual inspection of the grand average waveforms (see Fig. 1), the P300 component was defined as the mean amplitude value (μV) within the 300–450 ms time window (Picton et al., 2000).

Because P300 is known to be maximal in parieto-occipital regions (Polich & Kok, 1995), and to reduce the number of statistical analyses, the mean P300 amplitude was calculated for a posterior cluster, consisting of 10 parietal and occipital scalp positions (i.e., P3, P7, PO3, O1, P4, P8, PO4, O2, Pz, Oz). These average posterior P300s in response to food and neutral pictures were included in statistical analyses.

Bogus taste task

Participants were exposed to five identical pre-weighed bowls filled with high-caloric snack foods: ±400 g of cake (418 kcal/100 g), ±550 g of milk chocolate (532 kcal/100 g), ±140 g of paprika-flavored potato chips (549 kcal/100 g), ±250 g of chocolate cookies (492 kcal/100 g), and ±350 g of salted peanuts (613 kcal/100 g). The chocolate, cookies, and cake were broken and cut into small pieces to facilitate eating. The order of the bowls was random. Before each bowl a questionnaire was placed containing questions about the taste of the respective foods. The participants were left alone for 15 min with the instruction to taste the foods meticulously, one by one, and to evaluate the taste of each food on the questionnaires. They were told

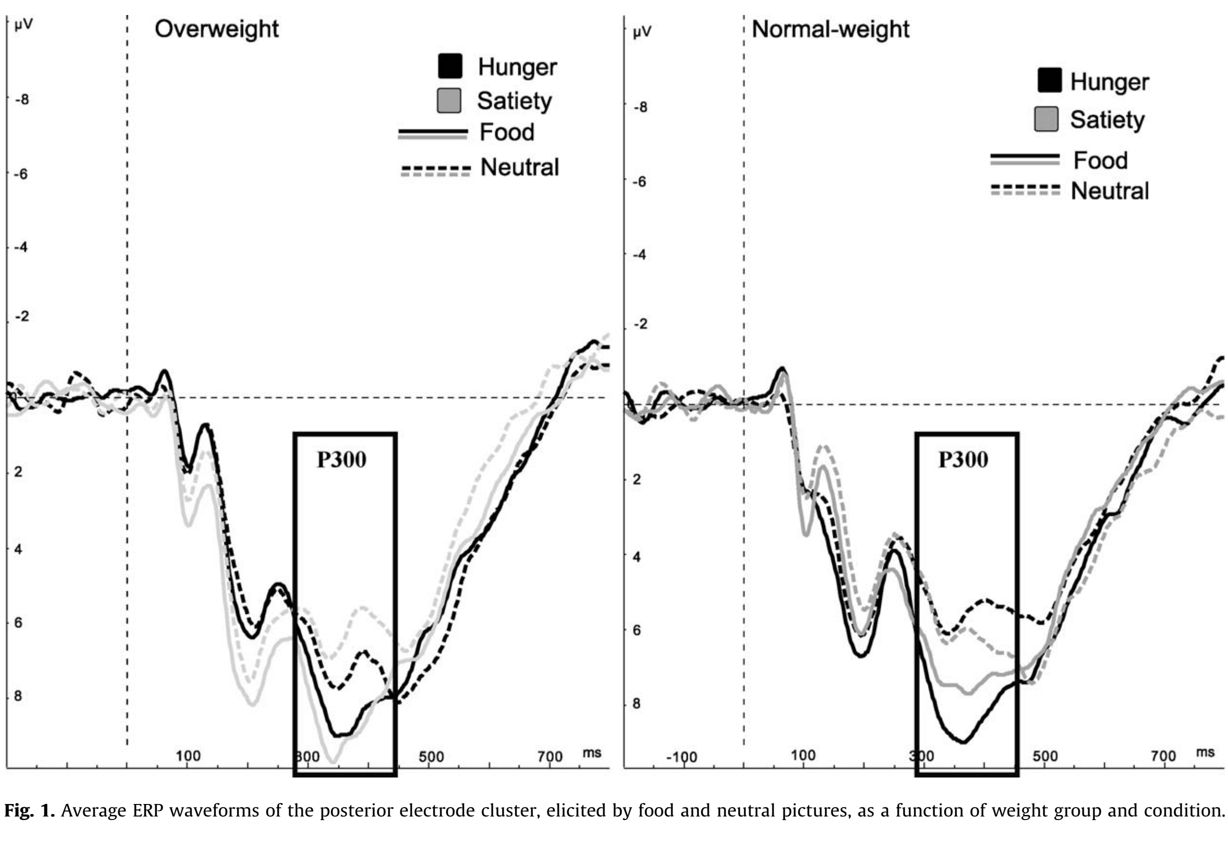

Fig. 1. Average ERP waveforms of the posterior electrode cluster, elicited by food and neutral pictures, as a function of weight group and condition.

Table 1
Mean hunger scores (standard deviations) of overweight/obese and normal-weight females in the hunger and the satiety condition, as assessed on 8 points-in-time during the course of the experiment.

	Overweight/obese ($N = 26$)		Normal-weight ($N = 40$)	
	Hunger ($n = 13$)	Satiety ($n = 13$)	Hunger ($n = 20$)	Satiety ($n = 20$)
VAS Hunger 1	72.00 (11.01)	61.85 (11.95)	64.95 (23.38)	72.70 (18.13)
VAS Hunger 2	–	13.46 (19.77)	–	19.15 (20.98)
VAS Hunger 3	70.00 (18.56)	15.00 (20.36)	69.60 (22.62)	26.35 (21.87)
VAS Hunger 4	68.69 (22.74)	13.08 (13.51)	72.10 (26.94)	26.45 (24.29)
VAS Hunger 5	64.23 (25.62)	11.85 (11.97)	68.10 (27.81)	31.20 (26.65)
VAS Hunger 6	69.69 (25.66)	14.15 (12.78)	69.79 (28.81)	33.06 (25.43)
VAS Hunger 7	81.23 (12.81)	22.85 (19.49)	76.50 (26.20)	44.45 (25.30)
VAS Hunger 8	86.23 (10.35)	31.23 (22.89)	84.00 (19.70)	52.90 (27.09)

Note—VAS: 100 mm visual analogue scale. The order of tasks was as follows: VAS Hunger 1 → milk shake (only in satiety condition) → VAS Hunger 2 (only in satiety condition) → eye-tracking task → VAS Hunger 3 → visual probe task → VAS Hunger 4 → attachment to EEG electrodes → VAS Hunger 5 → distraction task → VAS Hunger 6 → ERP counting task → VAS Hunger 7 → picture ratings → VAS Hunger 8 → bogus taste task.

explicitly that they could eat as much as they liked. Participants were not aware of the fact that their food intake was weighed afterwards, and that food intake (in kcal) was calculated.

Statistical analyses

To check whether the satiety manipulation was successful, subjective hunger levels (VAS) of participants in the satiety condition before and after the consumption of the milk shake were compared by means of a repeated measures analysis of variance (ANOVA) with time (before [VAS1] vs. after [VAS2] milkshake consumption) as within-subjects factor and weight group (overweight/obese vs. normal-weight) as between-subjects factor. In addition, 2 (time) × 2 (condition: hunger vs. satiety) × 2 (weight group) repeated measures ANOVAs were conducted to compare hunger levels of the participants at the start of the experiment (VAS1) with hunger levels after the first (eye-tracking) task (VAS3) and before the last (bogus taste) task (VAS8; see Table 1 for the time course of the experiment).

