Attentional Mechanisms in Food Craving and Overeating

A study of an addiction model of obesity

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Attentional Mechanisms in Food Craving and Overeating

A study of an addiction model of obesity

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1

General introduction*

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1

Line of reasoning

1

The obesogenic environment

During the past few decades, the prevalence of overweight (Body Mass Index [BMI] $\geq$ 25 kg/m^2) and obesity (BMI $\geq$ 30 kg/m^2) has increased substantially in developed societies. For example, in the Netherlands, where the present research was conducted, in 1981, 5.1% of adults were obese, whereas in 2004, this figure was more than doubled to 10.9% (Schokker, Visscher, Nooyens, van Baak, & Seidell, 2007). The emergence of this obesity 'epidemic' has gone hand in hand with changes in the environment. The most obvious environmental change, associated with increased obesity figures, is the increased availability of energy-dense food (e.g., Hill & Peters, 1998). The overwhelming presence of high-calorie foods appears to stimulate an excessive food consumption. Indeed, an increased energy intake, rather than a decreased energy expenditure, has been demonstrated to be the lifestyle factor that accounts best for the increased obesity prevalence (Westerterp & Speakman, 2008).

Being responsive to food-related stimuli is considered to be an adaptive characteristic, which has been essential to survival of the species. During evolution, due to unpredictable recurring periods of food scarcity, particularly energy-dense food has become a rewarding, wanted substance (Gerber, Williams, & Gray, 1999). As a result, foods that are rich in carbohydrates and fat must have, to some extent, an attractive quality to all human beings. However, not every human being becomes obese in the 'obesogenic' environment, suggesting that there is individual variability in the intensity of responsiveness to food and the motivation to eat. An examination of shifts over time in the distribution of body mass index (BMI) has demonstrated that the high obesity statistics of today are not only the result of a larger number of people having become overweight, but particularly of overweight people having become more overweight (Flegal & Troiano, 2000). This suggests that especially overweight individuals are susceptible to overeat and gain weight in response to environmental food temptations. Therefore, in the present thesis, the central hypothesis is that obese individuals demonstrate an enhanced sensitivity and responsivity to food-related stimuli as compared to normal-weight individuals.

Food cue-reactivity: A little history

The idea of an enhanced food cue-responsiveness in obese individuals is not new. In the 1960's, Schachter (1971) already put forward that the eating behavior of obese individuals might be more determined by salient external food-related stimuli than the eating behavior of normal-weight individuals. The tendency to eat in response to food-related cues, such as the sight, smell, or taste of food was referred to as 'external eating'. According to Schachter, as a result from an insensitivity to internal signs of hunger and satiety, obese individuals were as much responsive to salient food stimuli in a state of satiety as in a state of hunger, whereas in normal-weight individuals food-cue reactivity interacted with food deprivation state and was thus enhanced during hunger as compared to satiety.

Although a series of behavioral experiments (in which food-related responsiveness was primarily measured by means of the amount of food eaten) supported this 'internal-external' eating theory (for a review, see Herman & Polivy, 2008), there was also substantial evidence contradicting the assumption of an over-responsivity to food in obese as compared to normal-weight persons. For example, substantially enhanced food-related cue-reactivity was observed in normal-weight persons who were attempting to restrict their food intake (i.e., dietary restrained eaters) when compared to non-restrained normal-weight individuals (Herman & Mack, 1975; Herman & Polivy, 1975; Polivy, Herman, & Coelho, 2008). This finding suggested that the feature of 'externality' was not confined to obese individuals, but that also within normal-weight samples there was interindividual variability in the intensity of responses to external food cues (Rodin, 1981). As a result, the focus of scientific attention became more directed to dietary restraint than to obesity per se.

In the 1990's, cue-reactivity models were formulated in relation to dietary restraint and excessive eating behavior. An important study, initiating the development of these theories, came from Weingarten (1983), who demonstrated that rats, which were fed to satiety, nevertheless ate a large meal after being exposed to a sound which was, via classical conditioning, associated with the obtention of food. This finding demonstrated that learning mechanisms could play an important role in excessive eating behavior. By then, it was long known that physiological responses, related to the normal ingestion and digestion of food, i.e., cephalic phase responses, such as the secretion of saliva, could be brought under the control of (conditioned) stimuli predicting food intake (e.g., Pavlov, 1927). According to a number of theoretical models (Jansen, 1998; Wardle, 1990), individuals with high weight concerns and a tendency to overeat, such as restrained individuals, displayed enhanced classically conditioned physiological responses to food-related stimuli, which were experienced as craving. Several studies tested and found support for this theory in restrained eaters (for an overview, see Coelho, Jansen, Roefs, & Nederkoorn, 2009). However, only few studies, testing this theory directly in relation to (non-clinical) obesity, were conducted. For instance, in a study of Jansen et al. (2003), it was found that overweight children reported more subjective desire and ate more after being exposed to the smell and taste of food as compared to their normal-weight peers. Moreover, only in overweight children, a positive association was observed between the amount of food eaten and the amount of saliva secreted, although no between-group differences were found in the salivary response.

Until recently, behavioral researchers seemed to be rather reluctant to conduct studies in (non-clinical) obese as opposed to normal-weight samples, because of the general knowledge that there are multiple 'obesities' (Rodin, 1981; Spitzer & Rodin, 1981). Indeed, obesity is a heterogeneous and complex syndrome, and multiple (genetic, environmental, biological, psychosocial, cultural) factors have been identified that play a role in the eating behavior and body weight of humans. However, as mentioned in the beginning of this chapter, findings of epidemiological studies do indicate that the food-rich environment has a differential impact on weight groups (Flegal & Troiano, 2000). For this reason, it seems warranted to investigate the mechanisms underlying this differential responsiveness to food cues directly in overweight/obese versus normal-weight study samples. Moreover, thanks to the development of neuroimaging techniques and extensive neurobiological research, knowledge has accumulated with regard to neural substrates involved in the hedonic (external) and homeostatic (internal) drives to eat, and the interaction between both. Differences between obese and normal-weight individuals have been reported with regard to the brain regions activated during exposure to food-related stimuli, and these appear to be situated in the reward system (Rothemund et al., 2007; Stoeckel, Kim, Weller, & Cox, 2009; Stoeckel et al., 2008).

Neurobiology of food wanting

Until a few years ago, most (biological) obesity researchers were convinced that the origin of obesity should be looked for in an aberrant functioning of the body's homeostatic system. The central brain structure of the homeostatic system is the hypothalamus. The hypothalamus basically receives signals from peripheric hunger and satiety hormones (such as leptin, which is released in the adipocytes during satiation, and ghrelin, which is released in the stomach during hunger). Simply put, thanks to the homeostatic system, humans (and animals) are aware of an empty or a full stomach, and are able to respond correspondingly, i.e., to start or to finish eating (Lutter & Nestler, 2009; O'Rahilly & Farooqi, 2008).

The observation that humans and animals continue to eat despite being satiated, and have other (i.e., hedonic) motives to eat than the experience of physiological hunger, led to the idea that a second system had to be involved in food motivation. This second system is the motivation or reward system. The reward system consists of a complex network of cortical and mesolimbic brain structures, but a central role appears to be reserved for the nucleus accumbens, which is situated in the striatum. During evolution, the reward system has developed to see that pleasurable stimuli, which are essential to survival (such as food, sex-related stimuli, and other natural rewards) are attended, wanted, approached and liked, whereas aversive stimuli (such as predators and poisons) are also attended, but subsequently avoided and disliked. Thus, it is the reward system that drives responses to motivationally relevant cues.

In the specific context of food motivation, the reward system seems to regulate the experience of a desire to eat ('wanting' or craving) and hedonic responses to food ('liking'). Food wanting seems to be primarily associated with the release of the neurotransmitter dopamine, whereas liking seems to be also modulated by the release of endogeneous opioids, such as endorphin, in the reward system (Berridge, 2009). Accumulating evidence suggests that the homeostatic system and the reward system interact with each other to drive eating behavior. The general assumption is now that motivational/hedonic mechanisms are able to overrule homeostatic mechanisms (e.g., Berthoud, 2004; Lutter & Nestler, 2009; Zheng, Lenard, Shin, & Berthoud, 2009). This means that the mere presence of salient food stimuli (inducing food wanting) can be more powerful than signals of satiety in driving food intake.

It is only recently that neurobiologists started to investigate the role of the reward system in normal and pathological eating behavior. Interesting results were specifically found with regard to the dopaminergic modulation of food craving and food consumption. Animal research, for instance, has shown that rats do less effort to obtain food and eat less when their brain's dopamine activity is 'knocked-out' (Wise & Rompre, 1989). Human neuroimaging research has confirmed that dopamine is directly involved in food craving. Using positron emission tomography (PET), Volkow et al. (2002), for instance, reported an increase of dopamine release in the striatum of hungry as compared to satiated participants, who were exposed to food stimuli. In addition, the amount of released dopamine correlated positively with the subjectively experienced food craving. By then, it was already known that antipsychotic drugs (which block dopamine-D2-receptor binding) increase appetite and may lead to substantial weight gain, whereas amphetamines (which augment dopamine activity in the brain) reduce appetite (Towell, Muscat, & Willner, 1988).

Regarding obesity, a key publication linking dopamine dysfunctioning with human obesity came from Wang et al. (2001), who discovered, using PET scans, a significantly reduced density of dopamine-D2-receptors in the striatum of severely obese individuals as compared to normal-weight individuals. The number of dopamine-D2-receptors correlated negatively with the BMI of the obese participants, indicating that the most severely obese participants had the lowest number of striatal D2-receptors. Earlier, other authors had already reported a higher prevalence of the Taq1-A1-allele in obese individuals (Noble et al., 1994), which is also associated with a reduced number of dopamine-D2-receptors. During the past few years, the link between a depressed reward-related dopaminergic neurotransmission and overeating/obesity has been corroborated in various other studies (e.g., Geiger et al., 2009; Stice, Spoor, Bohon, & Small, 2008).

The finding of a reduced dopamine-D2-receptor density in obese individuals is of particular interest, because this has also been found in addiction. A similar dysfunctional reward system appears to be a core feature of several forms of addiction, and seems to be specifically expressed as an enhanced responsiveness to drug-related cues (Volkow & Wise, 2005). It is not clear yet whether the dopamine-D2-receptor density reduction is a cause or a consequence of substance use or obesity. According to some researchers, it may reflect a downregulation caused by the overstimulation of the reward system by chronic repeated drug use or overeating (Wang et al., 2001). Others are convinced that a reduced density of dopamine-D2-receptors reflects an innate vulnerability for becoming addicted (Volkow & Fowler, 2000). The underlying idea of this 'reward deficiency syndrome' (Blum et al., 2000) is that individuals with few dopamine receptors lack the capacity to enjoy simple, everyday rewards (because of an inadequate release of dopamine in response to these stimuli). For this reason, these individuals are inclined to seek stronger rewarding stimulations, for instance by eating or administering drugs. Altogether, the conclusion is that similar mechanisms seem to underlie addiction and obesity, and these underlying mechanisms seem to involve the dopaminergic reward system, which is responsible for the modulation of motivational and hedonic responses to salient cues, such as drugs- and food-related cues.

Obesity and addiction

Entering the term 'food addiction' in Google yields millions of hits, suggesting that, in common language, there is an intuitive link between food intake and addiction. There are obvious behavioral similarities between obesity and classic substance dependence. In both conditions, the central problematic behavior is the uncontrollable repeated excessive intake of a substance, which has immediate reinforcing effects, but has adverse long-term consequences to the physical and psychosocial health of the individual (Volkow & Wise, 2005). Substantial relapse rates are observed in both addiction treatments and weight-loss programs. A generally reported trigger of relapse is an intense craving for the substance, leading to loss of control (Garner & Wooley, 1991; Gossop, 1992). As discussed above, accumulating evidence suggests that these phenomenological commonalities of addiction and obesity also have a common neural substrate in the brain's dopaminergic reward system. This indicates that the core commonality of obesity and addiction might be an enhanced responsiveness to substance-related (i.e., food- or drug-related) stimuli.

By many recent addiction theories, drug-related cue-reactivity (particularly craving) is acknowledged to be a central feature of addiction, which has a strong impact on the persistence of substance use and relapse after a period of drug abstinence (Drummond, 2001). Dopamine release in the reward system has been found to be associated with cognitive (e.g., attentional bias), physiological (e.g., elevated heart rate), subjective (e.g., craving) and behavioral (e.g., approach behavior) reactivity to the perception of substance-related cues (for a review, see Franken, 2003; Franken, Booij, & van den Brink, 2005). This knowledge has led to the formulation of integrative theoretical models, which aim to explain the mechanisms behind the relation between stimulus perception and drug use. One of these models is the incentive sensitization theory of Robinson & Berridge (1993). According to this theory, due to a sensitization of the dopaminergic reward system (resulting from repeated drug use), incentive salience qualities are attributed not only to the substance itself, but to all stimuli that are, via a process of classical conditioning, associated with substance use. The mere perception of substance-related stimuli induces a classically conditioned dopamine release in the mesolimbic reward system. As a consequence, substance-related stimuli automatically grab the attention, elicit craving, and ultimately lead the individual to seek and use the substance. Franken (2003) extended this model with the explicit addition that attentional bias and craving have mutually excitatory relationships with each other. Various other contemporary addiction models are in agreement that attentional bias and subjective craving are central concepts in the understanding of addictive behaviors (for a review, see Field & Cox, 2008).

In support of these models, there is an impressive and still growing body of evidence that addicts exhibit an attentional bias to drug-related cues, which is associated with drug craving (for a meta-analysis, see Field, Munafó, & Franken, 2009), drug use (Fadardi & Cox, 2008) and relapse (Cox, Hogan, Kristian, & Race, 2002; Marissen et al., 2006; Waters et al., 2003). This was demonstrated in individuals who were addicted to different kinds of substances, in current substance users and in currently abstinent addicts who were in treatment or seeking treatment. In addition, the relationship between attentional bias to substance-related cues and craving was demonstrated using different attentional bias measures (behavioral and electrophysiological, direct and indirect measures) and different craving measures (single-item visual analogue scales and multi-item questionnaires).

A neurocognitive model of obesity and hypotheses

Given the neurobiological and phenomenological similarities between addiction and obesity, in the present thesis, it is hypothesized that neurocognitive addiction models are applicable to the enhanced drive to eat in overweight/obese individuals. In Figure 1, a neurocognitive model of obesity is visualized, which is derived from the addiction model of Franken (2003). Contrary to earlier addiction-based models of excessive eating behavior, which primarily focused on *physiological* food cue-reactivity (e.g., cephalic phase responses, Jansen, 1998; Wardle, 1990), the current model has a central position for an *attentional bias* to food-related stimuli.

Generally, it is hypothesized that obese individuals display an enhanced reactivity to food-related stimuli as compared to normal-weight individuals. More specifically, central hypotheses are as follows:

Hypothesis 1: Obese individuals exhibit an enhanced attentional bias to food-related stimuli as compared to normal-weight individuals. Contrary to addiction-related studies, in which normal controls generally were found not to display an attentional bias to substance-related stimuli (Field & Cox, 2008), it is assumed that normal-weight participants will also demonstrate an attentional bias to food-related relative to neutral control stimuli, because of the high motivational significance of (high-calorie) food. Next to obvious similarities between substance use and food intake, there are also obvious differences. One of these differences is the 'substance of abuse'. Contrary to general addictive substances, such as heroin and cocaine, but also nicotine and alcohol, food is an essential 'substance' to every living being, which has to be consumed to survive. For this reason, the reward system has evolved to respond to food as being an attractive, attention-grabbing, and wanted substance in all living beings. In this perspective, everyone might be seen as being, to a certain extent, 'addicted' to food. However, as explained

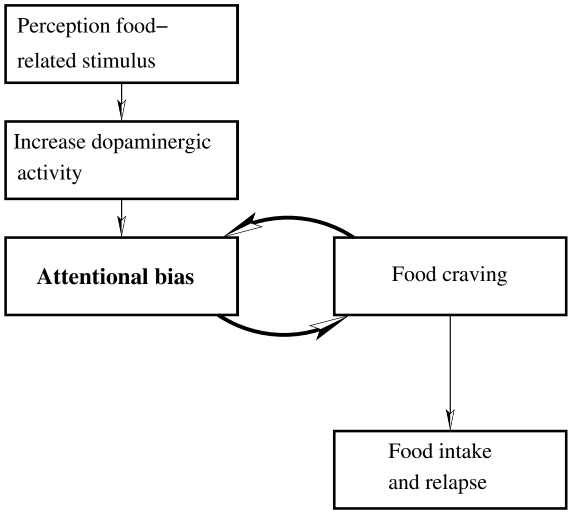

Figure 1: *A neurocognitive model of excessive food intake and obesity (derived from Franken, 2003)*

above, due to an (innate or acquired) oversensitivity and overreactivivity of the reward system, it is hypothesized that in obese individuals the attentional bias (and further food-cue reactivity) is significantly enhanced as compared to normal-weight individuals

Hypothesis 2: Both in states of hunger and satiety, obese individuals demonstrate an enhanced attentional bias to food-related stimuli as compared to normal-weight individuals. Substance-related cue-reactivity appears to be particularly present in substance-dependent individuals, who are in a state of explicit craving, for instance after a period of abstinence (Field & Cox, 2008). In a similar vein, a modulation of food-related cue-reactivity is expected by hunger (i.e., food deprivation) and satiety state in both normal-weight and overweight individuals. That is, the attentional bias to food-related stimuli is expected to be generally enhanced in a state of hunger as compared to a state of satiety (Mogg, Bradley, Hyare, & Lee, 1998; Stockburger, Hamm, Weike, & Schupp, 2008; Stockburger, Schmälzle, Flaisch, Bublatzky, & Schupp, 2009). This hypothesis is in contrast with the internal-external theory of Schachter (1971), which assumed that obese individuals were insensitive to internal signals of hunger and satiety, an for this reason would have similar responses to food during hunger and satiety. However, this idea has been refuted as evidence was found that the degree of sensitivity to internal sensations of hunger varied substantially within both weight groups (Rodin, 1981). Moreover, in a relatively recent study, hunger reports of obese individuals actually seemed to be *more* tightly associated with physical sensations than hunger reports of normal-weight individuals. In addition, in this latter study, the general increase of hunger during food deprivation was similar in both weight groups, suggesting that obese individuals, like normal-weight individuals, *are* aware of hunger (Lowe, Friedman, Mattes, Kopyt, & Gayda, 2000). Therefore, in the present research, it was hypothesized that in obese individuals, food-related attention (and further food cue- reactivity) would be modulated by hunger and satiety in a similar manner as in normal-weights. However, due to an oversensitive reward system, it was expected that obese would generally show enhanced food cue-reactivity as compared to normal-weight participants, under both conditions of hunger and satiety.

Hypothesis 3: There is a positive association between food-related attentional bias and subjective food craving. As is displayed in Figure 1, similar to addiction models, strong positive correlations are expected between food-related attentional bias scores and subjective food craving levels, as both are regarded as (cognitive and emotional) outputs of the brain's reward system. In line with the model of Franken (2003), a mutually excitatory relationship is assumed between attentional bias to food and food craving. That is, it is believed that when food-related stimuli become the focus of attention, this will increase food craving, and food craving, in its turn, will increase or maintain the attentional focus to food. This also means that obese individuals are expected to report higher levels of food craving in response to food-related stimuli as compared to normal-weight individuals.

Hypothesis 4: There is also a positive association between food-related attentional bias and energy intake, and between subjective food craving and energy intake. According to the proposed model, the mutually enhancing effects that the attention to food and food craving exert on each other, ultimately lead the individual to seek and consume food. It is hypothesized that this behavioral responsiveness is enhanced, and is observed as an increased energy intake (c.f., Jansen et al., 2003) in obese individuals as compared to normal-weight individuals.