Pre-experimental differences between weight groups and conditions with respect to age, BMI, and DEBQ scores were assessed by means of separate univariate ANOVAs.

Univariate ANOVAs were also conducted to examine differences between weight groups and conditions with regard to the eye fixation direction and duration bias. Regarding the other attention-related measures (reaction times in 100 and 500 ms trials of the visual probe task, and P300 amplitude), 2 (cue: food vs. neutral) × 2 (condition) × 2 (weight group) repeated measures ANOVAs were conducted with cue as within-subjects factor, and condition and weight group as between-subjects factors. Food intake as obtained with the bogus taste task was analyzed by means of a univariate ANOVA with condition and weight group as between-subjects factors.

All repeated measures ANOVAs were carried out with Greenhouse–Geisser *dfs* (uncorrected *dfs* are reported). In case of significant interaction effects, post-hoc *t*-tests were conducted with Bonferroni adjustments for multiple comparisons.

To examine the relationships between measures of attention, food motivation (hunger and energy intake), and eating styles (external eating, emotional eating, and dietary restraint) in both weight groups, Pearson correlations were computed.

Results

Manipulation check

As can be observed in Table 1, there was an immediate significant decrease in hunger reports of participants of the satiety condition after milk shake consumption (VAS1 vs. VAS2), $F(1,31) = 2.04$, $p < .001$. No significant time × weight group interaction was observed, so the satiety effect appeared to be similar for normal-weight and overweight/obese women.

When comparing VAS1 with VAS3 hunger scores, a significant time × condition interaction was found, $F(1,62) = 117.10$, $p < .001$. Post-hoc *t*-tests revealed that at the start of the experiment (VAS1) there were no differences in hunger between participants of the hunger and satiety condition, $p > .05$, but on VAS3 satiated women reported significantly less hunger than food-deprived women, $p < .001$. Moreover, in hungry participants there were no changes in hunger level between time points 1 and 3 ($M = 67.73$, SD = 19.55 vs. $M = 69.76$, SD = 20.81, $p > .05$). Satiated participants, however, still reported a significantly decreased level of hunger at time 3 as compared to time 1 ($M = 68.42$, SD = 16.66 vs. $M = 21.88$, SD = 21.70, $p < .001$).

When comparing VAS1 with VAS8, a significant time × condition interaction was still observed, $F(1,62) = 63.82$, $p < .001$. Post-hoc *t*-tests demonstrated that satiated participants continued to report significantly less hunger on VAS8 than on VAS1, $M = 68.42$, SD = 16.66 vs. $M = 44.36$, SD = 27.34, $p < .001$, whereas in hungry participants there was a significant increase of hunger between time points 1 and 8, $M = 67.73$, SD = 19.55 vs. $M = 84.88$, SD = 16.49, $p < .001$. In addition, on VAS8, satiated women were found to report significantly less hunger than hungry women ($M = 44.36$, SD = 27.34 vs. $M = 84.88$, SD = 16.49, $p < .001$). A significant weight × condition interaction effect was also found, $F(1,62) = 6.05$, $p < .05$. Post-hoc *t*-tests showed that satiated normal-weight women reported significantly more hunger at time 8 than satiated overweight/obese women, $p < .01$. However, even satiated normal-weight women were still significantly less hungry at time 8 than at time 1, and less hungry than normal-weight hungry women at time 8, $ps < .001$. In summary, these results show that the satiety manipulation succeeded and lasted until the end of the experiment.

Pre-experimental differences

A main effect of weight group was found for BMI, $F(1, 65) = 146.98$, $p < .001$. The mean BMI of overweight/obese participants was significantly higher than the mean BMI of normal-weight participants. A significant main effect of weight group was also observed with regard to DEBQ dietary restraint, $F(1,65) = 19.32$, $p < .001$, with overweight/obese females displaying significantly higher scores than normal-weight females (see Table 2). There was a significant positive correlation between BMI and DEBQ dietary restraint, $r = .44$, $p < .001$. Since dietary restraint and BMI are strongly associated with each other, removal of the variance of dietary restraint would also remove considerable variance due to BMI. For this reason, it was decided not to include the variable of dietary restraint as a covariate in further statistical analyses (Miller & Chapman, 2001).

Table 2
Characteristics of overweight/obese and normal-weight females in the hunger and satiety conditions.

	Overweight/obese (N = 26)		Normal-weight (N = 40)	
	Hunger (n = 13)	Satiety (n = 13)	Hunger (n = 20)	Satiety (n = 20)
BMI	30.14 (5.96)	29.85 (2.98)	20.50 (1.24)	20.76 (1.05)
Age (in years)	20.92 (3.71)	22.08 (3.01)	22.15 (1.46)	20.60 (1.60)
DEBQ External	3.09 (.65)	2.98 (.78)	3.12 (.60)	3.21 (.34)
DEBQ Emotional	2.94 (.88)	2.49 (.56)	2.36 (1.00)	2.53 (.56)
DEBQ Restraint	3.13 (.59)	3.45 (.48)	2.54 (.95)	2.49 (.60)

Note—BMI: Body Mass Index; DEBQ: Dutch Eating Behavior Questionnaire; DEBQ External: DEBQ external eating subscale; DEBQ Emotional: DEBQ emotional eating subscale; DEBQ Restraint: DEBQ dietary restraint subscale. Mean values are displayed and standard deviations are given between parentheses.

Eye-tracking

Outcomes of all the attention-related measures are displayed in Table 3. For the eye-tracking data, a direction bias (>.50), indexing an initial automatic orientation to food pictures, and a duration bias (>.50), indexing maintained attention to food pictures, was observed in all participants, regardless of weight group or condition. Additional one-sample t-tests demonstrated that these bias scores differed significantly from the value of zero, all $ps < .001$.There were no significant differences in the magnitude of bias scores between weight groups or conditions.

Visual probe task

Regarding 100 ms trials, a significant cue × condition interaction was found, $F(1, 61) = 4.94$, $p < .05$. Post-hoc t-tests demonstrated that participants generally showed faster responses to the probe in food-relevant trials than in office-relevant (neutral) trials, indicating an automatic orientation toward food pictures, and this was the case in both the hunger (M = 425. 15, SD = 37.84 vs. M = 436.92, SD = 43.40, $p < .001$) and the satiety condition (M = 452.76, SD = 48.43 vs. M = 459.53, SD = 44.15, $p < .05$).

The cue × weight group interaction approached significance, $F(1,61) = 3.34$, $p = .07$. Post-hoc t-tests revealed that both normal-weight ($p < .01$) and overweight/obese females ($p < .001$) had faster responses to the probe in food-relevant than in office-relevant trials. Normal-weight individuals responded faster to the probes than overweight/obese individuals, in both food-relevant trials ($p < .05$) and office-relevant trials ($p < .01$).