Hypothesis 5: Obese individuals generally have higher scores on an external eating questionnaire as compared to normal-weight individuals. In addition, (obese and normal-weight) high external eaters show an enhanced food-cue reactivity as compared to low external eaters. In general, positive correlations are observed between external eating scores and indices of cue-reactivity (attentional bias, craving, energy intake), in both obese and normal-weight subjects. As mentioned, Restraint Theory (Herman & Mack, 1975; Herman & Polivy, 1975) suggests that, at least in normal-weight individuals, the intensity of responses to food-related stimuli is associated with dietary restraint. Similar interindividual differences are far less studied, but might as well be present within a sample of (non-clinical) obese persons. For this reason, although between-weight group differences were explicitly expected, the present research also examined the relationship between food-related cue-reactivity outcomes and measures of (over)eating styles, i.e., dietary restraint, emotional eating, and external eating, in both weight groups. Because of its obvious close association with an incentive sensitization model of overeating, the emphasis was put on external eating, being defined as a general tendency to eat in response to food-related cues, such as the sight or smell of food. Contrary to dietary restraint, the construct of external eating received rather little attention in psychological eating behavior research. As a result, the validity of self-report scales assessing external eating was hardly scientifically tested. That is, it is still largely unclear whether individuals who report to have high external eating tendencies, actually respond more intensely to food-related stimuli as compared to low external eaters. For this reason, as an additional purpose, the present research tested the external eating-related postulations combined under Hypothesis 5.

In the following paragraphs, the methodology to test above-mentioned hypotheses will be briefly introduced, and a broad outline of this thesis will be given.

Methodological issues and thesis outline

Food craving

Food craving may be defined as the subjective experience of wanting to eat. To the individual, food craving may have various origins and various consequences. For instance, one may experience a desire to eat after a period of food deprivation (c.f., hunger), or because a positive outcome is expected from eating, or the desire to eat may lead to a loss of control over eating. Because of this multidimensionality of the craving construct, multifactorial self-report scales have been developed to assess food craving. **Chapter 2** describes the development and validation of a Dutch version of two such multifactorial food craving questionnaires, i.e., the state and trait version of the General Food Cravings Questionnaires (G-FCQ-T and G-FCQ-S). Novel about these questionnaires is that they do not intend to assess cravings for one specific food item (as is usually the case in food craving scales, e.g., the Food Cravings Questionnaires developed by Cepeda-Benito, Gleaves, Williams, & Erath, 2000), but rather a more general desire to eat. The trait version of the G-FCQ intends to measure features of food craving that are stable across times and situations, whereas the state version assesses state-dependent or situational food craving.

Another way to assess momentary food craving is by means of a one-item visual analogue scale (VAS). The use of VASs has been critisized because they may have a limited reliability, and scores may depend on the chosen terminology. However, advantages are that VASs give a fast and spontaneous index of the desire to eat, whereas multi-item questionnaires are more time-consuming, may lead to rumination on craving and be more sensitive to tendencies for giving socially desirable answers (Field & Cox, 2008; Sayette et al., 2000; Stubbs et al., 2000). Despite disadvantages of both types of craving measures, high positive correlations are generally observed between scores of multi-item and one-item measures of craving, suggesting that they do measure the same underlying construct (Rosenberg & Mazzola, 2007; Sussner et al., 2006). Throughout the present thesis, G-FCQ-S and VAS scores were used to check whether there were between-group differences in subjective food craving/hunger levels at the beginning of an experiment, to examine changes in food craving during the experiment due to the exposure to food-related stimuli, and to examine relationships among food craving/hunger scores, attentional bias scores, and overeating styles.

1

Attentional bias

In the present thesis, attentional bias refers to the observation that the attention is automatically directed and/or maintained to food-related stimuli. Food-related attentional bias was measured in various direct and indirect ways. A food-modified Stroop task and a visual probe task were used as indirect measures of attention. In these ('dual task') measures, attentional bias is inferred from participants' altered performance on a primary task (i.e., color-naming in the Stroop task and responding to a probe in the visual probe task) in the presence of a food-related stimulus as compared to a neutral control stimulus. More direct measures of attentional engagement, which were also applied, are the monitoring of eye-movements and the recording of electroencephalographic (EEG) activity in response to the food-related stimuli, i.e., event-related potentials (ERPs).

As target stimuli, generally pictures or words of foods with *high-caloric* content were chosen. There were several reasons to choose specifically high-caloric food stimuli. First, as was already mentioned, from an evolutionary perspective it is believed that humans and animals are specifically attracted to energy-dense foods, because of their highly rewarding and valuable qualities to survival (Gerber et al., 1999). Second, there seems to be a direct association between the abundant presence and availability of specifically energy-dense foods in the environment and the current obesity epidemic. Third, several studies have suggested that the food intake of obese individuals is more determined by the palatability of foods than the food intake of normal-weight individuals, and that obese individuals specifically have a preference for high-fat and high-carbohydrate foods, to a larger extent than normal-weight individuals (Lowe & Levine, 2005; Nasser, 2001; Rissanen et al., 2002). As control stimuli in the attention-related tasks, generally neutral pictures or words were chosen from the category of office items, and sometimes (Chapter 4 and 5) an additional control category of positively valenced stimuli (pictures of babies) was added. This was done to demonstrate that enhanced attentional responses in obese participants or external eaters were specifically observed to food-related stimuli, and not emotionally salient stimuli in general.

Different selective attentional mechanisms are thought to underlie the effects obtained with (different variants of) various attention-related tasks. More specifically, a distinction can be made between the mechanism of initial orientation of attention, which is assumed to involve an involuntary, automatic, passive, bottom-up attentional process, and delay of disengagement of attention (or maintained attention), which is believed to concern a more voluntary, controlled, active, top-down attentional process. For example, with the visual probe task it is possible to measure the initial attentional orientation to a stimulus category as well as maintained attention by varying the presentation duration of the stimuli. That is, the initial, automatic shift of attention is assumed to be measured when short trial durations are used ($\leq$ 200 ms, because in this time frame only one shift of attention is possible), whereas a bias in maintained attention is assumed to be measured with longer durations ($\geq$ 500 ms, because multiple shifts of attention are then possible; Field & Cox, 2008). For this reason, in the study that is described in **Chapter 5**, a visual probe task was used including pairs of food-related and neutral pictures which were presented to the participants with durations of 100 ms and 500 ms. Contrary to the visual probe task, it is still unclear which attentional mechanisms are underlying Stroop reaction time effects. Although Stroop interference effects generally have been assumed to operate on an automatic level, there is also evidence, from studies using emotional Stroop tasks, that more conscious, strategic processes might play a role as well (Phaf & Kan, 2007; Thomas, Johnstone, & Gonsalvez, 2007). For this reason, in **Chapter 6**, EEG activity was recorded during performance of a Stroop task including food-related and neutral control words. By combining a Stroop task with a more direct measure of attentional processing, it was aimed to shed more light on the issue whether Stroop reaction times reflect automatic or strategic attentional processes.

Event-related potentials were used as indices of attentional engagement to food-related and neutral pictures/words in high and low external eaters (**Chapter 4**), as well as in obese/overweight and normal-weight participants (**Chapter 3, 5, 6**), during states of hunger (17hr food deprivation) and satiety (**Chapter 5**) or after a 2hr food deprivation (**Chapter 3 and 6**). Initially, only long-latency positive waves, such as the P300 and Late Positive Potential (LPP) component, were selected, because ample evidence, particularly from addiction and emotion research had demonstrated that these were the components that reflected neuroelectric activity related to attention allocation (for reviews, see Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). Moreover, it has been assumed that the amplitude of long-latency waves directly reflects the degree to which the underlying reward system in the brain is activated (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). Another reason to choose late positive waves as main indices of attention is that in addiction research, the amplitudes of the P300 and LPP seem to be consistently positively correlated with self-report measures of craving (for a meta-analysis, see Field et al., 2009), suggesting that P300/LPP amplitude is a reliable index of conscious motivation-related attentional engagement. However, during the present research, evidence accumulated that also early ERPs are modulated by the emotional or motivational content of stimuli (e.g., Franken, Muris, Nijs, & van Strien, 2008; Kissler, Assadollahi, & Herbert, 2006; Schupp et al., 2007). It has been suggested that early ERPs index the automatic orienting of attention towards stimuli (e.g., Pourtois, Grandjean, Sander, & Vuilleumier, 2004), whereas long-latency ERPs would index more controlled sustained attention or the delayed disengagement of attention (Schupp et al., 2006). For this reason, in the study described in **Chapter 6**, the amplitude of an early (P200) ERP component was also analyzed as alleged index of oriented attention.

As an additional direct measure of (visuo-spatial) attention, in **Chapter 5** eye movements were recorded while participants were exposed to pairs of pictures with food-related and neutral content. As indices of oriented and maintained attention, the direction of the initial eye fixation and the average duration of gaze during each trial were analyzed.

Food intake

In the study, described in **Chapter 5**, a bogus taste task was included at the end of the experiment to examine cue-elicited food intake of the participants. For this purpose, the participants were asked to evaluate the taste of a number of high-caloric snack foods. To stimulate spontaneous eating behavior, participants were not told beforehand that their food intake would be weighed and calorie intake calculated. In general, the exact purposes and research questions of the studies (of Chapter 4 and 5) were a priori concealed from the participants. For instance, in the study described in Chapter 4, participants were told that the study concerned general brain activity underlying focused attention. In the study of Chapter 5, it was told that the study concerned the influence of hunger on general information processing, task performance, and taste evaluation.

External eating

The study of **Chapter 4** focused on differences in the attentional processing of food-related pictures between normal-weight high and low external eaters. The purpose of this study was to get more insight in the mechanisms underlying self-reported external eating. External eating scores were generally obtained by means of the frequently used Dutch Eating Behavior Questionnaire (DEBQ; van Strien, Frijters, Bergers, & Defares, 1986). The DEBQ assesses external eating (i.e., the tendency to eat in response to the exposure to food-related cues), emotional eating (i.e., the tendency to eat in response to emotions), and dietary restraint (i.e., the tendency to restrict food intake). Differences between overweight/obese and normal-weight individuals regarding external eating scores (and also emotional eating and dietary restraint) were investigated in **Chapter 5 and 6**, and so were associations between eating style scores and various food-related cue-reactivity outcomes.

Research relevance

Obesity has become a worldwide health problem, which has clear associations with several life-threatening diseases (e.g., diabetes mellitus, cardiovascular diseases, osteoarthritis, cancer), as well as psychosocial problems (e.g., depression), and adverse economical outcomes (e.g., high work absenteeism). Traditional weight-loss programs appear to be not effective in the long-term (Byrne, Cooper, & Fairburn, 2003; Garner & Wooley, 1991). To develop more effective treatments, it seems essential to get more insight in the underlying mechanisms regulating food intake and body weight. As discussed, similar to addiction, an attentional bias to food-related stimuli and further food-related cue-reactivity is presumed to play an important role, particularly in the current food-rich environment, in the development and/or maintenance of overeating behavior and in relapse in persons who are attempting to reduce their calorie intake.

In the context of obesity and external eating, only few investigations were conducted and published regarding food-related attention before and during the realization of the present PhD research. This points to the fact that the neurocognitive model of obesity, which was proposed in this chapter, and the methodological approach to test this model, is relatively novel to obesity research. Results of the present PhD research and related studies will be given in Chapter 2 to 6, followed by an integrated discussion of these results in **Chapter 7**.

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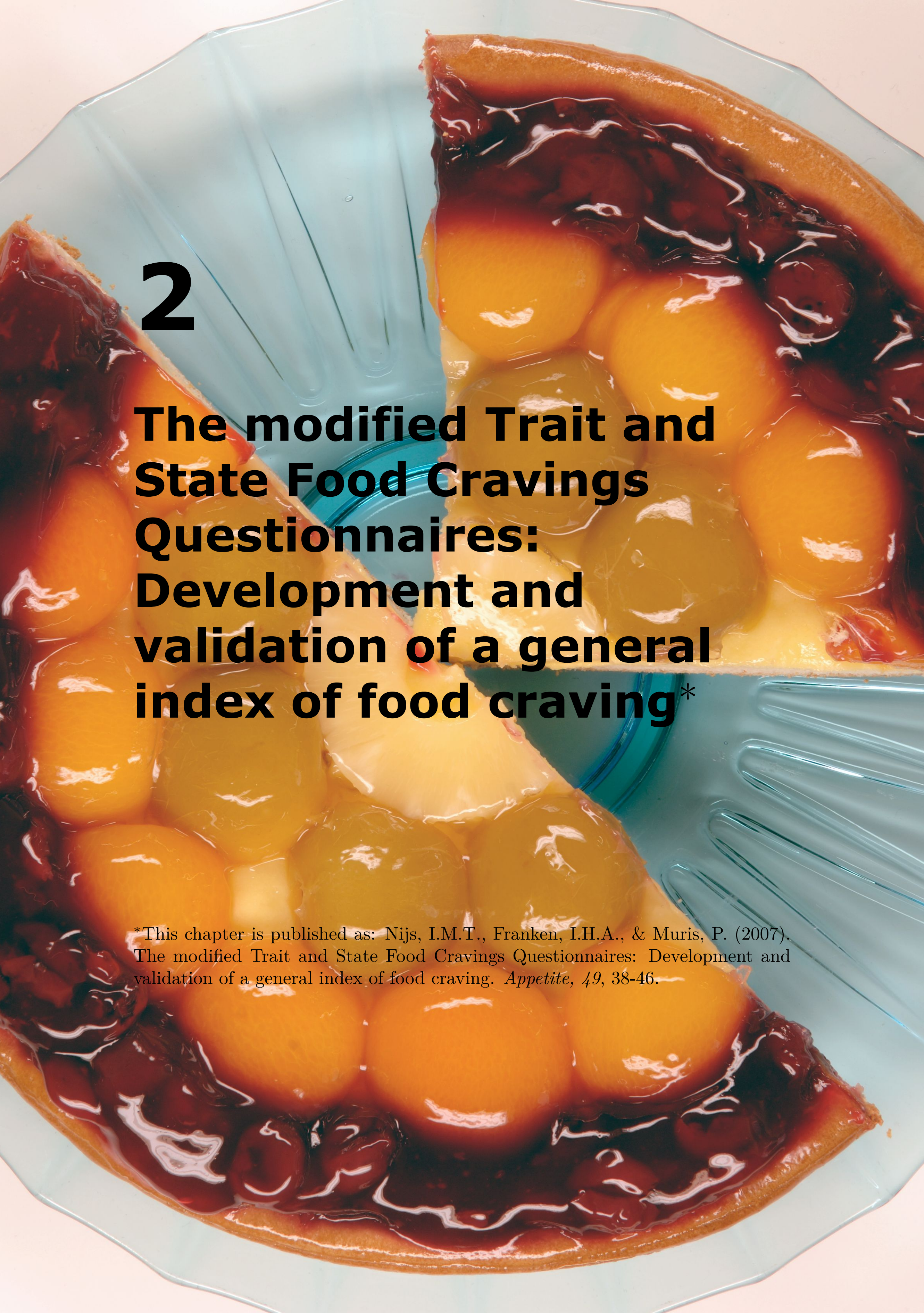

2

The modified Trait and State Food Cravings Questionnaires: Development and validation of a general index of food craving*

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Abstract

In the present study, the multidimensional Trait and State Food Cravings Questionnaires (FCQ-T and FCQ–S), as developed by Cepeda-Benito, Gleaves, Williams et al. (2000), were modified in order to construct an index of *general* food craving instead of *specific* food craving. The factor structure, validity and reliability of the modified questionnaires, renamed as the Trait and State *General* Food Cravings Questionnaires (G-FCQ-T and G-FCQ–S), were investigated in three separate studies. Firstly, exploratory factor analyses were conducted, which yielded a G-FCQ-T with a four-factor structure, that was considerably shorter as compared to the original (nine-factor) FCQ-T, and a G-FCQ-S of which the factor structure was highly comparable to the original FCQ-S. Secondly, in an attempt to replicate the factor structures of the G-FCQ-T and the G-FCQ-S as found in study 1, confirmative factor analyses were performed. Results indicated adequate fits for both questionnaires. In addition, the test-retest reliability of both versions was satisfactory and an analysis of the construct validity generally revealed the expected results. In study 3, the validity of the state version of the G-FCQ was further investigated by relating scores on this questionnaire to indices of food deprivation and satiation. Results indicated that the G-FCQ-S indeed measures food craving as a variable state, which is influenced by situational and temporal variables. Altogether, it can be concluded that the G-FCQ-T and G-FCQ–S are both reliable and valid measures of general trait-like and state-dependent food craving.

Introduction

Craving, a construct that is primarily known from addiction research, refers to a subjective motivational ('wanting') state promoting substance-seeking and ingestive behaviors. Drug craving is generally believed to contribute to the transition from casual to compulsive drug use, persistence of addictive behaviors, and relapse in substance dependent patients who are abstinent from drugs of abuse (Robinson & Berridge, 1993). In the same vein, food craving is thought to mediate uncontrolled eating behavior, such as seen in obesity, binge eating disorder, and bulimia nervosa (Cepeda-Benito, Fernandez, & Moreno, 2003; Cepeda-Benito, Gleaves, Williams et al., 2000; Gendall, Joyce, Sullivan, & Bulik, 1998; Greeno, Wing, & Shiffman, 2000; Waters, Hill, & Waller, 2001; Weingarten & Elston, 1990). In overweight dieters, this craving for food is thought to be involved in the inability to comply with a low-calorie diet, resulting in relapse to initial over-eating patterns (Bjorvell, Ronnberg, & Rossner, 1985; Fedoroff, Polivy, & Herman, 2003; Sitton, 1991). In addition, in non-clinical samples, food craving has been found to be related to body weight, suggesting a ubiquitous role of craving in food consumption (Franken & Muris, 2005).

Food craving is generally defined as an intense desire to eat a specific food item (Weingarten & Elston, 1990). Different types of food cravings have been described, from craving for chocolate, being the most frequently craved food, to craving for all sorts of palatable, mostly sweet and/or high-fat foods (Hill, Weaver, & Blundell, 1991; Rogers & Smit, 2000; Weingarten & Elston, 1991). Although food craving is frequently observed in pathological states, it is an omnipresent phenomenon that is not necessarily pathological or maladaptive. For example, Pelchat (1997) found no less than 100% of young adult females and 70% of young adult males reporting to have experienced an "urge for a certain food" in the foregoing year. High prevalence rates have also been described by Weingarten and Elston (1991) who found 97% of female and 68% of male psychology students to ever have experienced a craving for a certain food item.

On the origin of and mechanisms behind food craving, several theories have been formulated (for reviews, see Cepeda-Benito Gleaves, Williams et al., 2000; Pelchat, 2002; Rogers & Smit, 2000; Weingarten & Elston, 1990). Physiological theories underline the nutritional and energetic homeostatic role of food cravings (e.g., food cravings are suggested to appear more frequently in individuals who are food-deprived; Wardle, 1987) or the psychoactive abilities of certain compounds of the craved foods (e.g., carbohydrate craving is suggested to be elicited as a 'self-medication' to relieve a central serotonin deficit; Wurtman & Wurtman, 1986). Psychological affect-based theories stress the role of negative emotional states, such as anger and boredom, as triggers for food cravings (e.g., Hill et al., 1991; Rogers, Anderson, Finch, Jas, & Gatenby, 1994; Schuman, Gitlin, & Fairbanks, 1987). Learning theories claim food cravings to be conditioned responses to sensory, situational, or interoceptive food-related cues and emphasize the expected rewarding, pleasurable consequences of consuming the craved food (Rozin, Levine, & Stoess, 1991). There is no general agreement on the exact

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mechanism regulating food craving. In fact, it appears that food craving is a complex, multidimensional phenomenon, that can be elicited and expressed in several physiological and psychological ways, both inter- and intra-individually (Cepeda-Benito, Gleaves, Williams et al., 2000; Pelchat, 1997).

In light of this multidimensionality of food craving, Cepeda-Benito and colleagues (2000) developed and validated two self-report food cravings questionnaires: the Food Cravings Questionnaire-Trait (FCQ-T) and the Food Cravings Questionnaire-State (FCQ-S). The FCQ-T aims to assess food cravings as stable traits and thus intends to measure features of food cravings that are stable across times and situations within specific populations or individuals. The FCQ-S assesses state-dependent cravings, i.e., assesses whether food cravings are experienced in response to specific, momentary situations or psychological and physiological states. Both food craving scales and their respective subscales have been shown to possess good internal consistency, satisfactory test-retest stability and adequate construct and discriminant validity (Cepeda-Benito, Gleaves, Williams et al., 2000). Moreover, the multi-cultural applicability of the instruments was supported in a validation study in which the Spanish translations of the FCQ-T and FCQ-S were examined (Cepeda-Benito, Gleaves, Fernandez et al., 2000) and were also found to possess adequate psychometric qualities. Thus, the FCQ-T and FCQ-S have been shown to be reliable and valid instruments for measuring food cravings, and this appears true for populations in various countries.

Both the FCQ-T and the FCQ-S were constructed to assess *specific* food cravings. That is, both FCQ versions contain the explicit instruction to 'think of (generally or momentary) craved food(s), while completing the scales' (Cepeda-Benito et al., 2003). This means that subjects fill in the questionnaires with one specific food item in mind. Although this approach is fruitful in studies concerned with cravings for specific foods (e.g., chocolate), the usefulness of the original FCQ scales for studies concerning the more *general* phenomenon and experience of food craving seems limited. Firstly, cravings for different foods may have different origins within one individual. For example, an individual's carbohydrate cravings might be exclusively elicited by negative emotions, while social situations might solely trigger cravings for salty foods. Clearly, focusing on a specific food item while completing the FCQ scales might hinder the study of cravings for other types of food or food classes (such as carbohydrates). Secondly, inter-individual comparisons in cravings are hampered when focusing on specific foods. For example, scores on the FCQ scales in one subject might reflect his or her craving for chocolate, while in another subject craving for potato chips is measured. In sum, the interpretation of the original FCQ scales might be somewhat limited, since individuals frequently crave for various types of food items and food classes.

In the present study, we modified the FCQ-T and the FCQ-S in order to deal with these problems. In other words, Cepeda-Benito, Gleaves, Williams et al.'s (2000) FCQ scales were changed to construe questionnaires for measuring a general 'desire for food' or 'desire to eat' instead of a desire for a specific type of food. To emphasize the different purposes of the original FCQ and the modified FCQ scales, i.e., to assess 'craving for specific food(s)' and 'craving for food in general' respectively, we will further refer to the latter as the Trait and State *General* Food Cravings Questionnaires: G-FCQ-T and G-FCQ-S. The current investigation is a first attempt to examine the psychometric properties of the G-FCQ-T and G-FCQ-S. In study 1, the structure of the G-FCQ-T and G-FCQ-S is investigated by means of exploratory factor analysis. Study 2 retests the factor structure of the scales, this time employing a confirmatory factor-analytic approach. In addition, this study examines the reliability and validity of the G-FCQ-T and G-FCQ-S. Finally, in study 3 the construct validity of the G-FCQ-S is further explored.

Study 1: Test construction and exploratory factor analysis

The original FCQ-T and FCQ-S were both translated into the Dutch language by the present authors. Two modifications were made to the FCQ scales during translation. The first modification involved the translation of the word 'craving' into the Dutch language. Because no exact equivalent for craving exists in this language, the Dutch word '(stevige) trek' was chosen, which can best be retranslated as '(strong) desire to eat' or 'appetite'. Secondly, as mentioned earlier, because of our intention to construct a general index of craving, the instruction of the questionnaires and the content of specific items were changed. For instance, the FCQ-item 'I'm craving (one or more specific foods, i.e., this particular food I'm thinking of(' was rephrased in more general terms as 'I have a strong desire to eat something tasty'. The global content of the items, however, was kept identical to the original FCQ-items. Because of the aforementioned adjustments, it seemed appropriate to first examine the factor structure of the G-FCQ scales by means of exploratory factor analysis. By choosing an exploratory approach, we also intended to reduce the number of items (especially of the 39-item FCQ-T) in order to obtain a shorter, more time-efficient scale for assessing food cravings.

Method

Participants and procedure

Two hundred and twenty-seven undergraduate psychology students (39 males and 188 females) completed the G-FCQ-T in exchange for course credits. Participants had a mean age of 19.98 years (SD = 2.22; range 17 to 28 years). One hundred and nineteen of these students (30 male; 89 female) also completed the G-FCQ-S. The mean age of these participants was 19.86 years (SD = 2.31; range 17 to 28 years).

Instruments

G-FCQ-T

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Just like to the original FCQ-T (Cepeda-Benito, Gleaves, Williams et al., 2000), the G-FCQ-T consists of 39 items that originally can be allocated to 9 subscales, each reflecting a dimension concerned with possible precipitants and consequences of food craving. These subscales are (1) intentions and plans to consume food (3 items); (2) anticipation of positive reinforcement that may result from eating (5 items); (3) anticipation of relief from negative states and feelings as a result of eating (3 items); (4) possible lack of control over eating (6 items); (5) thought or preoccupation with food (7 items); (6) craving as a physiological state (4 items); (7) emotions that may be experienced before or during food cravings or eating (4 items); (8) environmental cues that may trigger food cravings (4 items); and (9) guilt that may be experienced as a result of cravings and/or giving into them (3 items). Individuals have to indicate, using a Likert scale ranging from 1 (never or not applicable) to 6 (always), the degree to which each item would be *generally* true for them (Cepeda-Benito, Gleaves, Williams et al., 2000; Cepeda-Benito, Gleaves, Fernandez et al., 2000).

G-FCQ-S

In keeping with the original FCQ-S (Cepeda-Benito, Gleaves, Williams et al., 2000), the G-FCQ-S consists of 15 items for which individuals have to indicate on a Likert scale (1 = strongly disagree, 5 = strongly agree) to what extent they agree with each statement on the moment of completing the questionnaire (*right now, at this very moment*). The five original factors of the G-FCQ-S, which all contain 3 items, measure (1) an intense desire to eat; (2) anticipation of positive reinforcement that may result from eating; (3) anticipation of relief from negative states and feelings as a result of eating; (4) obsessive preoccupation with food or lack of control over eating; and (5) craving as a physiological state (Cepeda-Benito, Gleaves, Williams et al., 2000; Cepeda-Benito, Gleaves, Fernandez et al., 2000).

Statistical analysis

Exploratory principal component analysis was performed on both the G-FCQ-T and the G-FCQ-S. Because of the umbrella construct of 'food craving', correlations between factors were expected. For this reason, an oblique rotation method (PROMAX) was employed (Hair, Anderson, Tatham, & Black, 1995). As a measure for internal consistency, Cronbach's alpha was determined for the full questionnaire as well as for the factors/subscales.

Table 1: *Final factor solution for the G-FCQ-T as obtained with exploratory factor analysis (Study 1)*

Items	Factor I	II	III	IV
I feel like I have food on my mind all the time	**.85**	.47		.44
I can't stop thinking about eating no matter how hard I try	**.82**	.53		.49
I find myself preoccupied with food	**.80**	.44		.46
If I am craving something, thoughts of eating it consume me	**.76**	.56		
Food cravings invariably make me think of ways to get what I want to eat	**.73**	.50		
I spend a lot of time thinking about whatever it is I will eat next	**.65**			
If I eat what I'm craving, I often lose control and eat too much	.49	**.84**		.41
Once I start eating, I have trouble stopping	.59	**.81**		.46
When I crave something, I know I won't be able to stop eating once I start	.44	**.76**		
If I get what I'm craving I cannot stop myself from eating it		**.67**		
When I am with someone who is overeating, I usually overeat too		**.63**		
Whenever I go to a buffet I end up eating more than what I needed		**.57**		
Eating what I crave makes me feel better			**.72**	
When I eat what I crave, I feel great			**.69**	
I feel less anxious after I eat			**.52**	
When I eat food, I feel comforted			**.50**	
Sometimes, eating makes things seem just perfect			**.47**	
I crave foods when I'm upset		.42		**.80**
My emotions often make me want to eat	.44	.46		**.79**
When I'm stressed out, I crave food				**.76**
I crave foods when I feel bored, angry or sad	.49			**.74**

Note. $N = 227$. G-FCQ-T = General Food Cravings Questionnaire-Trait; Factor I = Preoccupation with food; Factor II = Loss of control; Factor III = Positive outcome expectancy; Factor IV = Emotional craving. Item retention criteria are: loading exclusively on 1 factor; in case of loading on various factors, loading $\geq$ .7 AND loading difference $\geq$ .2. Significant loadings, on the basis of which items are retained and allocated to a factor, are printed in bold; loadings <.30 are not shown.

Results

G-FCQ-T

For the G-FCQ-T, the Kaiser-Meyer-Olkin measure (Kaiser, 1974) revealed a value of .91 and Bartlett's test of sphericity (Lawley, 1956) was significant ($p < .001$), both suggesting that the dataset was adequate for factor analysis. The scree plot suggested a four-factor structure for the G-FCQ-T, rather than the nine factors as reported by Cepeda-Benito et al. (2000) for the original FCQ-T. An extraction of the nine factors indeed demonstrated that this factor solution was not satisfactory, as it contained various components that were rather heterogeneous in content and hence not theoretically meaningful. The suggested four-factor solution explained 53.16% of the variance, and displayed factor eigenvalues of 10.10, 9.50, 5.52 and 7.52. Inspection of this solution indicated 17 items as problematic. These items either did not load convincingly on any of the factors or loaded equally high on various factors. Further, one additional item was removed as its content did not correspond with the factor on which it loaded. After removing these unsatisfactory items from the questionnaire, 21 items were left that reflected 4 dimensions of trait food craving (see Table 1). These dimensions were labeled as (1) preoccupation with food; (2) loss of control (once eating); (3) positive outcome expectancy (from eating); and (4) emotional craving. Cronbach's alphas were .94 for total score of the new G-FCQ-T and between .72 and .87 for its four factors.

G-FCQ-S

For the G-FCQ-S, the Kaiser-Meyer-Olkin measure (Kaiser, 1974) and Bartlett's test of sphericity ($p < 0.001$) again indicated that the dataset was appropriate for factor analysis. The scree plot suggested a five-factor structure for the G-FCQ-S, which was similar to the factor structure of the FCQ-S as described by Cepeda-Benito et al. (2000). The five-factor solution explained 80.02% of the variance, and had eigenvalues of 5.38, 3.90, 4.26, 4.48 and 3.92. Table 2 shows the factor loadings for all 15 items. Although it should be mentioned that a number of items showed quite substantial secondary loadings, it can be concluded that the factor structure of the G-FCQ-S was fully in line with that of Cepeda-Benito et al.'s (2000) FCQ-S. Cronbach's alphas were .92 for the full scale and between .80 and .91 for various subscales.

Discussion

As for the G-FCQ-T, exploratory factor analysis resulted in a four-factor, 21-item questionnaire to assess *general* trait food cravings. The resulting four dimensions of trait food craving could be defined as (1) preoccupation with food (i.e., obsessively thinking about food and eating), (2) loss of control (i.e., the tendency to demonstrate disinhibited eating behavior when exposed to food cues), (3) positive outcome expectancy (i.e., believing eating to be positively or negatively reinforcing), and (4) emotional craving (i.e., the tendency to crave food when experiencing negative emotions).

As compared to the original FCQ-T (Cepeda-Benito, Gleaves, Williams et al., 2000; Cepeda-Benito, Gleaves, Fernandez et al., 2000), the number of factors as well as the number of items was significantly reduced (from nine to four factors, and from 39 to 21 items respectively), resulting in a more economic and time-efficient trait food craving questionnaire, in which the most essential characteristics of food craving were retained. The 'emotional craving' dimension appeared to be the only dimension that was fully retained from the original questionnaire. Two

Table 2: *Final factor solution for the G-FCQ-S as obtained with exploratory factor analysis (Study 1)*

	Factor				
Item	I	II	III	IV	V
I'm craving tasty food	**.94**		.52	.55	.51
I have an urge for tasty food	**.91**	.38	.53	.53	.48
I have an intense desire to eat something tasty	**.90**		.41	.55	.45
If I ate something, I wouldn't feel so sluggish and lethargic	.39	**.89**	.45	.34	.44
Satisfying my appetite would make me feel less grouchy and irritable		**.89**	.35	.31	.44
I would feel more alert if I could satisfy my appetite	.32	**.88**			.35
If I ate right now, my stomach wouldn't feel as empty	.48	.34	**.92**	.34	
I am hungry	.49		**.88**	.44	.34
I feel weak because of not eating	.44	.55	**.86**	.33	
My desire to eat something tasty seems overpowering	.57	.41	.40	**.88**	
I know I'm going to keep on thinking about tasty food until I actually have it	.54	.30	.53	**.86**	.40
If I had something tasty to eat, I could not stop eating it	.44			**.80**	.47
If I were to eat what I'm desiring, I am sure my mood would improve	.42	.45		.35	**.91**
Eating something tasty would feel wonderful	.74	.41	.34	.54	**.78**
Eating something tasty would make things just perfect	.62	.39	.36	.55	**.76**

Note. $N = 119$. G-FCQ-S = General Food Cravings Questionnaire-State; Factor I = An intense desire to eat; Factor II = Anticipation of relief from negative states and feelings as a result of eating; Factor III = Craving as a physiological state; Factor IV = Obsessive preoccupation with food or lack of control over eating; Factor V = Anticipation of positive reinforcement that may result from eating. Highest loadings, on the basis of which items are allocated to a factor, are printed in bold; loadings <.30 are not shown. The results indicated that the structure of the original (G-)FCQ-S was retained.

other original dimensions ('guilt' and 'craving as a physiological state') could not be identified in the present dataset and disappeared. Items of the remaining six original dimensions appeared to be consolidated in three dimensions. That is, the present dimension of 'preoccupation with food' appeared to consist of items derived from the original dimensions 'intentions to consume food' (1 item) and 'preoccupation with food' (5 items). In the same way, the present dimension of 'loss of control' is composed of items from the initial dimensions 'lack of control over eating' (4 items) and 'environmental cue-elicited eating' (2 items). Finally, items from the initial dimensions 'anticipation of positive reinforcement' (4 items) and 'anticipation of relief from negative states as a result of eating' (1 item) appear to be combined to form the present dimension of 'positive outcome expectancy'. These fusions make sense, and it is likely that there already may have been strong covariations among the original factors. Despite the changes that were made to the original FCQ-T scale to form the G-FCQ-T scale, one might question the actual difference between both questionnaires. To examine whether the G-FCQ-T and

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the original FCQ-T are indeed different, the ideal test would be to administer the two versions of the questionnaire to the same population and to directly compare the factor structure of both versions.

In reviewing psychological drug craving theories, Verheul, van den Brink, and Geerlings (1999) defined three essential pathways to craving for alcohol: *reward craving*, which reflects a strong desire for the rewarding effects of a substance; *relief craving*, which represents a desire for the reduction of tension and arousal; and *obsessive craving*, which can be regarded as a lack of control over intrusive thoughts about drinking. Roughly, these three factors also seem to be present in the current G-FCQ-T dimensions. The food craving dimension 'positive outcome expectancy' could be seen as reward craving, 'emotional food craving' might be interpreted as relief craving, whereas 'preoccupation with food' might reflect obsessive craving.

An exploratory factor analysis was also performed on the G-FCQ-S data. Five factors were found, identical to those originally found by Cepeda-Benito, Gleaves, Williams et al. (2000). Briefly, this measure intends to assess whether someone desires to eat *at a certain moment* (the dimension 'an intense desire to eat', which is the core feature of craving), and which mechanisms underly this urge to eat (the expectance of positive/negative reinforcing effects from eating and obsessively thinking about food or hunger). The results of factor analysis were straightforward, and indicated that the structure of the original G-FCQ-S was retained.

Study 2: Confirmatory factor analysis, test-retest reliability, and construct validity

To test the four-dimensional, 21-item model, which was found for the G-FCQ-T in the exploratory factor analyses of study 1, and to reconfirm the G-FCQ-S five-factor structure, a new sample was recruited and requested to fill in both questionnaires. On this new dataset, a confirmatory factor analysis was performed. Internal consistency was also reexamined, as well as the test-retest reliability of both scales. Because the G-FCQ-T intends to assess *stable* traits, whereas the G-FCQ-S is developed to measure *variable* states, higher test-retest correlations were expected for the G-FCQ-T scores than for the G-FCQ-S scores.

Study 2 also made an attempt to investigate the construct validity of the G-FCQ-T and G-FCQ-S by studying their relationship with the Dutch Eating Behavior Questionnaire (DEBQ; van Strien et al., 1986), which measures three types of disturbed eating behavior, namely emotional eating (i.e., the tendency to overeat in response to emotions), external eating (i.e., the tendency to overeat in response to food-related stimuli), and restrained eating (i.e., the tendency to restrict food and calorie intake successfully). Food cravings are thought to be significantly linked with binge eating (Mitchell, Hatsukami, & Eckert, 1985). Therefore, significant positive correlations were hypothesized between the G-FCQ-T scales and the DEBQ external and emotional eating scales, which are both scales reflecting a tendency toward disinhibited eating behavior (van Strien, 2004). Particularly high correlations were expected to be found between the G-FCQ-T emotional craving subscale and the DEBQ emotional eating scale, and between the G-FCQ-T loss of control subscale and the DEBQ external eating scale. In contrast with disinhibited eating behaviors, food cravings appear to be rather weakly related to restrained eating (Hill et al., 1991; Weingarten & Elston, 1991). Thus, compared to the DEBQ emotional eating and external eating scales, weaker correlations were hypothesized between the DEBQ restrained eating scale and the G-FCQ scales. Because the DEBQ measures general eating-related tendencies, it was hypothesized that the scores on this scale would be more convincingly associated with G-FCQ-T scales than with G-FCQ-S scales. This hypothesis can be regarded as a preliminary test of the discriminant validity of these trait and state food cravings questionnaires.

Method

Participants, instruments and procedure

As part of a survey including various eating- and personality-related topics, 205 undergraduate psychology students (35 males and 170 females) completed the G-FCQ-T/S scales (see study 1) in exchange for course credits. Participants had a mean age of 19.86 years (SD = 3.18; range 17 to 41 years). Three weeks after completing the first set of questionnaires, 50 students were asked to fill in the G-FCQ-T/S scales for a second time.

Next to the G-FCQ-T and G-FCQ-S, participants also completed the DEBQ (van Strien et al., 1986). The DEBQ contains 33 interrogative items, which measure three types of eating behavior, namely emotional eating, external eating and restrained eating. For each item, there are five response categories (1 = never, 5 = very often). The psychometric qualities of the DEBQ are good, with good alphas and factorial validity for each of the three scales (van Strien et al., 1986).

Statistical analysis

Both the G-FCQ-T and G-FCQ–S were subjected to a confirmatory factor analysis, using maximum likelihood estimations (Amos 6.0; Arbuckle, 2003). As absolute fit indices, the chi square per degree of freedom (χ^2/df) statistic and the Root Mean Square Error of Approximation (RMSEA; Steiger, 1990) were chosen. A χ^2/df value of less than 3 indicates a close fit between the observed and predicted covariance matrices (Byrne, 2001). A RMSEA value of .08 or lower is indicative of an adequate fit. However, lower values ($\leq$ .05) are preferred, given that smaller RMSEA values are indicative of a better fit (Hu & Bentler, 1999). As incremental fit indices the Tucker Lewis Index (TLI; Tucker & Lewis, 1973) and the Comparative Fit Index (CFI; Bentler, 1990) were selected. Both indices range between 0 and 1, with higher values indicating a better fit. Values of .90 or more

Table 3: *Pearson correlations between G-FCQ-T/S total and subscale scores and scores on the DEBQ scales (Study 2)*

	DEBQ Emotional	DEBQ Externality	DEBQ Restraint
G-FCQ-T			
Total score	.71**	.51**	.31**
Preoccupation with food	.53**	.37**	.37**
Loss of control	.51**	.48**	.27**
Positive outcome expectancy	.31**	.41**	.04
Emotional craving	.84**	.32**	.23**
G-FCQ-S			
Total score	.19**	.30**	.04
Desire to eat	.13	.34**	-.08
Anticipation to positive reinforcement	.15*	.31**	-.06
Anticipation to negative reinforcement	.23**	.19**	.11
Obsessive preoccupation	.33**	.34**	.10
Craving as a physiological state	.00	.08	.02

Note. $N = 205$; G-FCQ-T = General Food Cravings Questionnaire-Trait; G-FCQ-S = General Food Cravings Questionnaire-State; DEBQ = Dutch Eating Behavior Questionnaire; * $p < 0.05$, ** $p < 0.01$.

are associated with well-fitting models (Bentler, 1990; Marsh et al., 1994). As a measure of internal consistency, Cronbach's alphas were again computed for the entire scale as well as for the factors/subscales. Test-retest reliability for the instruments was determined by computing interclass correlations (ICCs) between scale and subscale scores as obtained on the first and second occasion. Finally, to examine the construct validity of the scales, Pearson correlations were calculated between G-FCQ-T/S scores and scores on the DEBQ.