To further examine these interaction effects, an index of attentional bias *size* was calculated by subtracting reaction times to the probe in food-relevant trials from those in office-relevant trials (Brignell et al., 2009; Mogg et al., 1998). This attentional bias score was subjected to a univariate ANOVA with condition and weight group as between-subject factors. A significant main effect of condition was found, $F(1,64) = 4.94$, $p < .05$. This finding indicates that the attentional shift toward food pictures was significantly larger in hungry (M = 11.77, SD = 15.91) than satiated individuals (M = 5.69, SD = 9.04). A nearly significant main effect of weight group was found, $F(1,64) = 3.34$, $p = .07$, indicating that overweight/obese females (M = 12.16, SD = 14. 67) tended to have a larger attentional bias toward food-related pictures as compared to normal-weight females (M = 6.51, SD = 11.77). The weight group × condition interaction was not statistically significant. Nevertheless, as can be observed in Fig. 2, the attentional bias to food seemed to be largest in overweight/obese females in the hunger condition.

The analysis of the 500 ms trials revealed a significant main effect of cue, $F(1,61) = 12.91$, $p = .001$, indicating that participants' responses were generally faster in food-relevant than in office-relevant trials M = 413.28, SD = 37.28 vs. M = 419.47, SD = 39.18, which reflects maintained attention to food pictures. A significant main effect of weight group was also observed, $F(1,61) = 5.34$, $p < .05$, indicating that normal-weight participants generally responded faster than overweight/obese participants. No further significant effects were observed.

P300

A significant cue × condition × weight group interaction was found, $F(1,60) = 7.79$, $p < .01$. Post-hoc t-tests revealed a significantly enlarged P300 amplitude to food pictures as compared to

Table 3
Mean scores on attention-related measures and energy intake (standard deviations) in overweight/obese and normal-weight females in the hunger and the satiety condition.

	Overweight/obese		Normal-weight	
	Hunger	Satiety	Hunger	Satiety
Gaze direction bias	.59 (.09)	.58 (.11)	.59 (.10)	.59 (.07)
Gaze duration food	377.40 (224.76)	363.32 (210.32)	468.26 (273.26)	404.82 (223.81)
Gaze duration office	314.88 (218.09)	315.80 (183.49)	310.82 (182.44)	329.97 (195.12)
Gaze duration bias	.54 (.14)	.53 (.11)	.60 (.14)	.56 (.08)
RT food 100	438.96 (49.25)	452.76 (48.43)	416.86 (27.17)	429.62 (37.68)
RT office 100	456.97 (55.21)	459.52 (44.15)	424.88 (30.03)	434.60 (34.06)
RT office – RT food 100	18.00 (17.78)	6.76 (8.65)	8.03 (13.81)	4.98 (9.44)
RT food 500	421.71 (49.68)	431.36 (46.52)	400.59 (24.00)	409.15 (29.22)
RT office 500	428.97 (55.06)	436.50 (45.13)	407.39 (23.51)	414.77 (33.80)
RT office – RT food 500	7.26 (16.37)	5.13 (12.39)	6.80 (11.19)	5.62 (14.53)
P300 food	8.28 (4.51)	8.57 (4.09)	8.24 (3.39)	7.29 (2.59)
P300 office	7.24 (4.04)	6.19 (3.09)	5.52 (3.29)	6.16 (2.90)
P300 food – P300 office	1.04 (2.09)	2.38 (2.55)	2.72 (1.80)	1.13 (1.92)
Kcal intake	705.92 (202.49)	373.92 (317.28)	466.32 (155.96)	381.07 (264.23)

Note—Gaze direction bias: number of trials in which the first eye fixation was directed to the food picture as a proportion of the total number of trials in which eye fixations occurred; gaze duration food/office: average gaze duration to the food/office picture per trial; gaze duration bias: average gaze duration to the food picture per trial as a proportion of average gaze duration to either picture per trial; RT food/office: mean reaction time (in ms) to the probe in food-relevant and office-relevant trials of the visual probe task; 100/500: pictures are shown for 100/500 ms in the visual probe task assessing orienting attention and maintained attention respectively; P300 food/office: mean amplitude of the P300 component (in μV) to pictures of food and office items.

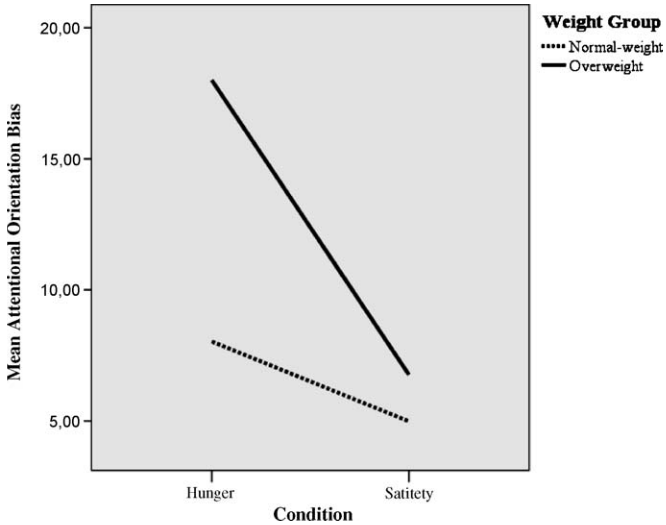

Fig. 2. Mean attentional bias as obtained during the 100 ms trials of the visual probe task as a function of weight group and condition.

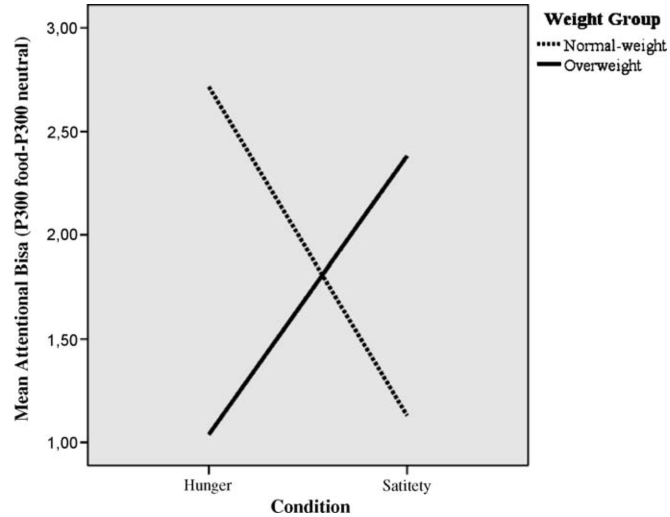

Fig. 3. Mean attentional bias scores, as indexed by P300 difference amplitudes, as a function of weight group and condition.

neutral (office-related) pictures in normal-weight hungry ($p < .001$) and satiated ($p < .05$) females, and in overweight/obese satiated women ($p < .001$). In overweight/obese hungry women the difference between P300s to food and neutral pictures approached significance, $p = .07$. In other words, in all participants a P300 amplitude bias, indexing a bias in the conscious allocation of attention, to food pictures was observed, irrespective of weight group or condition.