Results

G-FCQ-T

The fit indices for the G-FCQ-T reflected an adequate to good model fit with the following values: χ^2/df = 2.44, TLI = .86, CFI = .88, and RMSEA = .08. Cronbach's alphas were .90 for the G-FCQ-T total score and ranged between .71 and .91 for the various subscales, indicating adequate to good internal consistency. Inter-scale correlations ranged from .36 to .59. Test-retest reliability was .79 for the total scale, and between .62 and .78 for the subscales. Pearson correlations between G-FCQ-T and DEBQ scores are displayed in Table 3. As hypothesized, more substantial correlations were found between G-FCQ-T and DEBQ scores than between G-FCQ-S and DEBQ scores. Further, it should be noted that G-FCQ-T scores were especially strongly related to the DEBQ emotional and external eating scales, and substantially weaker to the DEBQ restrained eating scale. As predicted, the strongest correlations were found between the DEBQ emotional eating and G-FCQ-T emotional craving subscale, and between the DEBQ external eating and G-FCQ-T loss of control subscale.

G-FCQ-S

The fit indices for the G-FCQ-S were as follows: χ^2/df = 2.60, TLI = .91, CFI = .93, and RMSEA = .09. Except for the RMSEA, all indices suggested a good fit. The overall alpha for the G-FCQ-S was .93 and subscales alphas were all between .74 and .89, indicating an adequate to good internal consistency. Inter-scale correlations ranged from .47 to .71. Test-retest reliability for the total scale was .26 and the test-retest correlations for the subscales were ranging from .19 to .45. As expected the test-retest reliability of the G-FCQ-S was substantially lower than that of the G-FCQ-T, confirming the notion that the G-FCQ-S assesses a changeable state.

Discussion

Fit indices for the G-FCQ-T reflected an adequate to good model fit, which confirmed the four-factor structure of this scale that was found in study 1. Inter-scale correlations of the G-FCQ-T were notably smaller compared to the inter-factor correlations of the original FCQ-T as reported by Cepeda-Benito, Gleaves, Williams et al. (2000), which strengthens the idea that the G-FCQ-T subscales reflect related, but distinct factors. Most indices for the G-FCQ-S were also satisfactory, which confirmed the five-factor structure of this scale. The test-retest analysis indicated that the G-FCQ-T is a reliable instrument that indeed measures trait-like characteristics of food craving. As could be expected, the test-retest correlations for the G-FCQ-S were rather weak, which is in keeping with this instrument's intention to assess state-dependent craving. Further, in particular trait craving was substantially correlated with the tendency to (over)eat when being emotional or when exposed to food, as assessed by means of the DEBQ. As predicted, trait craving correlated less convincing with the DEBQ restrained eating scale, which reflects the tendency to successfully restrict food intake in order to maintain body weight. Finally, the finding that correlations between state craving and DEBQ scores were considerably smaller or even non-significant (in the case of restrained eating) as compared to those between trait craving and this measure, can be taken as support for the discriminant validity of the G-FCQ-T and G-FCQ-S scales. In sum, the G-FCQ-T and G-FCQ–S appear to be reliable and valid instruments for assessing general trait- and state-like food craving.

2

Study 3: Construct validity of the G-FCQ-S

As an additional test of the G-FCQ-S as an index of state craving, study 3 examined scores on this measure in two satiety conditions, that is, before and after eating a meal (dinner). Given that cravings emerge in a state of food deprivation/hunger, it was predicted that subjects would report more desire to eat before the meal than after the meal (when satiated). In other words, scores on the G-FCQ-S were predicted to be significantly higher before than after the meal.

Methods

Participants and procedure

Fifty subjects (31 females and 19 males), with a mean age of 29.8 years ($SD = 12.3$; range 19 to 61 years) volunteered to participate in this study. Participants were instructed to fill in the G-FCQ-S at home, before and after dinner.

Statistics

A paired samples *t*-test was carried out to determine whether G-FCQ-S scores changed significantly over the two measurement moments.

Results

As can be seen in Table 4, a significant decline was found for the G-FCQ-S scores before and after dinner, for the entire scale as well as the subscale scores [$t(49)$s between 6.48 and 14.01, all ps $< .01$].

Discussion

Study 3 examined whether the G-FCQ-S, which measures craving as a state, is indeed influenced by temporal and situational variables. For this purpose, volunteers were asked to complete the G-FCQ-S before dinner, when a certain extent of food deprivation is assumed, and after dinner, when satiation is assumed. The hypothesized significant decline in desiring food before and after dinner was demonstrated, suggesting that the G-FCQ-S is a sufficiently sensitive scale for measuring state-dependent craving. However, an important limitation of study 3 is the lack of data on the level of subjective hunger at dinner time or the time since last eaten. Results would have been more convincing if they had been controlled for hunger ratings.

Table 4: *Mean scores (SDs) on the G-FCQ-S before and after dinner (Study 3)*

	M (SD) before dinner	*M (SD)* after dinner	*t*(49)	*p*
Total score	46.60 (8.77)	25.58 (7.42)	14.01	<.01
Desire to eat	10.60 (2.47)	5.52 (2.16)	11.20	<.01
Anticipation to positive reinforcement	9.60 (2.43)	5.98 (2.19)	8.81	<.01
Anticipation to negative reinforcement	8.68 (2.72)	5.04 (1.58)	7.65	<.01
Obsessive preoccupation	7.82 (2.52)	4.86 (1.96)	6.48	<.01
Craving as a physiological state	9.90 (2.64)	4.18 (1.59)	13.65	<.01

Note. $N = 50$; G-FCQ-S = General Food Cravings Questionnaire-State.

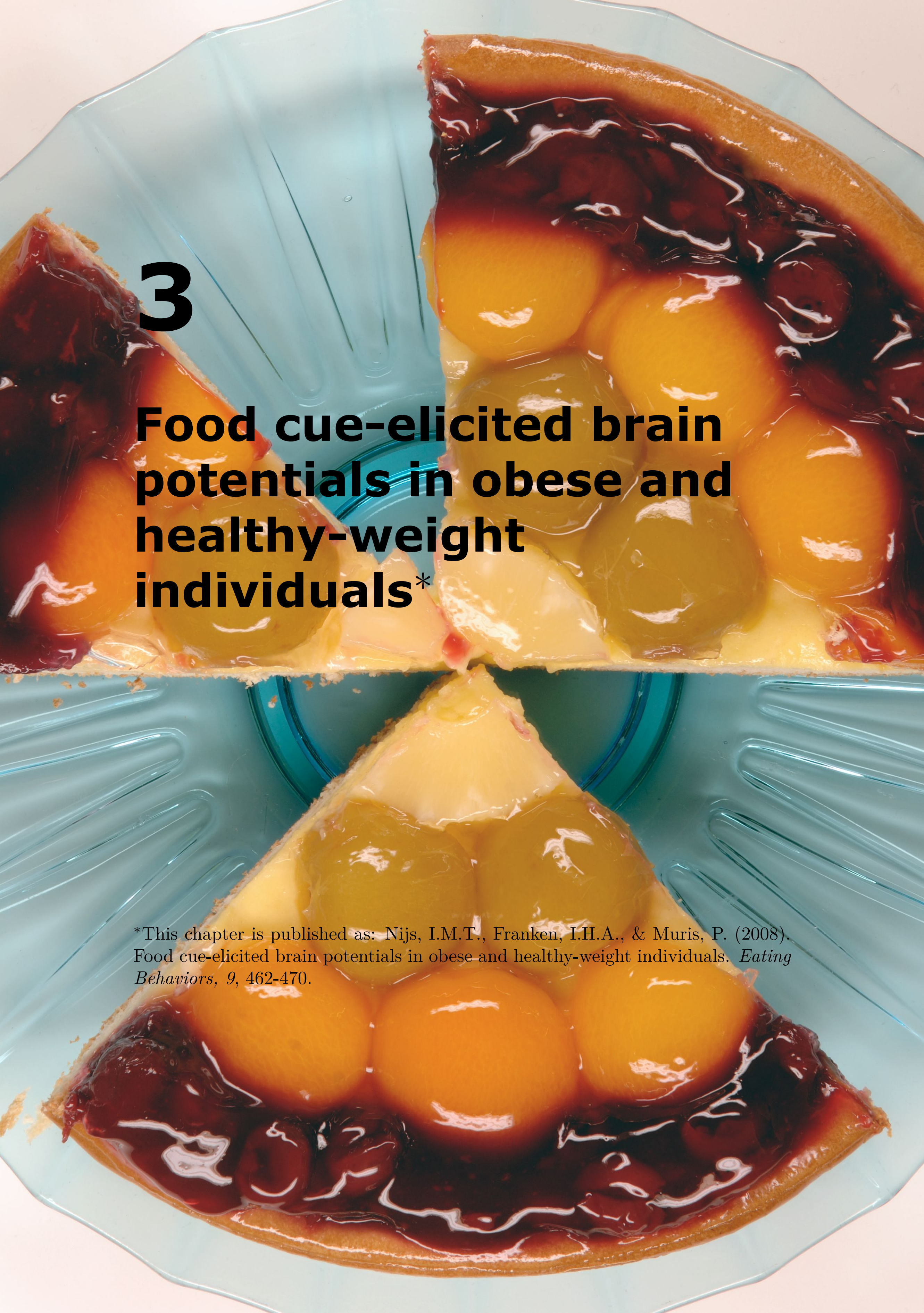
Summary and General Conclusion

The purpose of the present studies was to construct and validate a set of questionnaires to assess *general* trait and state food cravings (as opposed to cravings for specific foods). As a starting point for the development of these questionnaires, the Trait and State Food Cravings Questionnaires (FCQ-T and FCQ-S) as developed by Cepeda-Benito et al. (2000) were chosen, which intend to measure cravings for specific food items. The FCQ scales were translated into Dutch, modified to emphasize the generality of food cravings and renamed as the Trait and State *General* Food Cravings Questionnaires (G-FCQ-T and G-FCQ-S).

Exploratory and confirmatory factor analyses indicated that both the G-FCQ-T and the G-FCQ-S displayed a reasonable fitting and theoretically meaningful factor structure that nicely seemed to cover the multidimensional characteristic of trait and state food craving. Further, evidence was found supporting the reliability (internal consistency and test-retest stability) and validity of the scales. Altogether, it can be concluded that the G-FCQ-T and G-FCQ-S possess satisfactory psychometric properties.

The G-FCQ-T and G-FCQ-S were developed in the belief that a general urge to eat (in contrast with the classical definition of food craving as a desire to eat a *specific* food) might mediate excessive eating patterns, such as seen in obesity. The G-FCQ-T and G-FCQ-S might be useful to examine the role of this 'urge to eat' in the overeating behavior and relapse tendency of obese individuals. More particularly, it would be interesting to study whether the experimental exposure to food elicits general food cravings and to investigate the neurophysiological correlates of these food cravings. The scales could also be used in studies that focus on clinical eating disorders, such as bulimia nervosa and binge eating, which are both disorders characterized by episodes in which excessive amounts of different sorts of food items are craved and consumed.

2



3

Food cue-elicited brain potentials in obese and healthy-weight individuals*

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3

Abstract

The main objective of this study was to investigate, by means of event-related potentials (ERPs), whether obese individuals process food-related information differently as compared to normal-weight individuals. Because amplitudes of late positive ERP components (P3, LPP) reflect motivational tendencies, obese participants were expected to display enlarged P3 and LPP amplitudes towards food pictures. Obese and normal-weight adults were exposed to pictures of food and control items, while EEG was recorded. Subjective levels of food craving and hunger were also assessed. While there were no differences in ERP amplitudes between obese and normal-weight individuals, significantly larger P3 and LPP amplitudes were elicited by pictures of food items as compared to control pictures. Positive correlations were found between P3 and LPP amplitudes and self-reported increases of hunger. It was concluded that food-related information is processed differently in the brain as compared to non-food-related information, in a manner that reflects the natural motivational value of food. In the present study, there was no indication of an electrophysiological or subjective hyper-reactivity to food cues in obese adults.

Introduction

In western societies, health organizations raise the alarm because of increasing prevalence rates of overweight (Body Mass Index [BMI] $\geq$ 25 kg/m^2) and obesity (BMI $\geq$ 30 kg/m^2) in the general population. For example, in the Netherlands – where the present study was conducted – an epidemiological study during the period 1998-2001 revealed that 40 to 50% of adults between the age of 20 and 70 years are overweight, while circa 10% of them are obese (Visscher, Viet, Kroesbergen, & Seidell, 2006). Similar research, conducted between 2002 and 2004, led to the conclusion that about 15% of the Dutch children between 4 and 15 years are overweight, whereas 3% of them can be labelled as obese (van den Hurk et al., 2006). These figures have even doubled since the 1980s, and are expected to double once more in the upcoming two decades if no interventions are undertaken (Bemelmans, Hoogenveen, Visscher, Verschuren, & Schuit, 2004; Schokker et al., 2007).

In essence, overweight is the result of a chronic imbalance between energy intake and energy expenditure: more kilocalories are ingested than necessary for the body's metabolism. Although this imbalance is the consequence of a complex interplay between genetic-biological and environmental-behavioral factors, it is the *environment*, promoting an unhealthy lifestyle and 'obesogenic' behavior, that is held largely responsible for the dramatic worldwide increase in the prevalence of overweight (Hill & Peters, 1998; Hill, Wyatt, Reed, & Peters, 2003). More precisely, the abundant availability of rewarding, thus high-caloric and palatable, food is emphasized to contribute to overeating behavior (Hill & Peters, 1998; Speakman, 2007; Volkow & Wise, 2005). It has been suggested that there are individual differences in the sensitivity and reactivity to the rewarding properties of environmental food cues (Beaver et al., 2006; Franken & Muris, 2005). In sensitive individuals, the mere exposure to palatable food might induce excessive craving and a tendency to indulge in overeating behavior, even in the absence of physiological hunger or nutritional deficits (Berridge, 2007; Jansen, 1998; Wardle, 1990).

Individual differences in food cue-responsiveness are assumed to depend considerably on classical conditioning mechanisms (Jansen, 1998; Jansen et al., 2003; Wardle, 1990). Conditioning models for excessive eating propose that actual food cues and classically conditioned (external as well as internal) eating-related stimuli may become strong predictors for food intake and anticipatorily elicit physiological responses, which are associated with craving. Preliminary evidence suggests that conditioned food cue responsiveness is stronger in obese individuals than in normal-weight persons. For example, Jansen et al. (2003) investigated cue-elicited craving and overeating in obese and normal-weight children. After been exposed to the smell of tasty food or to the taste of an appetizing preload, obese children demonstrated a significantly increased food intake as compared to a control condition without food confrontation, whereas the food intake of normal-weight children generally decreased in the food exposure conditions.

Conditioned cue-reactivity models for overeating behaviors have their roots in classical addiction theories, in which conditioned drug cue reactivity and drug craving are believed to contribute considerably to the development and maintenance of addictive disorders and the well-known tendency to relapse when abstinent (Franken, 2003; O'Brien, Childress, Ehrman, & Robbins, 1998; Robinson & Berridge, 1993). Moreover, overeating clearly exhibits other features of addictive behavior: it is characterized by the impulsive seeking and intake of a rewarding substance in spite of the negative health and psychosocial consequences, and attempts to control the behavior frequently result in relapse to initial overeating and intake of high-caloric food (Kramer, Jeffery, Forster, & Snell, 1989; Stalonas, Perri, & Kerzner, 1984; Wadden & Frey, 1997). In addition, similarly to addiction, empirical findings suggest that the overeating behavior of (at least a subgroup of) obese individuals might be the result of a substantially enhanced motivation for food, which may have its origins in the aberrant functioning of reward-related brain processes (Volkow et al., 2002).

In substance-dependent individuals, electrophysiological research, using cue exposure paradigms, has yielded robust findings concerning the processing of drug-related information. When confronted with drug-related pictures, long-latency waves, such as the P3 and Late Positive Potential (LPP), in the event-related potential (ERP) pattern of addicted individuals were found to be significantly increased in centro-parietal regions as compared to non-addicted control subjects, suggesting an enhanced cortical processing of these stimuli (Herrmann et al., 2000; Herrmann, Weijers, Wiesbeck, Boning, & Fallgatter, 2001; Littel & Franken, 2007; Lubman, Allen, Peters, & Deakin, 2007; Warren & McDonough, 1999). Long-latency ERPs are thought to reflect the allocation of attention and cognitive effort (Kok, 1997). It is assumed that more cognitive resources are allocated to motivationally salient (positive and negative) stimuli. In emotional contexts, there is general agreement that long-latency ERP amplitudes are modulated by the motivational salience of cognitively processed information (Schupp et al., 2000). A sustained selective processing bias, reflecting the activation of the brain's motivation system, would induce an appropriate behavioral (approach or avoidance) response to motivational salient stimuli (Cuthbert et al., 2000; Franken, Stam, Hendriks, & van den Brink, 2003). Interestingly, in addiction-related ERP-studies the amplitude of LPPs appears to be positively correlated with self-reported drug craving, which supports the idea that LPP amplitude reflects motivational tendencies (Franken, Hulstijn, Stam, Hendriks, & van den Brink, 2004; Franken et al., 2003; Lubman et al., 2007; van de Laar, Licht, Franken, & Hendriks, 2004).

The present study addresses the processing of food cues in normal-weight and obese individuals. The aims of the present study are twofold. The first aim is to investigate whether palatable food-related stimuli result in enhanced processing as compared to non-food stimuli. We expected larger P3 and LPP amplitudes when individuals are exposed to food stimuli as compared to control stimuli (i.e., office items). The second aim was to examine whether obese individuals display enhanced processing of food-related information as compared to normal-weight controls. In other words, this study investigated whether there is a general processing bias for food-related information and whether this bias is enhanced in obese individuals as compared to normal-weight individuals. If obesity indeed is the result of an abnormally enhanced motivation for food, which is characterized by an excessive reactivity towards food cues, larger P3 and LPP amplitudes for food cues would be expected in the obese group. Furthermore, as LPP and P3 amplitudes reflect motivational tendencies, it can be expected that these measures correlate positively with self-report measures of food craving and hunger.

So far, few studies have addressed cortical processing of food information by means of ERPs. These studies were primarily concerned with the influence of hunger and satiety on food-related information processing (e.g., Carretié, Mercado, & Tapia, 2000; Hachl, Hempel, & Pietrowsky, 2003; Plihal, Haenschel, Hachl, Born, & Pietrowsky, 2001). However, for a number of reasons, the results of these studies are rather difficult to interpret when it comes to the mere processing of food stimuli. First of all, actual processing of stimuli was influenced by other cognitive tasks, which the participants had to perform simultaneously, such as stimulus identification or stimulus matching. Second, stimuli were not shown explicitly to participants (as is the case in real world), but presented as words or in a subliminal or deformed way. Third, the focus of these studies was the influence of food deprivation on brain activity in general. With this in mind, the present study adopts a more straightforward approach: participants are passively exposed to pictures of palatable foods as well as neutral control pictures while recording their EEG activity. Further, we not only examine the relation between hunger and ERPs, but are also interested in the influence of food craving on the processing of food-related information, because this process is thought to play a primary role in the origins of overeating behavior. Exploratively, we will also investigate the hemispheric distribution of ERPs: appetitive food cues are expected to predominantly activate left hemispheric brain areas, since electro-cortical activation in the left hemisphere is believed to be associated with approach behavior towards emotionally pleasant stimuli (Davidson, Ekman, Saron, Senulis, & Friesen, 1990; Sutton & Davidson, 2000).

Methods

Participants

Via advertisements, healthy obese (BMI $\geq$ 30 kg/m^2) and healthy normal-weight (BMI 20-25 kg/m^2) men and women between the age of 18 and 50 years were approached to volunteer in a study concerning brain activity and body weight. Participants were screened during a telephone interview and were excluded from the study for the following reasons: (1) presence of a psychiatric or physical illness within the past four weeks; (2) current use of any medication that might influence eating behavior, body weight or EEG activity; (3) any recent participation (within the past three months) in an intervention aimed at losing weight, such as low caloric diet, extreme physical activity, weight-loss medication, or surgery; (4) current smoking or excessive alcohol use, and (5) a history of drug abuse and/or any neurological problems.

Eventually, 20 obese adults (16 females and 4 males; mean BMI = 36.69, $SD = 6.47$; mean age = 28.65, $SD = 6.59$ in a range between 20 and 42 years) and twenty normal-weight controls (16 females and 4 males; mean BMI = 22.68, $SD = 1.53$; mean age = 28.65, $SD = 6.08$ in a range between 20 and 40 years), which were also matched for educational level, participated in the study. The study was approved by a local ethical committee of Erasmus University.

Questionnaires

3

Food craving was assessed by means of the State version of the General Food Cravings Questionnaire (G-FCQ-S; Cepeda-Benito, Gleaves, Willliams et al., 2000; Nijs et al., 2007), which is a 15-item self-report scale for measuring situational food craving. Briefly, the items refer to (1) an intense desire to eat; (2) anticipation of positive reinforcement that may result from eating; (3) anticipation of relief from negative states and feelings as a result from eating; (4) obsessive preoccupation with food or lack of control over eating; and (5) craving as a physiological state. Individuals have to indicate on a Likert scale to what extent they agree with each statement on the moment of completing the questionnaire (1 = strongly disagree; 5 = strongly agree). In the present study, a G-FCQ-S total score (ranging from 15 to 65) was used to assess pretest and posttest food craving. The G-FCQ-S has been shown to possess good reliability and adequate construct and discriminant validity (Cepeda-Benito, Gleaves, Williams et al., 2000; Nijs et al., 2007).

A 100-mm visual analogue scale (VAS; 0 = no hunger at all, 100 = extreme hunger) was used to index subjective levels of hunger at the start and at the end of the experiment. More precisely, subjects had to answer the question “To what degree do you experience hunger at this moment?” by placing a corresponding vertical line on the VAS.

Stimuli

Twenty photographs of generally palatable and high-caloric food items (e.g., French fries, chocolate) and 20 photographs of office items (e.g., paperclips, stapler) were shown on a computer monitor for a duration of 2000 ms and with a resolution of 1024 × 768 pixels. All pictures were presented four times with a fixed interstimulus interval of 1500 ms. The pictures were presented to the subjects in a semi-random order, in such way that no more than three pictures of the same category were shown successively.

Visual analogue scales were used to evaluate the valence (0 = very unpleasant; 100 = very pleasant) and arousability (0 = not at all arousing; 100 = very arousing) of each food and non-food picture. For this purpose, the participants received a file with printed versions of all pictures. For each picture individually, the participants were asked to place a vertical line on the two VAS's, corresponding to their ratings of valence and arousability. The non-food control pictures were expected to be assessed as neutral in valence and low in arousal by all participants. The food pictures, however, were expected to be assessed as significantly more pleasant and arousing than the control pictures.

Procedure

In order to bring all participants in a comparable hunger state and to exclude direct effects of food intake on ERP responses, participants were requested to eat a light meal two hours before the start of the experiment, and subsequently to abstain from any food or caloric drinks until the experiment was finished.

On arrival at the university laboratory, the experimental procedure was briefly explained. Participants were given the opportunity to ask remaining questions, and written informed consent was provided. First, all participants completed self-report questionnaires to assess pretest food craving and physiological hunger, as well as the exact time that they had last eaten, their present body weight, and length. Subsequently, participants were seated in a comfortable chair in a dimly-lit, sound-attenuated room and EEG electrodes were attached. Each participant first performed a modified Stroop task including food-related words (data not reported here), followed by the exposure session, during which the pictures of food and non-food items were displayed. The subject was instructed to sit as relaxed and quietly as possible and to look attentively at the pictures. To motivate the participants to remain attentive during the whole task, they were told that questions were going to be asked about the pictures after the experiment. At the end of the experiment, participants filled in the food craving and hunger scales for a second time and were asked to rate the valence and arousability of the pictures. All subjects received a financial remuneration for their participation.

Electroencephalographic (EEG) recording

EEG signals were recorded, using an Active-Two amplifier system (Biosemi, Amsterdam, the Netherlands), of 64 scalp sites (10-20 system) with active Ag/AgCl electrodes mounted in an elastic cap. Two additional scalp electrodes were used as reference and ground electrode, respectively. Furthermore, additional electrodes were attached to the left and right mastoids, and to the supraorbital regions of the left and right eye (VEOG). 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. Off-line, data were re-referenced to a computed linked mastoid. EEG and EOG activity was filtered with a bandpass of 0.10-30 Hz (phase shift-free Butterworth filters; 24dB/octave slope). After ocular correction (Gratton, Coles, & Donchin, 1983), epochs including an EEG signal exceeding

$\pm$100 μV were eliminated. When more than 50% of the epochs contained artifacts, subjects were excluded from further analyses. As a result, two participants had to be excluded (one obese and one control participant). The mean number of included food trials was 67.61 (SE = 1.50), and the mean number of office trials was 67.50 (SE = 1.50). The mean 200 ms pre-stimulus period served as baseline. EEG was recorded from 200 ms prestimulus to 2000 ms poststimulus. After baseline correction, ERP waves were calculated for each participant, at each scalp site, for the two stimulus conditions. Based on visual inspection of the grand average waveform (Figure 1) and the existing literature (e.g., Franken et al., 2003) P3 was defined as the average amplitude (μV) within the 300-400 ms time window, while LPP was defined as the average amplitude within the 400-800 ms latency window.

Statistical analyses

By means of an independent samples t-test, between-group differences were evaluated with regard to the elapsed time since last eaten (in minutes). To evaluate main and interaction effects for hunger (VAS) and food craving (G-FCQ-S), 2 $\times$ 2 repeated measures analyses of variance (ANOVA) were performed with group (obese/normal-weight) as between-subjects factor and time (pretest/posttest) as within-subjects factor. To compare the valence and arousal ratings of the pictures, 2 $\times$ 2 repeated measures ANOVAs were carried out with group as between-subjects factor and cue category (office/food) as within-subjects factor. In case of significant effects, post-hoc t-tests were conducted.

To analyze P3 and LPP data, repeated measures ANOVAs were performed with group as between-subjects factor, and cue category, hemispheric distribution (left/right) and electrode site as within-subjects factors. Fifty-four non-midline electrode sites were grouped into 6 clusters (e.g., Codispoti, Ferrari, & Bradley, 2007): 2 posterior clusters (left posterior: P1, P3, P5, P7, P9, PO3, PO7, O1; right posterior P2, P4, P6, P8, P10, PO4, PO8, O2); 2 central clusters (left central: FC1, FC3, FC5, FT7, C1, C3, C5, T7, CP1, CP3, CP5, TP7; right central: FC2, FC4, FC6, FT8, C2, C4, C6, T8, CP2, CP4, CP6, TP8) and 2 anterior clusters (left anterior: F1, F3, F5, F7, AF3, AF7, Fp1; right anterior: F2, F4, F6, F8, AF4, AF8, Fp2). For each cluster the ERP amplitudes of individual sites were averaged. A 2 (group) $\times$ 2 (cue category) $\times$ 2 (hemisphere) $\times$ 3 (cluster) repeated measures ANOVA (with Greenhouse-Geisser corrected df's; uncorrected df's are reported) was carried out for each ERP component. In case of significant effects, post-hoc t-tests were conducted with Bonferroni adjustments for multiple comparisons.

To evaluate the relationship between self-reported food craving, hunger, and valence and arousability ratings of pictures on the one hand, and amplitudes of the ERP components on the other hand, Pearson correlations were calculated. For food craving and hunger, G-FCQ-S and VAS difference scores (posttest-pretest) were calculated, because these scores best reflect the responsivity of these variables during the course of the experiment.

Table 1: *Mean pretest and posttest food craving (G-FCQ-S) and hunger (VAS) scores in the obese group (N = 20) and normal-weight control group (N = 20)*

		Obese		Normal-weight	
		M	*SD*	*M*	*SD*
G-FCQ-S	Pretest	26.4	11.0	30.3	7.3
	Posttest	33.8	12.8	37.9	9.4
Hunger	Pretest	13.4	16.1	33.3	22.3
	Posttest	22.6	24.5	47.7	23.7

Note. G-FCQ-S = General Food Cravings Questionnaire-State, VAS = Visual Analogue Scale.

Results

3

Self-report measures

No between-group difference was found with regard to the elapsed time since last eaten (t = 1.18, p > .05). Mean hunger and food craving scores for obese and normal-weight participants are displayed in Table 1. Main time effects were found for food craving, $F(1,37) = 31.66$, $p < .001$, as well as hunger scores, $F(1,38) = 17.31$, $p < .001$. This result indicates that participants generally reported significantly more food craving and hunger at posttest (after the food picture exposure) as compared to pretest. No significant time × group interaction effects were found (both $Fs < 1$), suggesting that the increase in food craving and hunger was similar in both groups. For hunger, a main group effect was found, $F(1,38) = 12.66$, $p < .01$. Post-hoc t-tests revealed that group differences were significant at pretest (t = 3.23, p < .01) as well as posttest (t = 3.29, p < .01): on both occasions, the normal-weight group reported higher levels of hunger than the obese group.

Main effects of cue category were found for the valence, $F(1,38) = 33.68$, $p < .001$, and arousability, $F(1,38) = 86.79$, $p < .001$, of the pictures. That is, food pictures were generally evaluated as more pleasant (M= 65.58, SD = 12.25 vs. M= 45.33, SD = 15.21) and arousing (M= 52.61, SD = 18.37 vs. M= 20.04, SD = 17.69) than office pictures. No main effect of group nor an interaction effect of group and cue category was found.

Event-related potentials

The analysis of the P3 data yielded significant main effects for cluster, $F(2,72) = 81.41$, $p < .001$, and cue category, $F(1,36) = 6.79$, $p < .05$. In addition, a significant interaction effect of cluster and cue category was found, $F(2,72) = 13.03$, $p < .01$. Post-hoc t-tests revealed that the cue effect was only significant at the central (p < .05) and the posterior (p < .001) clusters. For both clusters, the amplitudes elicited by food cues ($M_{\text{central}} = 3.72\ \mu$V, SE = .59; $M_{\text{posterior}} = 8.61\ \mu$V, SE = .70) were significantly larger as compared to the amplitudes elicited by office cues ($M_{\text{central}} = 2.92$ μV, $SE = .57$; $M_{\text{posterior}} = 6.92$ μV, $SE = .73$). No significant effects were found for group or hemisphere.

A highly similar pattern was observed for the LPP data. That is, significant main effects were found for cluster, $F(2{,}72) = 37.84$, $p < .001$, and cue category, $F(1{,}36) = 14.17$, $p < .01$, while the cluster × cue interaction effect was also significant, $F(2{,}72) = 13.56$, $p < .001$. Post-hoc t-tests demonstrated significant cue effects at the central ($p < .001$) and the posterior ($p < .001$) clusters. Again, amplitudes were significantly larger for food cues ($M_{\text{central}} = 4.47$ μV, $SE = .52$; $M_{\text{posterior}} = 6.00$ μV, $SE = .56$) than for office cues ($M_{\text{central}} = 2.99$ μV, $SE = .48$; $M_{\text{posterior}} = 4.18$ μV, $SE = .59$). No significant effects were found for group or hemisphere.

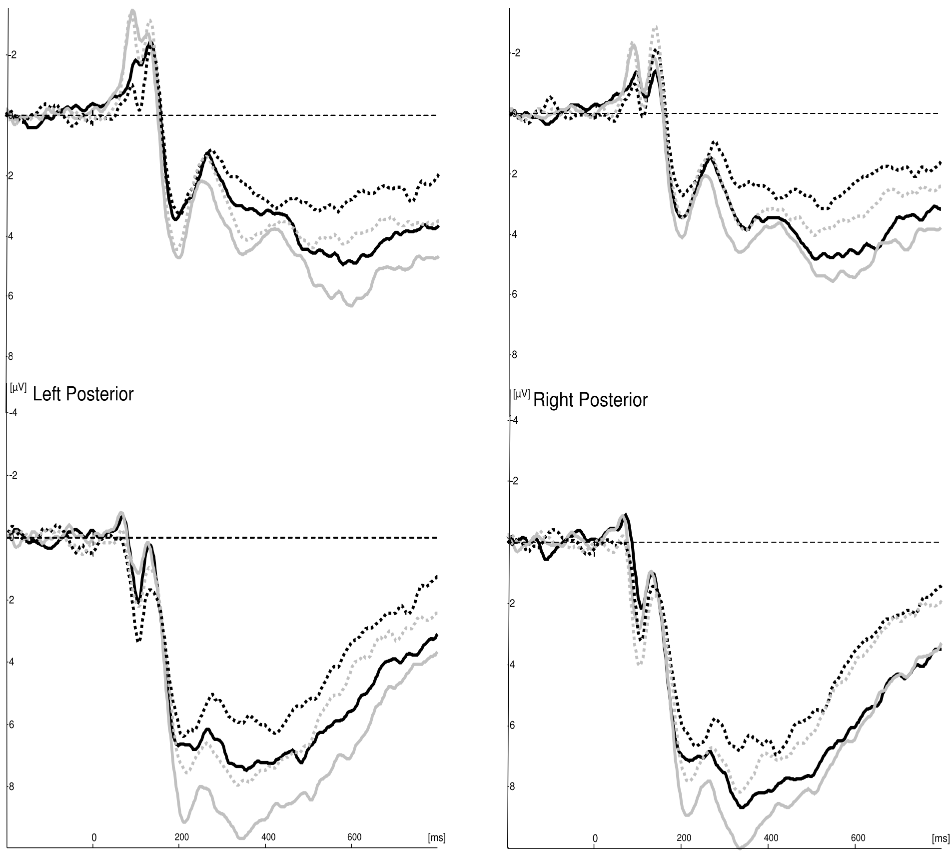

Figure 1: *Grand average food cue- (solid lines) and office cue-elicited (dashed lines) waveforms for left- and right-hemispheric central and posterior electrode clusters in obese (n = 19; black lines) and normal-weight (n = 19; grey lines) subjects.*

Table 2: *Pearson correlations between food cue- and office cue-elicited brain potential amplitudes (P3 and LPP, left and right posterior, left and right central) and increase (posttest – pretest difference scores) of self-reported food craving (G-FCQ-S) and hunger (VAS)*

	Food				*Office*			
	Left Posterior	Right Posterior	Left Central	Right Central	Left Posterior	Right Posterior	Left Central	Right Central
				P3				
G-FCQ-S	.21	.31	-.20	-.09	.26	.32	-.16	.00
VAS Hunger	**.48	**.44	.11	.10	**.46	**.43	.13	.17
				LPP				
G-FCQ-S	.10	.19	-.17	-.13	.15	-.22	-.18	-.08
VAS Hunger	*.33	*.35	.11	.03	*.36	*.37	.13	.11

Note. $N = 38$; LPP = Late Positive Potentials, G-FCS-S = General Food Cravings Questionnaire-State, VAS = Visual Analogue Scale. * $p < .05$, **$p < .01$

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Figure 1 presents grand average waveforms for the central and posterior electrode clusters. Figure 2 displays the scalp distribution of main cue effects (*p*-values; food > office) for P3 and LPP amplitudes.This figure nicely illustrates that significant cue effects are exclusively observed at central and posterior electrodes.

Correlational analyses

As can be seen in Table 2, a number of positive correlations were observed between posterior P3 and LPP amplitudes on the one hand, and self-reported increase of hunger (but not food craving) during the experiment (posttest-pretest) on the other hand. No significant correlations were found between ERP amplitudes and self-reported valence and arousability of the food and office pictures.

Discussion

This study investigated brain processing of food-related information in a passive exposure paradigm by means of event-related potentials (ERPs). In line with our expectations, significant larger P3 and LPP amplitudes were found for food stimuli as compared to office stimuli, which were particularly observed at posterior and central electrode clusters. Emotion and addiction researchers agree on the notion that long-latency ERP amplitudes at centro-parietal brain sites are modulated by the emotional and motivational relevance of stimuli. The enlarged ERP waves to food stimuli, which were found in the present study, can be interpreted to reflect the motivational relevance and reinforcing properties of palatable food items to humans. This finding is in accordance with the conclusions of recent neuroimaging studies, in which food-related stimuli were found to markedly increase cortical and

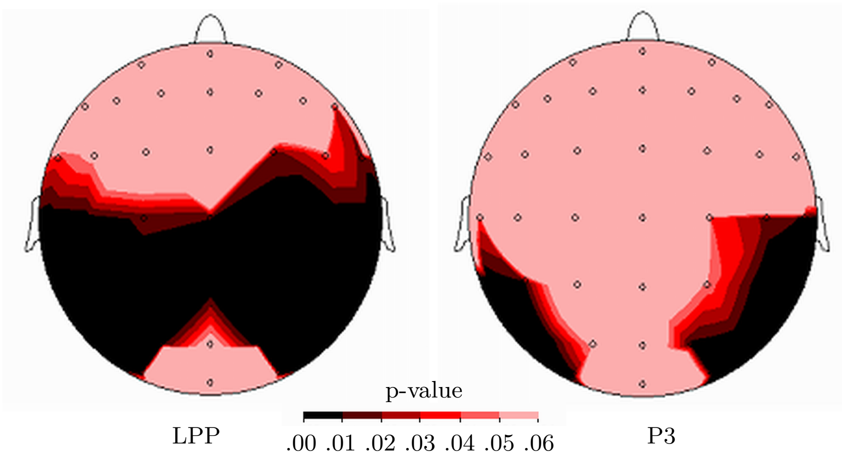


Figure 2: *Scalp distribution of main cue effects (p-values; food > office) for Late Positive Potentials (LPP; 400-800 ms) and P3 (300-400 ms).*

limbic brain activity as compared to neutral stimuli in normal-weight individuals, reflecting the natural reinforcing qualities of food (Killgore et al., 2003; Wang et al., 2004).