Additional analyses were conducted to examine differences in P300 amplitude bias *size*, i.e., P300 amplitude to food pictures minus P300 amplitude to office-related pictures. A univariate ANOVA was carried out with this P300 amplitude bias score as dependent variable, and with condition and weight group as between-subjects variables. A significant weight group × condition interaction[1] was found, $F(1,60) = 7.79$, $p < .01$, see Fig. 3. Post-hoc t-tests showed that only in normal-weight females P300-related attentional bias to food was significantly enlarged in hunger as compared to satiety, $p < .05$. Moreover, in the hunger condition P300-related attentional bias to food was significantly larger in normal-weight than in overweight/obese participants, $p < .05$, whereas in the satiety condition, P300-related attentional bias to food tended to be larger in overweight/obese than in normal-weight women, $p = .10$.

Bogus Taste Task

Analysis of the food intake yielded a significant interaction of condition and weight group, $F(1,62) = 4.26$, $p < .05$, see Fig. 4. Post-hoc t-tests revealed that overweight/obese females ate significantly more of the snack food (in kcal) as compared to normal-weight females, but only in the hunger condition, $p = .01$. Moreover, only in overweight/obese individuals, food intake was

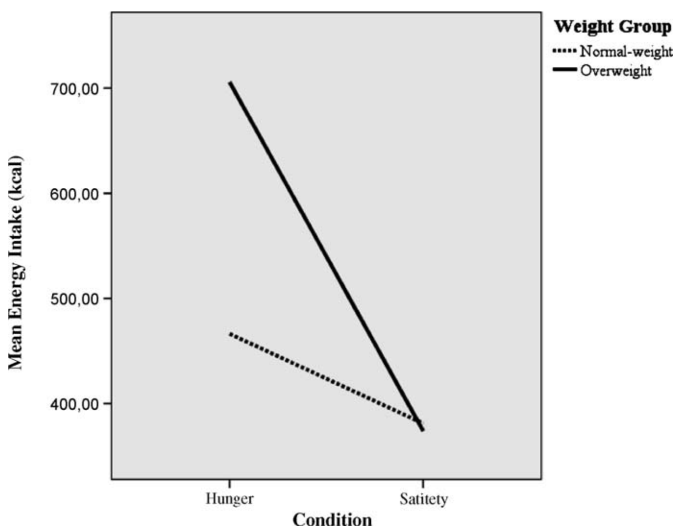

Fig. 4. Mean energy (kcal) intake as a function of weight group and condition.

significantly increased in the hunger state as compared to the satiated state, $p = .001$, see Table 3.

Correlational analyses

In normal-weight females, strong positive correlations were observed between the P300 index of attention bias, subjective hunger level, food intake, and external eating, see Table 4. This result indicates that in normal-weights, and particularly in normal-weight external eaters, attentional bias as measured with P300 amplitude is associated with food motivation. In overweight/obese females, there was a strong positive correlation between the attentional orienting bias (100 ms visual probe task) towards food pictures and hunger level, but not food intake. In normal-weights, the orienting bias towards food also correlated positively with dietary restraint.

Discussion

The main objective of the present study was to examine differences in attention to food pictures between normal-weight

[1] A similar 2 (cue: baby vs. neutral) × 2 (weight group) × 2 (condition) repeated measures ANOVA was conducted on the P300 data of the emotionally pleasant (baby) pictures. Only a significant main effect of cue was found, $F(1,60) = 85.50$, $p < .001$, indicating that the P300 amplitude to baby pictures was generally larger than the P300 amplitude to neutral office-related pictures ($M = 10.42$, SD = 3.61 vs. $M = 6.20$, SD = 3.29). The interaction effects did not attain significance, suggesting that this P300 bias to baby pictures was similar across conditions and weight groups. This means that differences in P300 bias scores between weight groups and conditions were specific for food-related information and were not seen for emotionally salient information in general.

Table 4
Correlations among attentional bias scores, energy intake, hunger, and eating styles.

	Normal-weight						Overweight/obese					
	Gaze direction	Gaze duration	VPT100	VPT500	P300	kcal	Gaze direction	Gaze duration	VPT100	VPT500	P300	kcal
VAS Hunger	.03	.28	.22	.20	$.47^{**}$	$.37^{*}$	.16	.28	$.54^{**}$	.26	−.26	$.41^{*}$
Gaze direction	1.00						1.00					
Gaze duration	$.54^{**}$	1.00					.34	1.00				
VPT100	−.09	.05	1.00				.11	.29	1.00			
VPT500	.18	−.01	−.27	1.00			.02	.18	$.49^{*}$	1.00		
P300	.13	.26	.26	$.34^{*}$	1.00		−.03	.06	−.20	.14	1.00	
Kcal	.10	.24	.16	.07	$.44^{**}$	1.00	.28	.24	.18	−.01	−.19	1.00
DEBQ External	.06	.25	.17	.05	$.44^{**}$	$.35^{*}$	.03	.03	−.23	.09	−.26	−.07
DEBQ Emotional	.06	.25	.06	−.18	−.08	.14	−.09	−.02	−.16	−.13	−.33	.37
DEBQ Restraint	.12	.09	$.35^{*}$	−.18	.27	.25	−.24	−.19	−.23	−.38	.16	−.04

Note—VAS Hunger: mean hunger rating (on a visual analogue scale) over the course of the experiment; gaze direction bias: number of trials in which the first eye fixation was directed to the food picture as a proportion of the total number of trials in which eye fixations occurred; gaze duration bias: average gaze duration to the food picture per trial as a proportion of average gaze duration to either picture per trial; VPT: difference reaction time (in ms) in food-relevant and office-relevant trials in the visual probe task; 100/500: picture pairs are shown for 100/500 ms in the visual probe task assessing orienting attention and maintained attention respectively; P300: difference P300 amplitude (in μV) to pictures of food and neutral control pictures; kcal: energy intake in the bogus taste task; DEBQ: Dutch Eating Behavior Questionnaire; DEBQ External: DEBQ external eating subscale; DEBQ Emotional: DEBQ emotional eating subscale; DEBQ Restraint: DEBQ dietary restraint subscale.

* $p < .05$.
** $p < .01$.

and overweight/obese, food-deprived and satiated females. Various attention-related tasks unanimously demonstrated that a bias in the oriented and maintained attention to food pictures was present in all participants, irrespective of weight group or hunger/satiety condition. From an evolutionary perspective, this could have been expected: a selective detection of (high-caloric) foods seems to be one of the most adaptive characteristics of humans and animals. In a number of tasks, but not all, differences between weight groups and/or conditions were observed in the magnitude of the attentional bias.

No differences between groups or conditions were found with regard to the outcomes of the first attention-related task the participants were presented with, i.e., the food-related biases in the initial orientation and maintenance of attention, as assessed by the direction and duration of eye fixations. This finding is in contrast with recent findings of Castellanos et al. (2009), who reported an enhanced food-related gaze direction and duration bias in obese as compared to normal-weight females who were in a state of satiety. In addition, these authors found that the food-related gaze direction and duration biases were modulated as expected by hunger and satiety state in normal-weight, but not in obese participants. One reason for inconsistencies between the present results and those of Castellanos et al. (2009) might be that – in the present study – participants of the satiety condition completed the eye-tracking task immediately after the consumption of the milk shake. Although participants did report a significant decrease in experienced hunger, it is possible that postprandial hormones not yet had the chance to send satiety signals to the brain. In future studies, it seems advisable to include a time delay between the satiation manipulation and the start of the experimental tasks, such as was done in the study of Castellanos et al. (2009).