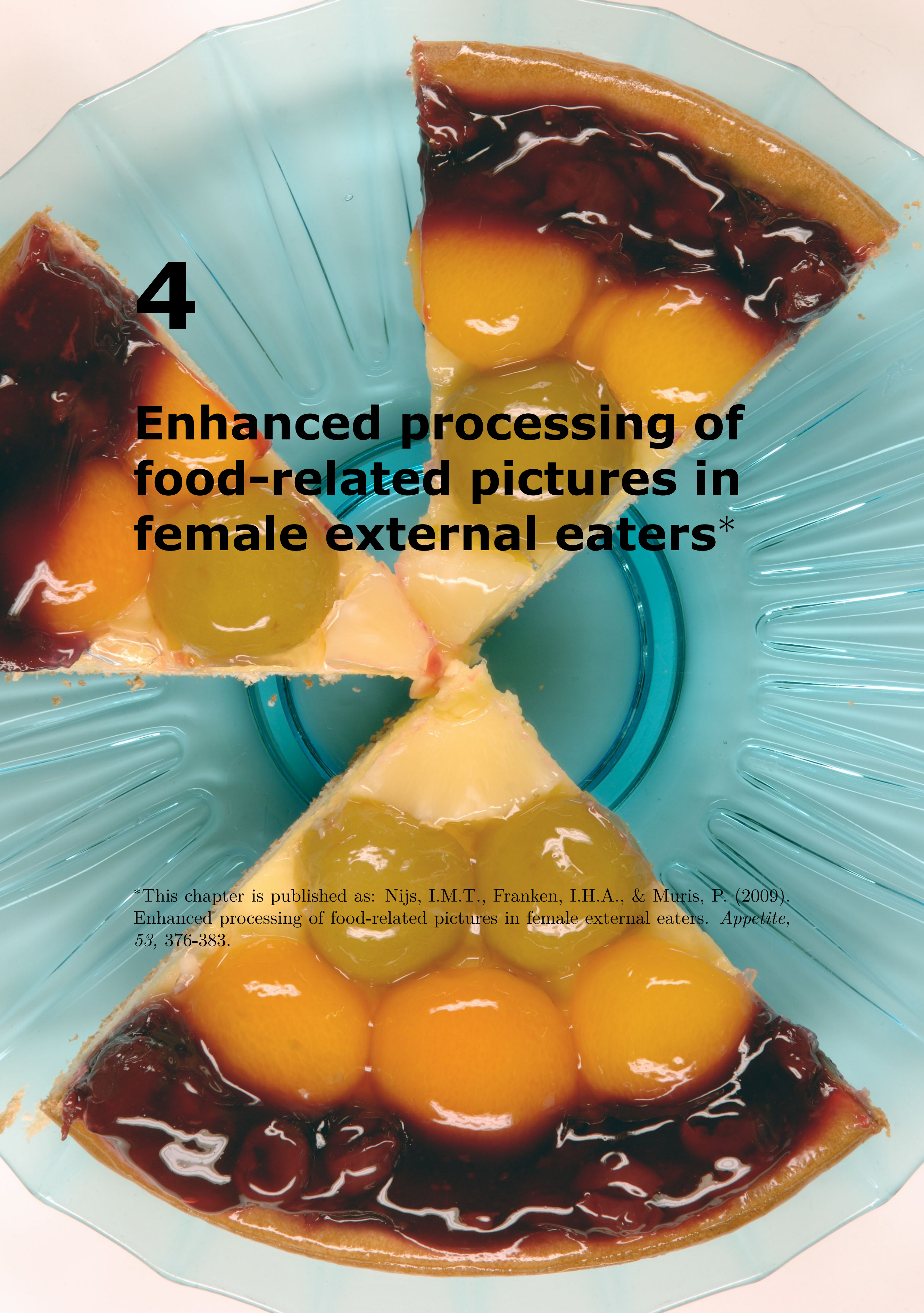
This is the first study that investigated differences in food-related information processing between obese and normal-weight individuals by means of ERPs. Contrary to our hypothesis, the obese group did not display larger ERP waves, when exposed to food stimuli, as compared to the normal-weight group. This suggests that the obese individuals of our sample did not process food information in a different way and neither attributed greater relevance or salience to food stimuli than the normal-weight participants. A similar pattern was observed in the valence and arousability ratings of the presented pictures: that is, evidence indicated that all participants similarly evaluated food pictures as more pleasant and arousing than control pictures. Further, both the obese and normal-weight group displayed a similar increase of food craving and hunger due to the exposure to food items. Interestingly, differences between obese and normal-weight individuals in the biological responsiveness towards food have been investigated before by means of more direct neuroimaging techniques. For instance, Karhunen et al. (2000) investigated cerebral responses to the exposure to food in obese binge-eating, obese non-bingeing and normal-weight women by means of single photon emission computed tomography (SPECT). Relative to a control stimulus, obese binge-eating women showed a greater increase in cerebral activity (at least in the frontal left hemisphere) when exposed to food than obese non-binge-eating and normal-weight participants. However, and most interesting in light of the present findings, the obese group without self-reported food binges did not differ from the normal-weight group in cortical brain responses to food. These findings suggest that obese individuals without explicit eating disorder symptoms do not respond differently to food cues as compared to normal-weight individuals. In a related study of the same research group, Karhunen, Lappalainen, Vanninen, Kuikka, and Uusitupa (1997) found differences in regional cerebral blood flow between healthy obese and normal-weight participants, when exposed to food. More specifically, increased brain activity as response to food (relative to a control stimulus) was found in the right parietal and right temporal brain regions of obese individuals, which was not the case for normal-weight controls. Importantly, the obese participants in this study had recently finished a weight-loss program and the increased cerebral response to food might have been due to the fact that they were still focused on controlling energy intake. Altogether, the present results seem to be in line with previous research indicating that obese persons do not habitually process food-related information in a different way than normal-weight persons. However, enhanced food information processing might occur in certain situations and states in which food becomes extra relevant to an (obese) individual, for example when dieting or suffering from an (over)eating disorder. Future ERP research should further investigate this issue.

As predicted, significant positive correlations were observed between self-reported increase of hunger during the experiment and P3 and LPP amplitudes, in particular at posterior sites. However, it should be admitted that such correlations not only emerged for EEG activity elicited by food cues, but also for brain activity elicited by office stimuli. Apparently, subjective feelings of hunger not just influenced the processing of food-related information, but seemed to have an effect on general information processing. As mentioned in the introduction of the present article, the effects of the hunger state on information processing has been the topic of a few studies, which generally yielded contradictory results. Perhaps the most relevant study in this perspective is the one by Hachl et al. (2003), who found differences between restrained (i.e., overeating-prone) and unrestrained individuals in the influence of hunger and satiety on information processing. Future research should further elucidate this issue, especially in relation to obesity.

Exploratively, we investigated hemispheric differences in ERP wave patterns to food- and office-related stimuli. We expected effects to be more pronounced in left-hemispheric electrode clusters, since activity in the left hemisphere is assumed to be associated with positive affect and approach tendencies (Davidson et al., 1990). However, in the present study we could not corroborate this hypothesis: no hemispheric differences were found in the ERP amplitudes of our participants. Studies using neuroimaging techniques have reported mixed results concerning hemispheric differences in cerebral activity during food exposure. For instance, the aforementioned study by Karhunen et al. (2000) reported increased blood flow to the exposure to food in the left hemisphere of obese binge-eating women, while in another study (Karhunen, Lappalainen, Vanninen et al., 1997) increased frontal responsiveness was situated in the right hemisphere of obese women. Hemispheric differences concerned in brain activity when exposed to food-related cues should be a topic of further studies.

The present investigation has some limitations. Late positive potentials are well-known to be modulated by the relevance of stimuli to the task an individual is subjected to. In the present study, it might have been too obvious that we were interested in EEG responsiveness to food pictures. For this reason, participants might have been more attentive to the food pictures than to the office-related pictures. To exclude task relevance effects, future ERP research should include a third emotionally charged picture category. In this way, it would be possible to determine whether enlarged ERP waves are really reflecting the emotional or motivational relevance of stimuli. Another limitation of this study is that we investigated an imbalanced number of male and female participants. Because men and women might respond differently to food, future studies should investigate sex differences in ERP reactivity to food-related cues. A third limitation concerns the fact that we had no control on participants' energy intake on the day of the experiment. There was an attempt to bring all participants in a similar hunger state by asking them to eat a light meal (like a sandwich) two hours before the start the experiment, but no recordings were made of what the participants exactly ate before the experiment, nor what they ate during the rest of the day. In addition, because of practical reasons, we also chose to conduct the experiment on different times of day. These might be reasons why both groups differed in initial hunger ratings.

In conclusion, the results of the present study suggest that food-related information is processed differently in the brain than neutral information. Yet, no differences were observed in cognitive and subjective food cue reactivity between obese and normal-weight individuals. This finding is adverse to conditioning models of overeating, which assume that there is an enhanced reactivity to food and food-related stimuli in individuals prone to overeating, such as obese individuals. However, as this is the first study to investigate food cue-elicited brain potentials in obese and normal-weight individuals, conclusions remain preliminary. It remains possible that obese individuals do display enhanced reactivity and motivation to food under certain conditions, such as when stressed, emotional, or food-deprived.



4

Enhanced processing of food-related pictures in female external eaters*

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Abstract

The main purpose of the present study was to investigate differences in the processing of food-related pictures between women with high and low scores on a scale of external eating. Electro-encephalographic brain activity was recorded, while participants were actively exposed to pictures of food items and control pictures. The amplitude of the P300 component of the even-related potentials was used as an index of motivation-related information processing. An enlarged P300 wave to food-related pictures was found in high external eaters as compared to low external eaters at several parieto-occipital electrode positions. No group differences in P300 amplitudes were found to neutral control pictures or pleasant, motivationally salient control pictures. It can be concluded that external eaters display an enhanced attentional processing of food-related information. The findings are discussed within an incentive sensitization model of overeating behavior.

Introduction

External eating is referred to as the tendency to eat when exposed to food-related cues, such as the sight, smell, or taste of food, even in the absence of physiological hunger. The concept of external eating has its origin in the externality theory of obesity, which was developed by Schachter in the 1960's (for a review, see Schachter, 1971). Schachter's initial theory posited that obese individuals are hypersensitive to external food-relevant stimuli, while being hyposensitive to internal signs of hunger and satiety. Nowadays, it is assumed that externality is a trait, which is not exclusively a characteristic of obese individuals, but might also be present in normal-weight individuals (e.g., Rodin & Slowocher, 1976). However, in the current obesogenic environment, in which attractive food is omnipresent and readily accessible, an external eating style might be an important vulnerability factor to overeat and to become obese (Rodin & Slowocher, 1976). For this reason, it is necessary to understand the mechanisms that underlie external eating.

As part of his externality theory, Schachter (1971; p.137) noted that obese individuals were "more efficient stimulus or information processors" than lean individuals. Generalizing this to external eating, it can be supposed that high external eaters demonstrate an enhanced processing of food-related information as compared to low external eaters. To our knowledge, only two studies directly examined food-related processing biases in high and low external eaters. In the first investigation, Johansson, Ghaderi, and Andersson (2004) employed a dot probe task and observed differences in the attentional processing of food words between normal-weight high and low external eaters. However, contrary to their hypotheses, high external eaters directed their attention away from food words (suggesting cognitive avoidance), whereas low external eaters directed their attention toward food words (suggesting attentional bias). A further study by Newman, O'Connor, and Conner (2008) relied on the Stroop paradigm to investigate the hypothesis that an attentional bias to food cues might be the core mechanism by which external eaters tend to increase food/snack intake under stress. In general, no straightforward support was found for the central hypothesis, but both high and low external eaters were found to demonstrate Stroop interference for food words, and this interference was largest in low external eaters in the no-stress condition. Altogether, both studies have not yielded clear evidence for the idea that external eating is associated with an increased processing of food cues. However, it should be noted that this previous research suffers from a number of limitations. First, the Stroop and the dot probe tasks that were used in these studies are both behavioral tasks, which means that they are rather indirect measures of attention allocation or information processing. Second, in both studies, the processing of food *words* was investigated. As Schachter (1971) already mentioned in his externality theory, obese individuals (or external eaters in general) will probably only be sensitive and responsive to cues that are sufficiently salient, such as pictures of food items (see also Pliner, 1973; Schachter, 1971). Third, the study by Johansson et al. (2004) did not assess hunger levels, although it has been demonstrated that an attentional bias to food might be more explicit in states of motivation for food, such as hunger (Mogg et al., 1998). The present study was set-up to overcome these limitations. Food-related information processing was assessed directly by means of event-related potentials (ERPs, i.e., electroencephalographic [EEG] brain activity) in high and low external eaters who were exposed to pictures of food items. All participants were brought in a comparable hunger state before the start of the experiment, and food craving levels were assessed at the beginning and at the end of the experiment.

ERPs can be defined as relatively time-locked positive and negative EEG waves that emerge when an individual is exposed to a stimulus. Of particular interest are the long-latency positive waves, which mainly consist of the P300 component and the Late Positive Potential (LPP). The P300 is a positive peak that appears, with maximal amplitudes at parietal scalp positions, at circa 300 milliseconds after the presentation of a stimulus (Picton, 1992; Polich & Kok, 1995). The P300 is the first of the so-called endogeneous ERPs, which reflect neuroelectric activity related to cognitive processes, such as attention allocation (Polich & Kok, 1995), and is the most widely explored ERP index in selective attention paradigms (Schupp et al., 2007). Emotion and addiction research has yielded convincing evidence to suggest that the amplitude of the P300 (and the following LPP) peak is modulated by the emotional content or the motivational significance of visual information that is processed (for reviews, see Olofsson et al., 2008; Schupp et al., 2006). For example, enlarged P300 (and LPP) waves have been found in response to (positive and negative) emotional material (e.g., Cuthbert et al., 2000; Schupp et al., 2000) or, in the case of addiction, to drug-related stimuli (e.g., Herrmann et al., 2000; Herrmann et al., 2001; Littel & Franken, 2007; Lubman et al., 2007), as compared to neutral stimuli. In general, it is assumed that the P300 (and LPP) amplitude reflects the activation of an underlying motivation system in the brain, which serves to allocate attention to relevant cues (Cuthbert et al., 2000). In addition, in addiction research, the amplitudes of the late positive waves, such as the P300 and LPP, seem to be fairly consistently positively correlated with self-report measures of drug craving (for a review, see Field et al., 2009), which confirms the idea that the P300 is an index of *motivated* attention. Moreover, a study investigating ERP responses to pictures of food in obese and normal-weight individuals (Nijs, Franken, & Muris, 2008) observed a positive relationship between P300 and LPP amplitudes and the subjective increase of hunger, suggesting that these late positive amplitudes may specifically reflect motivated attention to food, or the motivation to eat.

In the present study, the main hypotheses were as follows: first, it was expected that high external eaters display an enhanced processing of food stimuli, as indexed by a larger P300 amplitude response to pictures of food items, as compared to low external eaters. The P300 response to non-food-related (neutral and positive) pictures was hypothesized to be similar in both groups. Second, food cue-elicited P300 amplitudes were expected to correlate positively with self-report measures of food craving. Exploratively, we also investigated the hemispheric distribution of P300 amplitudes, as electro-cortical activation in the left hemisphere is believed to be associated with approach behavior towards emotionally pleasant stimuli (Davidson et al., 1990; Sutton & Davidson, 2000). So, it was expected that the amplitude of the P300 waves to appetitive food pictures (and positive emotional control pictures) would be larger at left-hemispheric than at right-hemispheric scalp sites.

Method

Participants

From a survey among undergraduate psychology students, normal-weight women were selected with high scores ($\geq$ 3.50) and low scores ((2.70) on the External Eating subscale of the Dutch Eating Behavior Questionnaire (DEBQ; van Strien et al., 1986), employing norm scores of Dutch female students as provided by the DEBQ manual (van Strien, 2004). All selected women were contacted by telephone, subjected to a brief screening interview, and, if they met inclusion criteria, invited to participate in the present study. Participants were excluded from participation if they reported (1) the current presence of a psychiatric, neurological or physical illness that might influence eating behavior, body weight, or EEG activity; (2) current use of any medication that might influence eating behavior, body weight, or EEG activity; (3) any recent participation in an intervention aimed at losing weight, such as a low calorie diet; and (4) a history of drug abuse.

Fifty-two individuals were selected and agreed to participate in this study. The data of three subjects were not included in the statistical analyses due to technical problems during the EEG recording (two high external eaters) or because a participant (low external eater) experienced severe nausea, which made it impossible to complete the experiment. Thus, the final sample consisted of 49 healthy, normal-weight females, of which 24 were low external eaters (mean DEBQ external eating score = 2.51, SD = .25) and 25 were high external eaters (mean DEBQ external eating score = 3.74, SD = .25; $t(47) = 17.39$, p (.001). The study protocol was approved by the ethical committee of the Institute of Psychology of Erasmus University Rotterdam. In return for their participation, participants received either course credits or a small financial reward.

Questionnaires

The DEBQ (van Strien et al., 1986) consists of 33 items that intend to assess external eating (10 items), emotional eating (13 items), and dietary restraint (10 items). Participants have to indicate on a Likert scale how often each item is applicable to them (1 = never; 5 = very often). The DEBQ has good psychometric properties (van Strien et al., 1986). In the present study, scores on the external eating subscale of the DEBQ were used because we wanted to compare ERP activity in high and low external eaters.

Because emotions and mood states are known to influence responses to food and the motivation to eat (e.g., Macht, 2008), pretest affect was assessed by means of the Positive Affect Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988), which consists of 10 items tapping positive affect (e.g., interested, excited) and 10 items tapping negative affect (e.g., distressed, upset). Participants are asked to rate on a scale from 1 (very slightly or not at all) to 5 (extremely) "how they are feeling at this moment". The PANAS has been demonstrated to possess good psychometric properties (Watson et al., 1988).

To investigate the relationship between P300 amplitudes and self-reported food craving, pretest and posttest food craving levels were assessed by means of the state version of the General Food Cravings Questionnaire (G-FCQ-S; Cepeda-Benito, Gleaves, Williams et al., 2000; Nijs et al., 2007), which is a 15-item self-report scale for measuring situational food craving and its underlying mechanisms. Briefly, the items refer to (1) an intense desire to eat; (2) anticipation of positive reinforcement that may result from eating; (3) anticipation of relief from negative states and feelings as a result from eating; (4) obsessive preoccupation with food or lack of control over eating; and (5) craving as a physiological state, cf., hunger. Individuals have to indicate on a Likert scale to what extent they agree with each statement on the moment of completing the questionnaire (1 = strongly disagree; 5 = strongly agree). The G-FCQ-S has been shown to possess good reliability and adequate construct and discriminant validity (Nijs et al., 2007).

Counting task

The present paradigm was based on a task developed by Schupp et al. (2007), and consisted of three subtasks, which were presented to the participants in a counterbalanced order. During each subtask the participants were exposed to a series of in total 450 pictures of three categories: there were 10 pleasant pictures (babies), 10 pictures of generally salient food items (e.g., chocolates, fries), and 10 neutral pictures (office items; e.g., stapler, scissors) which were each randomly displayed for 15 times on a computer monitor with a resolution of 1024 × 768 pixels. The presentation time of each picture was 500 ms, with an interstimulus interval of 0 ms. The food pictures were the main stimuli of interest, since differences in P300 responses between high and low external eaters were expected only to food stimuli. The pictures of office items were chosen as neutral (non-food-related) control stimuli, and baby pictures served as positively valenced (non-food-related) control stimuli.

The baby pictures were chosen from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005). The food and office pictures were used in a previous study, in which valence and arousal ratings were obtained by means of 100 mm visual analogue scales (ranging from 0 = very unpleasant/not at all arousing to 100 = very pleasant/very arousing; Nijs et al., 2008). From this previous study, the 10 food pictures were chosen that were generally evaluated as most pleasant (M = 69.96, SD = 13.98) and arousing (M = 58.15, SD = 20.44);

the office pictures were those which were evaluated as most neutral in valence (M = 46.20, SD = 15.82) and least arousing (M = 19.60, SD = 17.59).

The instruction for the three subtasks was to silently count the number of pictures of one category (i.e., food items, office items, or babies). The P300 component of the ERP waves is known to be more pronounced when one is asked to actively attend to (e.g., count) visual stimuli (Polich & Kok, 1995). Only the P300 responses to the pictures that were to be counted are reported in the present article.

After the tasks, VASs were used to check the valence (0 = very unpleasant; 100 = very pleasant) and arousability (0 = not at all arousing; 100 = very arousing) of various picture types. For this purpose, the participants received a file with printed versions of all pictures. For each picture, participants were asked to rate valence and arousability on two VASs.

Procedure

Participants were told that they participated in a study concerning ERP indices of attention. In order to bring all participants in a comparable hunger state and to preclude the direct effects of food intake on ERP responses (Geisler & Polich, 1992), participants were requested to eat a light meal (such as a sandwich) two hours before the start of the experiment, and subsequently to abstain from any food or caloric drinks until the experiment was finished.

Upon arrival in the laboratory, the experimental procedure was briefly explained and written informed consent was obtained from each participant. First, all participants completed self-report questionnaires to assess pretest affect and food craving, as well as to document the exact time they had eaten their last meal, their present body weight and length. Subsequently, participants were seated in a comfortable chair in a dimly-lit room and EEG electrodes were attached. Half of the participants (within each group) started with a cognitive task (data not reported here), followed by the counting tasks as described above. The other half of the participants (within each group) conducted the same tasks in the reversed order. After the tasks, participants were detached from electrodes and cap, and asked to fill in the questionnaires concerning posttest food craving, as well as the VASs to rate the valence and arousability of the various pictures.

EEG recording, EEG analyses and definition of P300

EEG signals were recorded at 32 scalp sites (positioned following the 10-20 International System), using an Active-Two amplifier system (Amsterdam; Biosemi) 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 a supraorbital and a suborbital position of the left eye (VEOG), and to the outer canthi of the left and right eye (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.

Off-line, data were referenced to the linked mastoids. EEG and EOG activity was filtered with a bandpass of 0.10-30 Hz (phase shift-free Butterworth filters; 24dB/octave slope). After ocular correction (Gratton et al., 1983), epochs (segments from 100 ms prestimulus to 500 ms poststimulus) that included an EEG signal exceeding $\pm 75\ \mu$V were eliminated. When more than 50% of the epochs contained artifacts, subjects were excluded from further analyses. The mean number of included food epochs was 142.22 ($SD = 8.48$), the mean number of office items epochs was 138.49 ($SD = 15.29$), and the mean number of included baby epochs was 150.94 ($SD = 10.68$). The mean 100 ms prestimulus period served as baseline. After baseline correction, ERP waves were determined for each participant, at each scalp site, for the three stimulus conditions. Based on visual inspection of the grand average waveforms (see Figure 1), the P300 of the counted stimuli was defined as the mean amplitude value (μV) within the 300-500 ms time window.

Statistical analyses

By means of independent samples *t*-tests, differences between high and low external eaters were evaluated with regard to BMI, age, and the elapsed time since last eaten (in minutes), as well as scores on the DEBQ subscales of external eating, emotional eating, and dietary restraint, and pretest scores of positive and negative affect. To evaluate main and interaction effects of food craving (G-FCQ-S total and subscale scores), 2 × 2 repeated measures analyses of variance (ANOVAs) were performed with group (high external/low external) as between-subjects factor and time (pretest/posttest) as within-subjects factor. To compare the valence and arousal ratings of the pictures, 2 × 3 repeated measures ANOVAs were carried out with group as between-subjects factor and stimulus category (office items/food/baby) as within-subjects factor. In case of significant effects, Bonferroni-corrected post-hoc *t*-tests were conducted.

To analyze the P300 data, repeated measures ANOVAs were performed with group as between-subjects factor, and stimulus category, hemispheric distribution (left/right), and electrode site as within-subjects factors. Since P300 is known to be maximal in parieto-occipital regions (Polich & Kok, 1995), and these are thus the main regions where significant effects were to be expected, 4 left-hemispheric parieto-occipital sites (P3, P7, PO3, O1) and 4 corresponding right-hemispheric parieto-occipital sites (P4, P8, PO4, O2) were included in the statistical analyses. As a result, a 2 (group) × 3 (stimulus category) × 2 (hemisphere) × 4 (electrode position) repeated measures ANOVA (with Greenhouse-Geisser corrected *df*'s; uncorrected *df*'s are reported) was carried out. In case of significant effects, post-hoc *t*-tests were conducted with Bonferroni adjustments for multiple comparisons. To evaluate the relationship between self-reported food craving and food cue-elicited amplitudes of the P300 ERP-component, Pearson correlations were computed.

Results

Pre-experimental differences and self-report measures

Independent samples t-tests revealed that there were no significant differences between high external eaters (M = 20.24, SD = 1.88) and low external eaters (M = 21.96, SD = 5.21) with regard to age, $t(47) = 1.52$, p (.05. Both groups did differ significantly with regard to BMI (based on self-reported body weight and length), $t(47) = 2.12$, $p < .05$. The mean BMI of the low external eaters (M = 21.45, SD = 1.90) was significantly higher than the mean BMI of the high external eaters (M = 20.24, SD = 2.12). Both groups also differed significantly with regard to DEBQ emotional eating, $t(47) = 3.79$, $p < .001$, and DEBQ dietary restraint, $t(47) = 2.36$, $p < .05$. High external eaters reported higher levels of emotional eating (M = 2.76, SD = .58 vs. M = 2.07, SD = .69), but lower levels of dietary restraint (M = 2.18, SD = .82 vs. M = 2.77, SD = .92) than low external eaters. Additional correlation analyses revealed that there was a strong positive correlation between external eating and emotional eating scores, $r = .58$, $p < .001$, whereas a significant negative correlation was found between external eating and dietary restraint scores, $r = -.37$, $p < .01$. Also strong correlations were found between BMI and dietary restraint, $r = .50$, $p < .001$, and between BMI and external eating, $r = -.31$, $p < .05$. The three eating styles and BMI appear to be strongly associated with each other, so that removal of the variance of emotional eating and/or dietary restraint and/or BMI would also remove considerable variance due to external eating. For this reason, it was decided not to include the variables of emotional eating, dietary restraint and BMI as covariates into further statistical analyses (Miller & Chapman, 2001).

No between-group differences were found with regard to positive affect, $t(46) = .25$, $p > .05$, and negative affect, $t(46) = -.24$, $p > .05$. Mean scores on positive affect were 27.46 (SD = 5.99) and 27.88 (SD = 5.79) for high and low external eaters, respectively. For negative affect, the mean score was 12.21 (SD = 2.32) for high external eaters and 12.04 (SD = 2.46) for low external eaters.

No between-group difference was found with regard to the elapsed time (in minutes) since last eaten, $t(47) = .67$, $p > .05$ (M = 109.20, SD = 29.85 for high external eaters; M = 114.38, SD = 23.74 for low external eaters). Mean pretest and posttest food craving scores (G-FCQ-S total score and G-FCCQ-S subscale scores) for high external eaters and low external eaters are displayed in Table 1. For the food craving total score, a main effect of time was found, $F(1,47) = 41.44$, $p < .001$. Participants generally reported significantly more food craving at posttest (after the exposure to pictures of food) as compared to pretest. In addition, a main effect was found of group, $F(1,47) = 5.51$, $p < .05$, which indicates that high external eaters generally tend to report stronger food craving as compared to low external eaters. The time × group interaction approached significance, $F(1,47) = 3.52$, $p = .07$. Post-hoc *t*-tests revealed that only at posttest there was a significant group difference ($p < .05$) in the food craving total score: high external eaters reported significantly stronger food craving than low external eaters after being exposed to pictures of food. With respect to the food craving subscales, a similar main time effect (i.e., posttest > pretest) was found for four of the subscales, namely an intense desire to eat, $F(1,47) = 28.84$, $p < .001$, the anticipation of relief from negative states or feelings as a result from eating, $F(1,47) = 13.76$, $p = .001$, preoccupation with food or lack of control over eating, $F(1,47) = 13.33$, $p = .001$, and craving as a physiological state (hunger), $F(1,47) = 48.43$, $p < .001$. In addition, a main group effect (i.e., high > low external eaters) was found for the subscales desire to eat, $F(1,47) = 9.17$, $p < .01$, and anticipation of positive reinforcement as a result from eating, $F(1,47) = 5.76$, $p < .05$. No significant time × group interaction effects were found for the food craving subscales.

Main effects of stimulus category were found for the valence, $F(1,47) = 54.13$, $p < .001$, and arousability, $F(1,47) = 96.48$, $p < .001$, of the pictures. Post-hoc *t*-tests revealed that food pictures and baby pictures were generally evaluated as equally pleasant (*p*s > .05; *M*food = 63.10, *SD* = 18.71 and *M*baby = 65.54, *SD* = 18.12 for high external eaters; *M*food = 56.15, *SD* = 12.19 and *M*baby = 58.95, *SD* = 16.93 for low external eaters) and arousing (*p*s > .05; *M*food = 48.07, *SD* = 22.05 and *M*baby = 53.16, *SD* = 24.27 for high external eaters; *M*food = 46.41, *SD* = 15.66 and *M*baby = 51.03, *SD* = 19.74 for low external eaters). However, food pictures and baby pictures were evaluated as significantly more pleasant (*p*s < .001; *M*office = 40.99, *SD* = 13.07 for high external eaters, *M*office = 38.10, *SD* = 17.69 for low external eaters) and more arousing (*p*s < .001; *M*office = 10.30, *SD* = 14.68 for high external eaters, *M*office = 7.99, *SD* = 12.98 for low external eaters) than office items pictures. No main effects of group or interaction effects of group and stimulus category were found for valence and arousal ratings.

P300 amplitude

The average values of the P300 waves' amplitudes (in μV), elicited by pictures of food, office items, and babies at 4 left-hemispheric (P3, P7, PO3, O1) and 4 right-hemispheric (P4, P8, PO4, O2) parieto-occipital scalp positions, for high external eaters and low external eaters, are displayed in Table 2.

Most interestingly, a significant fourfold interaction effect, stimulus category × electrode position × hemisphere × group, was found, $F(1,47) = 2.89$, $p < .05$. Post-hoc (Bonferroni-corrected) contrast analyses and*t*-tests were conducted to unravel this fourfold interaction. The nature of the cue effect appeared to be dependent on the electrode position and on group: in both groups the P300 amplitude at electrodes P7 and P8 was similar for baby pictures and food pictures (*p*s > .05), while the P300 amplitude at these electrode positions was significantly smaller

Table 1: *Mean pretest and posttest food craving (G-FCQ-S) scores in high external eaters (N = 25) and low external eaters (N = 24)*

		High external		Low external	
		M	*SD*	*M*	*SD*
G-FCQ-S total score	Pretest	33.28	7.51	29.50	8.20
	Posttest	41.48	11.86	34.00	7.99
Desire	Pretest	8.00	1.83	6.29	2.14
	Posttest	9.48	2.82	7.50	2.32
Positive outcome	Pretest	7.24	2.20	5.92	2.10
	Posttest	7.76	2.76	6.08	2.17
Relief from negative state	Pretest	6.60	2.06	6.38	2.60
	Posttest	8.08	2.53	6.96	2.53
Loss of control	Pretest	4.96	1.84	4.75	1.67
	Posttest	6.80	3.44	5.46	2.25
Hunger	Pretest	6.48	2.08	6.17	2.44
	Posttest	9.36	3.07	8.00	2.89

Note. G-FCQ-S = General Food Cravings Questionnaire-State, Desire = G-FCQ-S subscale intense desire to eat, Positive Outcome = G-FCQ-S subscale anticipation of positive reinforcement as a result from eating, Relief from Negative State = G-FCQ-S subscale anticipation of relief from a negative state or negative feelings as a result from eating, Loss of Control = G-FCQ-S subscale preoccupation with food or lack of control over eating, Hunger = G-FCQ-S subscale craving as a physiological state.

for office pictures ($ps < .001$). In high external eaters, a similar pattern (i.e., P300 baby = P300 food > P300 office) was also observed at O1 and P4, while at PO3, PO4, and O2 baby pictures elicited significantly larger P300 peaks than food pictures ($p < .05$), which in turn elicited significantly larger P300 peaks than office pictures ($p < .05$). This latter pattern (P300 baby > P300 food > P300 office) was seen at O1, O2, and PO4 in low external eaters. In low external eaters, the pattern at P3, P4, and PO3 was as follows: P300 peaks to baby pictures were significantly larger as compared to food and office pictures ($ps < .05$), while the P300's elicited by food pictures and office pictures were similar ($ps > .10$). This pattern (P300 baby > P300 food = P300 office) was only seen at electrode position P3 in high external eaters. These results are suggestive of a general pattern, in which high external eaters demonstrate similar P300 amplitudes to pictures of food and pictures of babies, which are significantly larger than P300 amplitudes to pictures of office items. In low external eaters, on the contrary, P300 responses to pictures of food seem to be generally smaller than P300's to baby pictures, and they even tend to be similar to P300 peaks elicited by pictures of office items

Significant hemispheric differences were only found for P300 elicited by pictures of food, and only at P7/P8 in high external eaters ($p < .01$). The P300 amplitude elicited by food pictures was larger at the right-hemispheric electrode (P8) as compared to the left-hemispheric electrode (P7).

Table 2: *Mean P300 amplitudes in μV (standard deviations), elicited by pictures of food, office items, and babies in high external eaters (N = 25) and low external eaters (N = 24) at left-hemispheric (P7, P3, PO3, O1) and right-hemispheric (P8, P4, PO4, O2) parieto-occipital scalp positions. Marginally significant ($_* = p < .10$) to significant ($_{**} = p < .05$) group differences (high external > low external) were found, exclusively in the P300 response to food pictures.*

	High External			Low External		
	Food	Office	Baby	Food	Office	Baby
P7	3.89 (1.56)	1.97 (1.51)	3.28 (1.81)	3.42 (1.22)	1.32 (1.44)	3.51 (1.65)
$P3_*$	4.42 (1.46)	3.68 (2.19)	5.50 (2.01)	3.60 (1.83)	3.34 (2.29)	5.62 (1.84)
$PO3_*$	4.86 (2.13)	3.44 (2.13)	6.07 (2.34)	3.89 (1.95)	3.14 (2.30)	6.01 (2.15)
$O1_*$	4.32 (2.33)	2.36 (1.80)	5.09 (2.35)	3.04 (2.27)	2.04 (2.24)	4.90 (2.41)
$P8_{**}$	4.89 (1.97)	1.62 (2.25)	4.02 (1.61)	3.79 (1.41)	1.48 (1.78)	3.51 (1.99)
P4	4.62 (1.95)	3.31 (2.01)	5.41 (2.46)	3.78 (2.12)	2.97 (2.21)	5.35 (2.11)
PO4	4.91 (2.26)	3.22 (2.11)	6.16 (2.47)	4.21 (2.39)	2.78 (2.52)	5.59 (2.13)
O2	3.98 (2.89)	2.03 (2.02)	5.17 (2.44)	3.57 (2.28)	2.01 (2.33)	4.72 (2.40)

The group effect -which is most relevant to this study- was only significant for P300 elicited by food pictures at P8 ($p < .05$). There was a trend for a significant group effect, and again this was only observed for food pictures, at O1 ($p = .06$), P3 ($p = .09$) and PO3 ($p = .10$). At all these electrode positions high external eaters showed larger P300 peaks to food pictures as compared to low external eaters.[1] No group differences were found in the P300 peaks to office pictures and baby pictures, at none of the electrode positions. Illustratively, Figure 1 displays the grand average waveforms at the left-sided scalp position PO3 for the three cue categories (food, office items, babies) in high external eaters and low external eaters.

Correlational analyses

As can be seen in Table 3, a number of positive correlations were observed between food cue-elicited P300 amplitudes on the one hand, and self-reported pretest and posttest food craving scores on the other hand. Results indicated that there were significant correlations between posttest G-FCQ-S total score and food cue-elicited P300 peaks at PO3. When looking at the correlations between G-FCQ-S subscale scores and P300's, it appears that pretest as well as posttest 'desire' subscale scores were positively linked to P300 amplitudes, at both left-hemispheric and right-hemispheric scalp positions. The P300 peak at PO3 seems to be the best correlate of self-reported food craving, since most consistent (positive) correlations were found, not only with pretest and posttest desire for food, but also with posttest "hunger", and the posttest tendency to lose control over eating behavior.

[1] Because of the observed strong positive correlation between DEBQ external eating and emotional eating scores, the data were also analyzed for high and low emotional eaters. No differences in P300 amplitudes, neither to food-related pictures nor to non-food-related control pictures, were found between high and low emotional eaters. This supports the idea that an enhanced attentional processing of food-related stimuli is a characteristic of high external eaters.

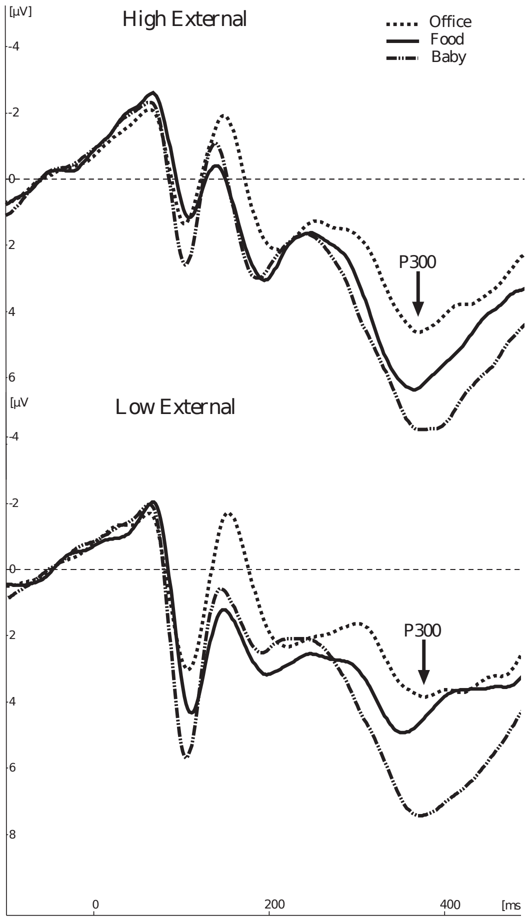

Figure 1: *Grand average event-related potential waveforms at parieto-occipital scalp position PO3 elicited by pictures of food, office items, and babies in high external eaters (n = 25) and low external eaters (n = 24).*

Discussion

The present study was designed to investigate whether an enhanced processing of food-related information -as assessed by means of the P300 ERP-component- would be characteristic of women with an external eating style. An enlarged P300 amplitude in response to pictures of food was observed in high external eaters as compared to low external eaters on several parieto-occipital electrode positions. This group difference was not seen in the P300 waves elicited by pictures of office items and babies. This shows that the P300 effect in external eaters was specific for food pictures and not motivationally salient pictures in general. Moreover, in high external eaters P300 amplitudes to food seem to be generally similar to P300's to baby pictures, or larger than P300 amplitudes to pictures of office items. In low

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Table 3: *Pearson correlation coefficients between food cue-elicited P300 amplitudes at left-hemispheric (P3, PO3, O1, P7) and right-hemispheric (P4, PO4, O2, P8) parieto-occipital scalp positions on the one hand, and pretest and posttest food craving scores (G-FCQ-S total score and G-FCQ-S subscale scores) on the other hand (N = 49).*

		P3	PO3	O1	P7	P4	PO4	O2	P8
G-FCQ-S total score	Pretest	.23	.22	.19	-.01	.18	.21	.15	.21
	Posttest	.28	.31$_{*}$	.25	.08	.21	.28	.18	.19
Desire	Pretest	.38$_{**}$	.42$_{**}$	.38$_{**}$	.10	.31$_{*}$	.37$_{**}$	.25	.31$_{*}$
	Posttest	.26	.31$_{*}$	.30$_{*}$	.08	.21	.28	.18	.23
Loss of control	Pretest	.19	.17	.13	.00	.19	.16	.13	.20
	Posttest	.25	.31$_{*}$	.28	.16	.17	.29$_{*}$	.29$_{*}$	.18
Hunger	Pretest	.18	.21	.20	.03	.15	.24	.27	.28
	Posttest	.24	.29$_{*}$	.22	.08	.20	.27	.19	.24

Note. G-FCQ-S = General Food Cravings Questionnaire-State, Desire = G-FCQ-S subscale intense desire to eat, Loss of Control = G-FCQ-S subscale preoccupation with food or lack of control over eating, Hunger = craving as a physiological state.
$_{*}$ $p < .05$, $_{**}$ $p < .01$

external eaters, on the contrary, P300 amplitudes to pictures of food seem to be rather similar to P300's to pictures of office items, or smaller than P300 amplitudes to pictures of baby items. The amplitude of the P300 peak is believed to reflect the activation of the brain's motivation system, which is assumed to direct attention to motivationally relevant cues. So, these results suggest that in high external eaters the brain's motivation system is activated and attention is allocated to food-related stimuli and highly positive, arousing stimuli to a similar degree. In low external eaters, however, the brain's motivation system and following attention allocation seems to be activated as much or just a little bit more by pictures of food as by pictures of neutral, non-arousing stimuli. Surprisingly, this difference was not seen in the self-report ratings of the valence and arousability of the pictures: all participants evaluated baby and food pictures as equally pleasant and arousing, and significantly more pleasant and arousing than pictures of office items.

After the experiment high external eaters reported significantly more food craving than low external eaters, while there was no group difference in pretest food craving reports. This indicates that high external eaters displayed stronger subjective craving in response to the exposure to food cues as compared to low external eaters. It matches with the idea that in high external eaters the tendency to eat is more controlled by the exposure to external food-related cues than in low external eaters.

The results of the present study support the idea that the P300 amplitude elicited by visual stimuli can be seen as an index of motivation: overall, positive correlations were found between food cue-elicited P300 amplitudes and self-reported food craving. Similar results were found previously in a study that investigated food-related information processing in obese and normal-weight individuals: P300 and LPP amplitudes at posterior scalp positions correlated positively with the self-reported increase of hunger during the exposure to pictures of food (Nijs et al., 2008). Several studies among substance dependent patients have demonstrated a similar association between craving and the amplitude of P300-like slow positive waves (for an overview, see Field et al., 2009).

To our knowledge, this is the first study that investigated differences in food-related information processing in high and low external eaters by means of ERPs. As mentioned in the introduction, there have been some studies that investigated food-related attentional biases in high and low external eaters by means of behavioral measures such as the Stroop and dot-probe task, which have generally yielded rather inconsistent results. That is, Johansson et al. (2004) demonstrated that low external eaters were directing attention towards food words, while high external eaters directed attention away from food words, whereas Newman et al. (2008) found an attentional bias for food words in both high and low external eaters, which, however, was more pronounced in low external eaters. The present results do not match these previous data. In line with hypotheses, high external eaters generally displayed an enhanced attentional processing of pictures of food (as indexed by an enlarged P300 amplitude) as compared to pictures of neutral items. This attentional 'bias' toward food was less obvious in low external eaters. To reconcile these diverging findings, it can be argued that ERPs are a more direct indication of information processing and the allocation of attentional resources than the behavioral reaction time tasks that have been employed in previous research. Moreover, in the present study pictures of food were used, which are assumed to be more salient than food-related words, and thus might elicit stronger responses.