In the visual probe task, with 100 ms lasting stimuli, an enhanced automatic orientation towards food pictures was generally seen in hungry versus satiated participants, and also in overweight/obese (especially hungry overweight/obese) versus normal-weight women. Although the latter finding only approached significance, it is believed to be an important finding, because it shows that overweight/obese individuals are, to a greater extent than normal-weight individuals, inclined to direct their initial attention automatically to food-related stimuli, particularly when they are in a state of hunger. The visual probe task with 500 ms trials did not yield any meaningful between-group or condition differences. In general, it is hypothesized that, if an attention bias is found with longer trials (i.e., 500 ms or more), this reflects maintained attention or a delay of attention disengagement (Field & Cox, 2008). Results thus suggest that all participants demonstrated maintained attention to food, irrespective of weight group or condition. This finding is in line with findings of Castellanos et al. (2009), who found, using a visual probe task with a stimulus presentation duration of 2000 ms, no differences in reaction time scores between weight groups or conditions. However, it is difficult to draw definitive conclusions from these results, because the use of longer presentation durations in the visual probe task appears to be quite problematic. That is, even with a rather short trial duration of 500 ms, multiple shifts of attention between the two stimuli are possible (Field & Cox, 2008), and reaction time scores only give information about at which stimulus the participant's attention was directed at the moment of stimulus offset (Bradley, Field, Mogg, & De Houwer, 2004; Field, Mogg, & Bradley, 2004). As a result, it is impossible to tell whether a reaction time bias using longer trial durations in a visual probe task reflects a delay of attentional disengagement to one stimulus category or is a rather coincidental outcome of attention shifting back and forth between the two stimuli. The monitoring of eye movements is assumed to be a more sensitive and direct measure of attentional orientation and engagement as compared to indirect reaction time measures, such as the visual probe task. Future studies should combine a visual probe task with the recording of eye movements. By investigating associations between reaction times and eye-tracking scores, it should be possible to pronounce better upon the meaning of reaction time scores, and particularly those allegedly reflecting maintained attention. Although a number of previous studies did report a meaningful relationship between reaction times scores of the visual probe task and eye fixation outcomes (e.g., Field, Mogg, Zetteler, & Bradley, 2004), this was not found in the present study, suggesting that in the present study different processes were assessed with these different measures. In general, correlations between various attention-related measures were not much meaningful, and seemed to depend on weight group. This is in line with previous studies, which also found only weak or no associations between several measures of cognitive processing, or found these associations to be only present in certain subsamples of the study population (Mogg & Bradley, 2002; Pothos, Calitri, Tapper, Brunstrom, & Rogers, 2009). For instance, Pothos et al. (2009) found no substantial associations between scores on a food-related visual probe task and Stroop task, which are both assumed to assess attention-related processes, but they did find significant correlations between the performance on the visual probe task and a task assessing attitudes toward food-related stimuli. The relationship between various attention-related measures and differences in the underlying processes determining outcomes on these measures seems to be an important topic of future studies.

When examining the P300 amplitude, as index of the conscious allocation of attention, in normal-weight participants, a bias to food-related pictures was observed, that was modulated in the predicted way by hunger and satiety state. This P300 bias (i.e., a significant difference in P300 amplitude to food-related and neutral pictures) was also clearly present in satiated overweight/obese participants, but was substantially reduced (and no longer significant) in hungry overweight/obese participants. That is, relative to neutral control pictures, overweight/obese participants who were in a state of hunger did not engage substantially more attentional resources in the processing of food-related pictures. There is evidence that the amplitude of late positive potentials, such as the P300, is – at least partly – under intentional control (Hajcak, Dunning, & Foti, 2009; Hajcak & Nieuwenhuis, 2006; Moser, Hajcak, Bukay, & Simons, 2006), and might reflect strategic, maintained, rather than automatic attention processes (Schupp et al., 2006). Speculatively, the present P300 results thus suggest that hungry overweight/obese women intentionally may use cognitive strategies to reduce a (maintained) attentional bias to food-related stimuli. However, it should be emphasized that from P300 amplitudes alone it is not possible to draw conclusions about approach or avoidance strategies. Contrary to the other used attention tasks, P300 amplitude is not a measure of visuospatial attention, but reflects the intensity by which cognitive resources in the brain are engaged to attend to certain stimuli. Both pleasant and aversive stimuli are known to elicit enlarged P300 amplitudes (Olofsson et al., 2008; Schupp et al., 2006) as compared to neutral stimuli. Moreover, the results of the other used attention-related measures (eye-tracking, visual probe task) in the present study have yielded no direct support for the idea that hungry overweight/obese participants may have a desire to avoid gazing at food pictures. Nevertheless, it is a conspicuous finding that the P300 bias was specifically reduced in hungry overweight/obese females, and this should be a topic of future replication studies.

Still, one speculative reason why hungry overweight/obese individuals might want to direct their attention away from food stimuli is because of a fear of disinhibited food intake when exposed to salient foods (Herman & Polivy, 2008). In line with this view, in the bogus taste task, hungry overweight/obese females ate significantly more of the snack foods than normal-weight and satiated overweight/obese females. Satiated overweight/obese participants did not consume more kilocalories during the taste task than satiated normal-weight women. Altogether, the results of the present study suggest that overweight/obese females are particularly sensitive to food stimuli when hungry: their attention is automatically oriented toward food stimuli, to a greater extent than is the case in normal-weight females (as was observed in the 100 ms visual probe task), and they display a tendency to overeat when exposed to snack foods (as was observed in the bogus taste task). However, it should be noted that an alternative explanation is possible for the results of the bogus taste task. Normal-weight participants did not eat significantly more of the snack foods during hunger as compared to satiety. It is possible that hungry normal-weight participants intentionally limited their food intake, perhaps because they did not want to spoil their actual (healthier) lunch by eating too much snack foods. This line of thinking also suggests that overweight/obese individuals might, particularly when hungry, have more difficulties to keep control over their food choices and food intake. Recent studies have indeed suggested that a poor behavioral inhibition (i.e., impulsivity) or reward sensitivity predicts overeating behaviors, and might form a vulnerability factor to become obese (Davis et al., 2007; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006a). This is an important issue for future studies.

The incentive sensitization model assumes a positive relationship between food-related attention, a desire to eat, and food intake (Berridge, 2009; Robinson & Berridge, 1993). Correlational analyses indicated that the P300 bias score seemed to be a good index of food motivation, but only in normal-weight individuals: the more hunger normal-weight participants reported, the more attention they consciously engaged to food pictures, and the more snack food was eaten in the bogus taste task. Moreover, an interesting positive relationship was found, only in normal-weight participants, between P300 bias and DEBQ external eating scores. This supports results of previous studies, which demonstrated an enhanced food-related attentional bias in normal-weight high versus low external eaters (Brignell et al., 2009; Nijs et al., in press). As an addition to these earlier studies, the present study also included a direct index of food consumption, which yielded a number of interesting results. That is, a positive relationship was found between external eating scores and the amount of food eaten during the bogus taste task, suggesting that high external eaters not only have more attention for food-related cues, but also eat more when exposed to such cues, which provides support for the validity of the external eating construct (Anschutz, van Strien, Van de Ven, & Engels, 2009), at least in normal-weight individuals. Previous studies also found enhanced food cue-reactivity in normal-weight persons with high dietary restraint scores (e.g., Green & Rogers, 1993; Polivy et al., 2005; Tapper et al., 2008). This result was also partly confirmed in the present study: in normal-weight participants, a positive correlation was found between dietary restraint scores and the reaction time bias score of the visual probe task with trials of 100 ms duration, reflecting the initial automatic orientation of attention to food pictures. However, it must be noted that there was no significant correlation between dietary restraint scores and the amount of kilocalories eaten in the bogus taste task. Apparently, normal-weight restrained (as identified by means of the DEBQ, i.e., voluntary eating restriction, Lowe, van Steenburgh, Ochner, & Coletta, 2009) individuals automatically notice food-related cues, but do not give in to eating them, whereas normal-weight external eaters intentionally attend to food, especially when hungry, and then indulge in eating.

In overweight/obese individuals, the pattern of these relationships was quite different. A positive association was found between hunger reports and a bias in the initial automatic attention to food pictures (as assessed by means of reaction times in the 100 ms visual probe task), and between hunger reports and the amount of food eaten during the bogus taste task: the more hunger overweight/obese participants reported, the more their attention was automatically drawn to food pictures, and the more they ate. No further meaningful associations were found between attentional bias scores and measures of food motivation, nor between attentional bias scores and eating styles. This is an important finding, because it suggests that findings in normal-weight individuals (e.g., regarding the association between external eating/restraint and attentional biases to food) may not be automatically generalized to overweight/obese individuals and vice versa.

It should be noted that unexpected findings were obtained regarding self-report measures during the present study. That is, in contrast to expectations derived from an incentive sensitization model of obesity, overweight/obese females did not differ from normal-weight females in terms of a self-reported tendency toward dietary disinhibition, as assessed by means of the DEBQ subscales of external and emotional eating. In other studies, significant between-weight group differences (Braet and van

Strien, 1997; Castellanos et al., 2009) and no differences (Caccialanza et al., 2004) have been reported in DEBQ measures of external and emotional eating. Similarly to dietary disinhibition scores, overweight/obese participants did not report more hunger during the experiment as compared to normal-weight participants, which was a priori expected. In fact, if differences in self-reported hunger were found, it were the normal-weight participants who reported more intense hunger as compared to the overweight/obese participants (in the satiety condition, at the end of the experiment). We do not have a direct explanation for this finding. However, it was first mentioned in the 1950s that in normal-weight individuals, physiologial signals of hunger (such as stomach contractions) corresponded well with the subjective experience of hunger, but that this was not the case in obese individuals (Stunkard, 1959). This peculiar finding was, by some obesity researchers, interpreted as that obese individuals were less sensitive to internal signals of hunger and satiety than normal-weight individuals (Schachter, 1971). However, in a quite recent study on the validity of various hunger measures in obese and normal-weight individuals, results revealed a rather inverse pattern, namely that hunger reports of obese individuals were *more* tightly associated with physical sensations than the hunger reports of normal-weight individuals (Lowe, Friedman, Mattes, Kopyt, & Gayda, 2000). As has been already pointed out by Stunkard, as early as in 1959, reports of less hunger in obese as compared to normal-weight individuals might also reflect a tendency of obese individuals to (consciously or unconsciously) underreport feelings of hunger and desire to eat, possibly because of social pressures or feelings of shame. In line with this idea, it is well-known that obese individuals tend to underreport, to a greater extent than normal-weights, other eating- and weight-related issues, such as their body weight (Dauphinot et al., 2009) and food intake (Goris, Westerterp-Plantenga, & Westerterp, 2000; Schoeller, 1995). This might as well be the case for self-reports of hunger and eating style. It seems of particular importance that future studies should do an attempt to systematically investigate the validity of these self-report measures, particularly in overweight/obese individuals, as invalid scores may distort study results and conclusions.

The present study has a number of limitations that should be taken into account. First, everyone who wanted and was qualified to participate in the study was included, with the result that the overweight/obese and normal-weight study samples were of different size. Therefore, the samples may have been subject to self-selection or referral biases. On the other hand, participants were not told beforehand that the study concerned differences between overweight/obese and normal-weight samples in food-related attention, but rather that it concerned the general influence of hunger on task performance and taste perception. A second limitation concerns the use of a fixed amount of milk shake to realize a state of satiety in the participants. Advantages of this approach are its easy and fast applicability, and the fact that the calorie and nutrient content of the consumed milk shake are exactly known and controlled. However, there are also a number of disadvantages to this approach. For instance, although the milk shake had a relatively high-calorie content, and although the consumption of the milk shake led to a significant reduction of subjective hunger in both weight groups, it may not have been satiating to an equal extent in all participants, and particularly not in the overweight/obese participants. To ensure similar levels of satiation, future studies could adjust the amount of milk shake (and the energy content) to a percentage of the estimated daily energy requirement for each individual. Another disadvantage concerns the palatability of the milk shake. A milk shake may be perceived as unsatisfactory when being in a state of 17 h food deprivation, and even if the physiological hunger was largely reduced by drinking the milk shake, participants in the satiety condition may still have experienced a 'hedonic hunger' (Lowe & Butryn, 2007) for the food items depicted in the pictures during the attentional tasks. Future studies could examine whether a normal lunch, selected by the participant herself and eaten until satiation, would yield similar results. A third limitation concerns the task order. In the present study, the task order was held constant for all participants. Since self-reported hunger increased during the course of the experiment in participants of the satiety state, this means that the effect of satiation was consistently lowest in the later tasks. Also, the same food-related pictures were used in the series of attention-related tasks. Research in the addiction field has pointed out that repeated cue exposure in the absence of cue availability may facilitate extinction of the desire (or general reactivity) to the cue (Drummond, Cooper, & Glautier, 1990). Both the fixed task order and re-using the same food pictures might have influenced the present results, and different results may have been found if the task order was reversed or counterbalanced, or if various sets of food-related pictures were used. Future studies should take these issues into consideration. A fourth limitation was that, in the present study, because of practical reasons, overweight and obese women were included. Addiction-like mechanisms, such as an incentive sensitization of the brain reward system and resulting enhanced attention to food, might particularly play a role in severely obese individuals, perhaps with severe overeating problems, such as binge eating (Davis & Carter, 2009) and less in moderately overweight individuals. Fifth, to fully test the incentive sensitization model of obesity, future studies could include a measure of dopamine release in the brain reward system (e.g., positron emission tomography) to examine the relationship between this dopamine release and various measures of attention, hunger, and food intake. Sixth, the present study relied on a correlational design, and so it is yet impossible to draw conclusions concerning causal relationships between the various variables. In addition, it cannot be concluded whether the enhanced sensitivity to hunger in overweight/obese individuals is innate or acquired (possibly due to multiple dieting). It is a challenge to future studies to further resolve these issues.

To summarize, some of the results of the present study are in favor of, and some contradict an incentive sensitization model of obesity. Only the results of the 100 ms visual probe task generally support the model, as they suggest that the incentive salience of food (which is regulated by dopaminergic activity in the reward system) is heightened during hunger versus satiety, and in overweight/obese versus normal-weight/obese individuals. However, only in overweight participants, there was a clear relationship between hunger reports, the automatic shift of attention to food, and food intake, which questions the idea that these outcomes are general manifestations of the activation of the same underlying reward system. The incentive sensitization model also assumes stronger food cue-elicited responses in overweight/obese than normal-weight individuals when satiated. The present study did not yield clear evidence for this assumption: marginally significant between-weight group differences within the satiety condition were only found for the P300 bias score, indicating that satiated overweight/obese females intentionally allocated their attention to food pictures to a larger extent than satiated normal-weight females. However, satiated overweight/obese females did not eat more during the bogus taste task than satiated normal-weight females. From addiction research, it is known that drug-deprived addicts mainly demonstrate a difficulty to disengage their attention from drug cues, and that this maintained attention to drug cues is related to the subjective experience of craving (Field, Munafó, & Franken, 2009). The present study shows that this might not be the case in overweight/obese individuals: in the eye-tracking task and the 500 ms visual probe task no differences were generally found between overweight/obese and normal-weight individuals in maintained attention, and the P300 data suggested that hungry overweight/obese individuals even made an effort to reduce their maintained attention bias to the food stimuli. These results indicate that, despite several commonalities, there are important differences in the neurocognitive mechanisms behind obesity and addiction. One explanation for these discrepancies might be that food is an indispensable substance that draws the attention of all, both normal-weight and overweight/obese persons.

Finally, the present results may ultimately have some implications for the treatment of overweight/obesity and the interpretation of study results concerning food cue-reactivity. First, overweight/obese females seem to be particularly sensitive and responsive to food stimuli when hungry. This might explain why so many overweight/obese individuals find it difficult to comply to a low energy diet (Warziski Turk et al., 2009). Diets containing too few kilocalories lead to constant feelings of hunger, which might make it extra difficult for overweight/obese individuals to resist temptations of the abundantly present food in the environment. Second, as already mentioned, it appears that results of normal-weight study samples cannot be generalized to overweight/obese study samples and vice versa. For instance, in the present study, the positive association between external eating and food cue-responsiveness, which was clearly visible in normal-weight individuals, was not present in overweight/obese individuals. Finally, it should be emphasized that from the present study results only preliminary conclusions can be formulated, as replication studies are necessary.

References

Anschutz, D. J., van Strien, T., Van de Ven, M. O., & Engels, R. C. (2009). Eating styles and energy intake in young women. *Appetite, 53*, 119–122.

Berridge, K. C. (2009). 'Liking' and 'wanting' food rewards: brain substrates and roles in eating disorders. *Physiology and Behavior, 97*, 537–550.

Bradley, B. P., Field, M., Mogg, K., & De Houwer, J. (2004). Attentional and evaluative biases for smoking cues in nicotine dependence: component processes of biases in visual orienting. *Behavioural Pharmacology, 15*, 29–36.

Bradley, B. P., Garner, M., Hudson, L., & Mogg, K. (2007). Influence of negative affect on selective attention to smoking-related cues and urge to smoke in cigarette smokers. *Behavioural Pharmacology, 18*, 255–263.

Braet, C., & van Strien, T. (1997). Assessment of emotional, externally induced and restrained eating behaviour in nine to twelve-year-old obese and non-obese children. *Behaviour Research and Therapy, 35*, 863–873.

Braet, C., Claus, L., Goossens, L., Moens, E., Van Vlierberghe, L., & Soetens, B. (2008). Differences in eating style between overweight and normal-weight youngsters. *Journal of Health Psychology, 13*, 733–743.

Braet, C., & Crombez, G. (2003). Cognitive interference due to food cues in childhood obesity. *Journal of Clinical Child and, Adolescent Psychology, 32*, 32–39.

Brignell, C., Griffiths, T., Bradley, B. P., & Mogg, K. (2009). Attentional, approach biases for pictorial food cues: influence of external eating. *Appetite, 52*, 299–306.

Burton, P., Smit, H. J., & Lightowler, H. J. (2007). The influence of restrained and external eating patterns on overeating. *Appetite, 49*, 191–197.

Caccialanza, R., Nicholls, D., Cena, H., Maccarini, L., Rezzani, C., Antonioli, L., et al. (2004). Validation of the Dutch Eating Behaviour Questionnaire parent version (DEBQ-P) in the Italian population: A screening tool to detect differences in eating behaviour among obese, overweight and normal-weight preadolescents. *European Journal of Clinical Nutrition, 58*, 1217–1222.

Castellanos, E. H., Charboneau, E., Dietrich, M. S., Park, S., Bradley, B. P., Mogg, K., et al. (2009). Obese adults have visual attention bias for food cue images: evidence for altered reward system function. *International Journal of Obesity, 33*, 1063–1073.

Channon, S., & Hayward, A. (1990). The effect of short-term fasting on processing of food cues in normal subjects. *International Journal of Eating Disorders, 9*, 447–452.

Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biological Psychology, 52*, 95–111.

Dauphinot, V., Wolff, H., Naudin, F., Guequen, R., Sermet, C., Gaspoz, J. M., et al. (2009). New obesity body mass index threshold for self-reported data. *Journal of Epidemiology and Community Health, 63*, 128–132.

Davis, C., & Carter, J. C. (2009). Compulsive overeating as an addiction disorder. A review of theory and evidence. *Appetite, 53*, 1–8.

Davis, C., Patte, K., Levitan, R., Reid, C., Tweed, S., & Curtis, C. (2007). From motivation to behaviour: a model of reward sensitivity, overeating, and food preferences in the risk profile for obesity. *Appetite, 48*, 12–19.

Drummond, D. C., Cooper, T., & Glautier, S. P. (1990). Conditioned learning in alcohol dependence: implications for cue exposure treatment. *British Journal of Addiction*, 725–743.

Field, M., & Cox, W. M. (2008). Attentional bias in addictive behaviors: a review of its development, causes, and consequences. *Drug and Alcohol Dependence, 97*, 1–20.

Field, M., Mogg, K., & Bradley, B. P. (2004a). Eye movements to smoking-related cues: effects of nicotine deprivation. *Psychopharmacology, 173*, 116–123.

Field, M., Mogg, K., Zetteler, J., & Bradley, B. P. (2004b). Attentional biases for alcohol cues in heavy and light social drinkers: the roles of initial orienting and maintained attention. *Psychopharmacology (Berl.), 176*, 88–93.

Field, M., Munafó, M. R., & Franken, I. H. A. (2009). A meta-analytic investigation of the relationship between attentional bias and subjective craving in substance abuse. *Psychological Bulletin, 135*, 589–607.

Goris, A. H., Westerterp-Plantenga, M. S., & Westerterp, K. R. (2000). Undereating and underrecording of habitual food intake in obese men: selective underreporting of fat intake. *American Journal of Clinical Nutrition, 71*, 130–134.

Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artefact. *Electroencephalography and Clinical Neurophysiology, 55*, 468–484.

Green, M. W., & Rogers, P. J. (1993). Selective attention to food and body shape words in dieters and restrained nondieters. *International Journal of Eating Disorders, 14*, 515–517.

Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: time course of the late positive potential. *Clinical Neurophysiology, 120*, 505–510.

Hajcak, G., & Nieuwenhuis, S. (2006). Reappraisal modulates the electrocortical response to unpleasant pictures. *Cognitive, Affective, and Behavioral Neuroscience, 6*, 294–297.

Herman, C. P., & Polivy, J. (2008). External cues in the control of food intake in humans: the sensory-normative distinction. *Physiology and Behavior, 94*, 722–728.

Jansen, A., Theunissen, N., Slechten, K., Nederkoorn, C., Boon, B., Mulkens, S., et al. (2003). Overweight children overeat after exposure to food cues. *Eating Behaviors, 4*, 197–209.

Johansson, L., Ghaderi, A., & Andersson, G. (2004). The role of sensitivity to external food cues in attentional allocation to food words on dot probe and Stroop tasks. *Eating Behaviors, 5*, 261–271.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2005). *International affective picture system (IAPS): digitized photographs, instruction manual and affective ratings. Technical report A-6*. Gainesville, FL: University of Florida.

Lavy, E. H., & van den Hout, M. A. (1993). Attentional bias for appetitive cues: effects of fasting in normal subjects. *Behavioural and Cognitive Psychotherapy, 21*, 297–310.

Lowe, M. R., & Butryn, M. L. (2007). Hedonic hunger: a new dimension of appetite? *Physiology and Behavior, 91*, 432–439.

Lowe, M. R., Friedman, M. I., Mattes, R., Kopyt, D., & Gayda, C. (2000). Comparison of verbal and pictorial measures of hunger during fasting in normal weight and obese subjects. *Obesity Research, 8*, 566–574.

Lowe, M. R., van Steenburgh, J., Ochner, C., & Coletta, M. (2009). Neural correlates of individual differences related to appetite. *Physiology and Behavior, 97*, 561–571.

Miller, G. A., & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology, 110*, 40–48.

Mogg, K., & Bradley, B. P. (2002). Selective processing of smoking-related cues in smokers: manipulation of deprivation level and comparison of three measures of processing bias. *Journal of Psychopharmacology, 16*, 385–392.

Mogg, K., Bradley, B. P., Hyare, H., & Lee, S. (1998). 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? *Behaviour Research and Therapy, 36*, 227–237.

Moser, J. S., Hajcak, G., Bukay, E., & Simons, R. F. (2006). Intentional modulation of emotional responding to unpleasant pictures: an ERP study. *Psychophysiology, 43*, 292–296.

Nederkoorn, C., Braet, C., Van Eijs, Y., Tanghe, A., & Jansen, A. (2006a). Why obese children cannot resist food: the role of impulsivity. *Eating Behaviors, 7*, 315–322.

Newman, E., O'Connor, D. B., & Conner, M. (2008). Attentional biases for food stimuli in external eaters: possible mechanism for stress-induced eating? *Appetite, 51*(2), 339–342.

Nijs, I. M. T., Franken, I. H. A., & Muris, P. (2008). Food cue-elicited brain potentials in obese and healthy-weight individuals. *Eating Behaviors, 9*, 462–470.

Nijs, I. M. T., Franken, I. H. A., & Muris, P. (in press). Enhanced processing of food-related pictures in female external eaters. *Appetite*, doi:10.1016/j.appet.2009.07.022.

Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: an integrative review of ERP findings. *Biological Psychology, 77*, 247–265.

Picton, T. W. (1992). The P300 wave of the human event-related potential. *Journal of Clinical Neurophysiology, 9*, 456–479.

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R. J., et al. (2000). Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. *Psychophysiology, 37*, 127–152.

Placanica, J. L., Faunce, G. J., & Soames Job, R. F. (2001). The effect of fasting on attentional biases for food and body shape/weight words in high and low Eating Disorder Inventory scorers. *International Journal of Eating Disorders, 32*, 79–90.

Polich, J., & Kok, A. (1995). Cognitive and biological determinants of P300: an integrative review. *Biological Psychology, 41*, 103–146.

Polivy, J., Coleman, J., & Herman, C. P. (2005). The effect of deprivation on food cravings and eating behavior in restrained and unrestrained eaters. *International Journal of Eating Disorders, 38*, 301–309.

Polivy, J., Herman, C. P., & Coelho, J. S. (2008). Caloric restriction in the presence of attractive food cues: external cues, eating, and weight. *Physiology and Behavior, 94*, 729–733.

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology, General, 109*, 160–174.

Pothos, E. M., Calitri, R., Tapper, K., Brunstrom, J. M., & Rogers, P. J. (2009). Comparing measures of cognitive bias relating to eating behaviour. *Applied Cognitive Psychology, 23*, 936–952.

Robinson, T. E., & Berridge, K. C. (1993). The neural basis of drug craving: an incentive-sensitization theory of addiction. *Brain Research Reviews, 18*, 247–291.

Schachter, S. (1971). Some extraordinary facts about obese humans and rats. *The American Psychologist, 26*(2), 129–144.

Schoeller, D. A. (1995). Limitations in the assessment of dietary energy intake by self-report. *Metabolism, 44*, 18–22.

Schupp, H. T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: event-related brain potential studies. *Progress in Brain Research, 156*, 31–51.

Sobik, L., Hutchison, K., & Craighead, L. (2005). Cue-elicited craving for food: a fresh approach to the study of binge eating. *Appetite, 44*, 253–261.

Soetens, B., & Braet, C. (2007). Information processing of food cues in overweight and normal weight adolescents. *British Journal of Health Psychology, 12*, 285–304.

Stockburger, J., Hamm, A. O., Weike, A. I., & Schupp, H. T. (2008). Deprivation selectively modulates brain potentials to food pictures. *Behavioral Neuroscience, 122*, 936–942.

Stockburger, J., Schmälzle, R., Flaisch, T., Bublatzky, F., & Schupp, H. T. (2009). The impact of hunger on food cue processing: an event-related brain potential study. *NeuroImage, 47*, 1819–1829.

Strien van, T., Frijters, J. E. R., Bergers, G. P. A., & Defares, P. B. (1986). The Dutch Eating Behavior Questionnaire (DEBQ) for assessment of restrained, emotional and external eating behavior. *International Journal of Eating Disorders, 5*, 295–315.

Stunkard, A. (1959). Obesity and the denial of hunger. *Psychosomatic Medicine, 21*, 281–290.

Tapper, K., Pothos, E. M., Fadardi, J. S., & Ziori, E. (2008). Restraint, disinhibition and food-related processing bias. *Appetite, 51*, 335–338.

Volkow, N. D., & Wise, R. A. (2005). How can drug addiction help us understand obesity? *Nature Neuroscience, 8*(5), 555–560.

Wang, G.-J., Volkow, N. D., Logan, J., Pappas, N. R., Wong, C. T., Zhu, W., et al. (2001). Brain dopamine and obesity. *Lancet, 357*, 354–357.

Warziski Turk, M., Yang, K., Hravnak, M., Sereika, S. M., Ewing, L. J., & Burke, L. E. (2009). Randomized clinical trials of weight loss maintenance. *Journal of Cardiovascular Nursing, 27*, 58–80.