Enlarged P300 amplitudes are also observed to negative emotional material as compared to neutral material (Olofsson et al., 2008; Schupp et al., 2006). One might argue that the enlarged P300 amplitudes to food, which were found in high external eaters in the present study, as compared to low external eaters, might also reflect a negative attitude towards food and a tendency to avoidance behavior, which would partly confirm the dot probe task results of the study of Johansson et al. (2004). However, the self-report ratings of the valence and arousability of the pictures make it clear that the women who participated in the present study had a rather positive attitude towards the pictures of food. Moreover, P300 amplitudes correlated positively with craving scores, and high external eaters reported stronger craving after the exposure to the food pictures than low external eaters, suggesting a stronger tendency to approach behavior in the former group.

Finally, hemispheric differences in P300 amplitudes were explored. It was hypothesized that P300 peaks to food would be enhanced in left-hemispheric scalp positions relative to right-hemispheric scalp positions, because the left hemisphere is believed to be associated with positive emotions and approach behavior (e.g., Davidson et al., 1990). Results were inconclusive: on the one hand larger P300 responses to food were found in right-positioned electrodes as compared to left-positioned electrodes in high external eaters. On the other hand, more pronounced positive correlations were found between food craving scores and left-sided P300 amplitudes (particularly P300 at PO3), than between food craving scores and right-sided P300 amplitudes. There are other studies reporting mixed results concerning hemispheric differences in neural food cue-reactivity (e.g., Karhunen, Lappalainen, Vanninen et al., 1997; Karhunen et al., 2000) and this could be a topic for future studies.

In conclusion, the results of the present study indicate that women with an external eating style process food-related information differently and have a stronger food cue-elicited craving response as compared to women who report to be not (or just a little) controlled by external food cues in their eating behavior. These results indirectly support an incentive sensitization model for eating behavior in external eaters. In short, incentive sensitization theories (which have their origin in addiction) assume that a sensitization of the brain reward system leads to strong conditioned dopaminergic responses when exposed to rewarding cues, by which these rewards become highly salient and *attention-grabbing*. As a consequence, attention is automatically directed to rewarding stimuli in the environment, followed by strong craving, approach behavior and the tendency to consume the reward (Berridge, 2007; Franken, 2003; Franken et al., 2005; Robinson & Berridge, 1993,2001). The results of the present study suggest that incentive sensitization-like mechanisms might play a role in the eating behavior of external eaters. In the current western environment, in which we are continuously exposed to attractive, rewarding food, these individuals might be peculiarly vulnerable to overeat and become obese. However, it should be emphasized that the results of the present study were subtle: differences in food cue-elicited P300 amplitudes between high and low external eaters were only found on a limited number of electrodes, so there was no overall stimulus category × group effect. In addition, the effects that were found were rather subtle and thus amenable to discussion. Replication studies are needed to corroborate the present findings. It should also be noted that the food intake of the participants was not assessed in the present study. Although external eaters report that they are inclined to eat in response to food cues, it is still unclear to what extent they actually do (over)eat after food cue exposure. In the present study the mean BMI of the high external eaters was within a healthy range and even significantly smaller than the mean BMI of the low external eaters. This indicates that, next to food cue-reactivity processes, various other (e.g., decision-making-related) factors are involved in determining actual food intake and body weight. Future studies should include an eating behavior measure (such as a bogus taste task) following the exposure to pictures of food in order to investigate whether differences between high and low external eaters in P300 amplitude and self-reported food craving are also reflected in differences in food intake.

5

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 et al., 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 et al., 1998; Placanica, Faunce, & Soames Job, 2001; Stockburger et al., 2008; Stockburger et al., 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 a Stroop interference of 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 overweight adolescents. Finally, Nijs et al. (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 hours, 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 milliseconds after the presentation of a stimulus (Picton, 1992; Polich & Kok, 1995). The P300 amplitude reflects electrophysiological activity related to conscious attention allocation (Cuthbert et al., 2000), and is the most widely explored ERP index in selective attention paradigms (Olofsson et al., 2008; Schupp et al., 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 food craving and food intake are triggered by the exposure to external food cues is not new (Herman & Polivy, 2008; Sobik, Hutchison, & Craighead, 2005). In the 1960's, 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, food craving, 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 et al., 2004; Newman et al., 2008; Nijs, Franken, & Muris, 2009). 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 (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 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), participants of only one gender, i.e., females, 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-hour 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]; van Strien et al., 1986), which was completed at home. Participants were asked to fast for 17 hours 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 kilocalories. 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 DEBQ (van Strien 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 (van Strien 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 et al., 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 $\times$ 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 of 3 subjects (all normal-weight, of which 2 were satiated) because of calibration difficulties. No fixation data were found in 1 subject (normal-weight satiated). 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 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 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 x 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 was 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 participant (overweight/obese hungry) 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 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 seconds 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 2.6) 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 0.10-30 Hz (phase shift-free Butterworth filters; 24dB/octave slope). After ocular correction (Gratton et al., 1983), epochs (segments from 200 ms prestimulus to 800 ms poststimulus) that included an EEG signal exceeding ±75 μV were eliminated. Data of 2 subjects (both normal-weight, 1 hungry and 1 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 Figure 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 minutes 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 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 *df*'s (uncorrected *df*'s 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, $p < .001$.

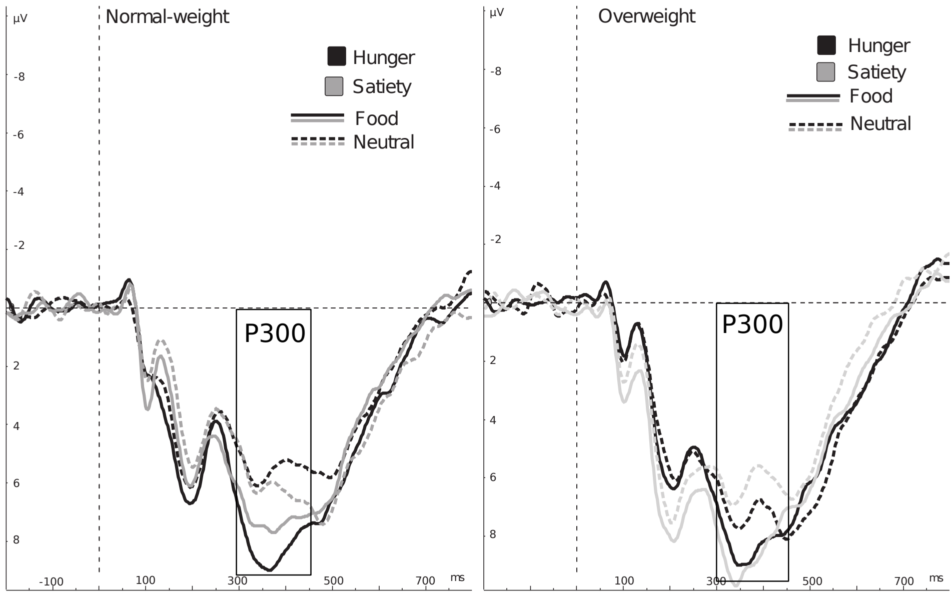

Figure 1: *Average ERP waveforms of the posterior electrode cluster, elicited by food and neutral pictures, as a function of weight group and condition*

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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 x 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 $\times$ 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.

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		Normal-weight	
	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.

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).

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

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

	Overweight/Obese		Normal-weight	
	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.

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

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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 (224.8)	363.32 (210.3)	468.26 (273.3)	404.82 (223.8)
Gaze duration office	314.88 (218.1)	315.80 (183.5)	310.82 (182.4)	329.97 (195.1)
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 (202.5)	373.92 (317.3)	466.32 (156.0)	381.07 (264.2)

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.

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 x condition interaction was not statistically significant. Nevertheless, as can be observed in Figure 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.

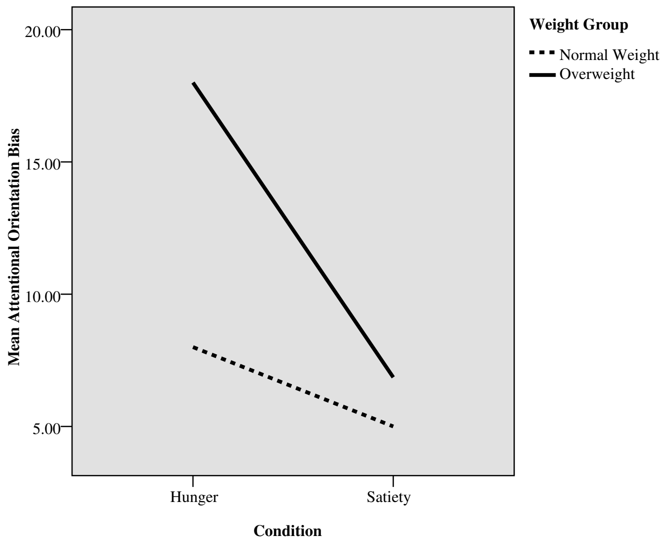

Figure 2: *Mean attentional bias as obtained during the 100 ms trials of the visual probe task as a function of weight group and condition.*

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 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[2] was found, $F(1,60) = 7.79$, $p <.01$, see Figure 3. Post-hoc t-tests showed that only in normal-weight females P300-related attentional bias to food was significantly enlarged

[2] 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.

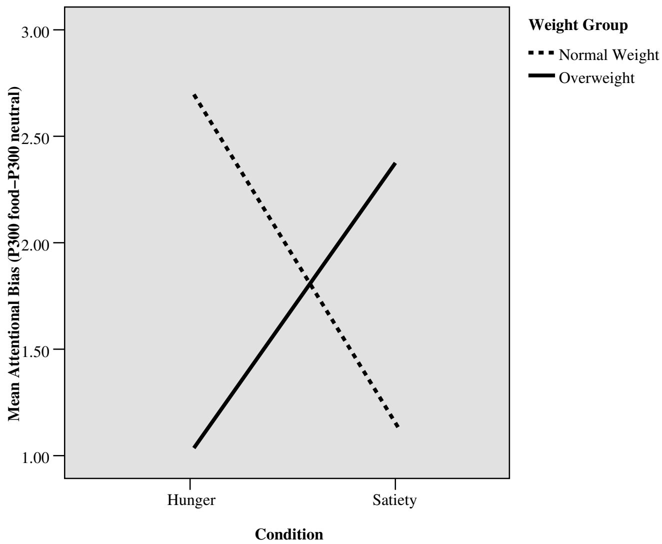

Figure 3: *Mean attentional bias scores, as indexed by P300 difference amplitudes, as a function of weight group and condition.*

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 Figure 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 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

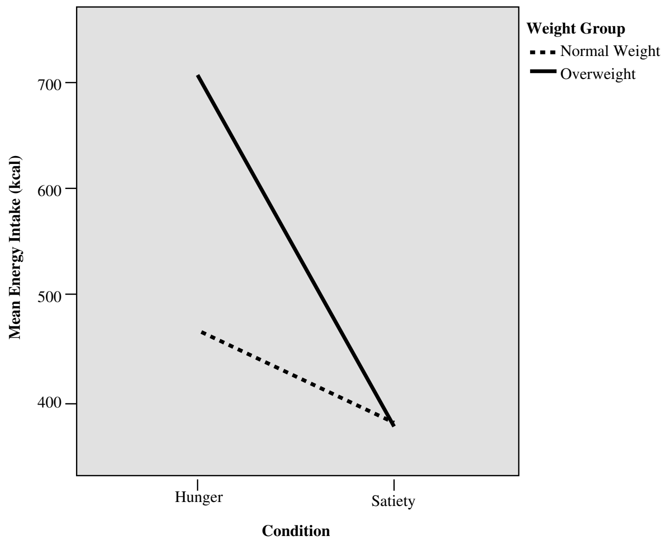

Figure 4: *Mean energy (kcal) intake as a function of weight group and condition.*

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.

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

Discussion

The main objective of the present study was to examine differences in attention to food pictures between normal-weight 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, Zetteler, & 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, & 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 this 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 of 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, overweight/obese participants who were in a state of hunger did not engage substantially more attentional resources in the processing of food-related pictures than neutral control 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 reduced specifically 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, 2006). 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., 2009). 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 (Castellanos et al, 2009; Braet & van Strien, 1997) and no differences

(Caccialanza et al., 2004) have been reported in DEBQ measures of external and emotional eating. Similar 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 1950's that in normal-weight individuals, physiological 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 et al., 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 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 17hr 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) for 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, and 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, 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, the present study tested cognitive/subjective/behavioral aspects of an 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 can not be concluded whether the enhanced sensitivity to hunger in overweight/obese individuals is innate or acquired (possibly due to multiple dieting). It is 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 et al., 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. However, it should be emphasized that from the present study results only preliminary conclusions can be formulated, as replication studies are necessary.

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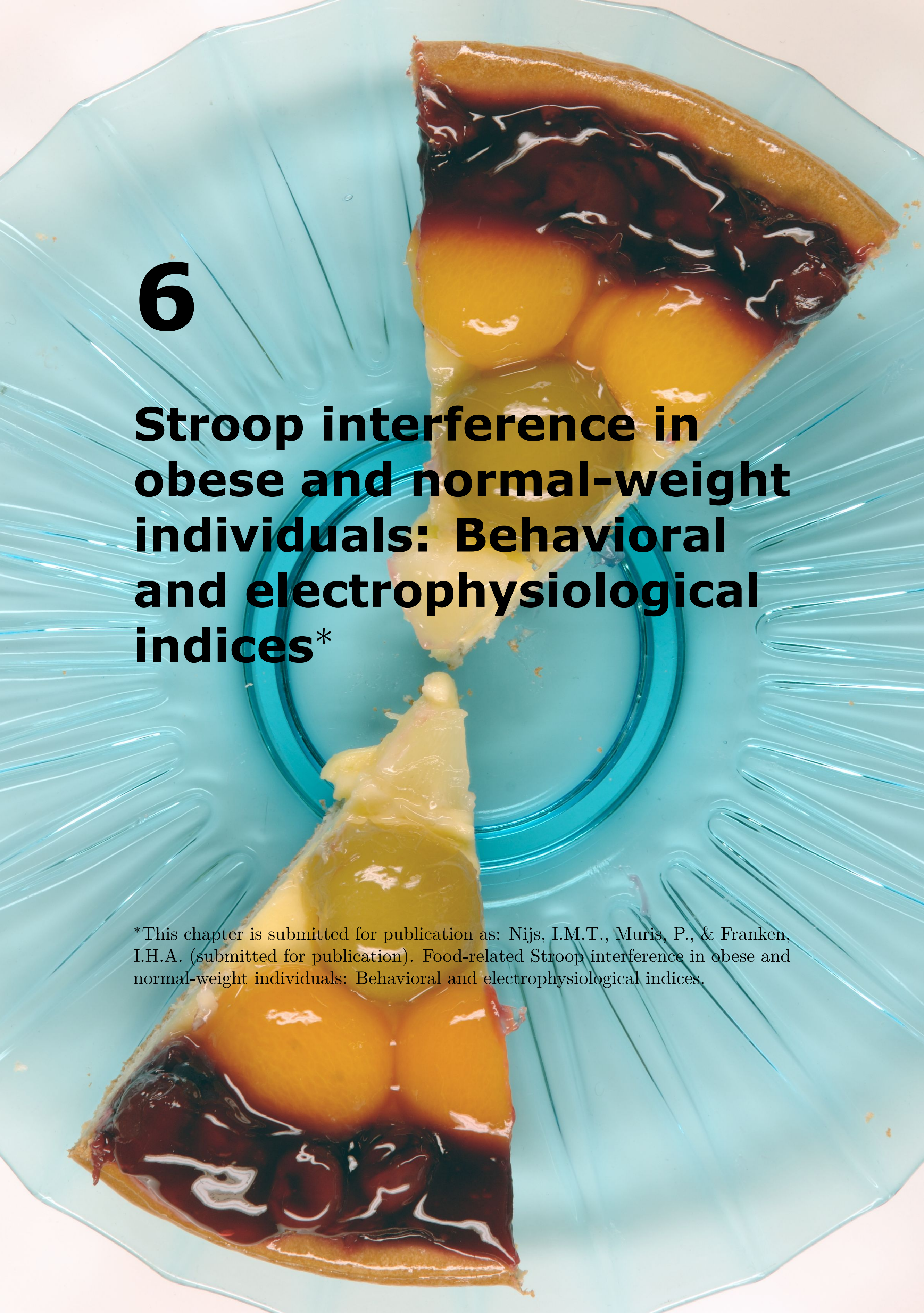

6

Stroop interference in obese and normal-weight individuals: Behavioral and electrophysiological indices*

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6

Abstract

The primary objective of the present study was to investigate differences in the attentional processing of food-related words in a Stroop task, as assessed by means of behavioral (reaction times) and electrophysiological (P200 and P300 amplitudes) indices, between obese and normal-weight individuals. Results revealed a P200 bias to food-related words in obese participants, which was not seen in normal-weight participants. This indicates that, in an early, automatic stage of information processing, obese participants already tend to engage more attention towards food-related stimuli than to neutral stimuli. With respect to reaction times and P300 scores, as alleged indices of more conscious maintained attention, a general food-related bias was observed, with no between-group differences. Further, in the obese group, significant positive correlations were observed between the food-related reaction time bias, food craving, and external eating, whereas in the normal-weight group, food craving scores correlated positively with P200/P300 amplitude biases. It can be concluded that obese individuals display an enhanced automatic, preconscious attentional processing of food-related stimuli, and this can be regarded as an initial expression of a greater responsiveness to food cues. In the current food-abundant environment, such a heightened food cue-responsiveness might contribute substantially to the tendency to overeat.

Introduction

The emergence of the obesity epidemic during the past decades has gone hand in hand with changes in the environment of Western(ized) societies. The most obvious environmental change, which seems to be associated with increased obesity prevalence, is the grown availability of energy-dense food. The abundant presence of food seems to stimulate an excessive food consumption (Westerterp & Speakman, 2008). Moreover, an examination of shifts over time in the distribution of body mass index (BMI) has demonstrated that the high obesity statistics of today are not only the result of a larger number of people having become overweight, but also, and particularly, of heavy people having become more heavy (Flegal & Troiano, 2000). This suggests that especially overweight individuals are susceptible to overeat and gain weight in response to environmental food temptations.

For obesity researchers it is a challenge to develop effective obesity treatments, and therefore it seems necessary to gain more insight in the mechanisms that are involved in the regulation of responses to food-related stimuli. Neuroimaging studies have yielded more knowledge about the brain substrates that seem to play a role in food-related cue-responsivity (e.g., Rothemund et al., 2007; Stoeckel et al., 2009; Stoeckel et al., 2008). Of particular interest is the involvement of the mesolimbic dopaminergic reward system in motivational and hedonic responses to food reward (Berridge, 2009; Volkow et al., 2002). Specific addiction-like deficits in the striatal dopaminergic system of obese individuals have been observed (Geiger et al., 2009; Stice et al., 2008; Volkow & Wise, 2005; Wang et al., 2001). Neurocognitive models of addiction emphasize a direct association between an aberrant dopamine release in the brain's reward system and sensitized cognitive, subjective, and behavioral responses to drug-related stimuli (Franken, 2003; Franken et al., 2005; Robinson & Berridge, 1993). More precisely, there is growing evidence that suggests that substance-dependent individuals are characterized by an attentional bias to drug-related cues, which has a mutually excitatory relationship with the subjective experience of drug craving, and ultimately leads the individual to seek out and self-administer the substance of preference (for reviews, see Field & Cox, 2008; Field et al., 2009). In a similar vein, given the neurobiological and behavioral similarities between obesity and addiction (Volkow & Wise, 2005), it can be hypothesized that obese individuals demonstrate an enhanced attentional bias towards food-related stimuli, and experience enhanced food craving as compared to normal-weight individuals. This enhanced food cue-reactivity might play a central role in the maintenance of the weight problem and in the inability to comply with weight-loss diets.

The traditional way to assess attentional biases is by means of behavioral measures, such as the Stroop task (Stroop, 1935; Williams, Mathews, & MacLeod, 1996). In a food-modified Stroop task, differences in reaction times to the font color of food-related and neutral control words are assumed to reflect differences in attentional engagement. More specifically, color-naming reaction times to food-related words are assumed to be slower than reaction times to neutral words because the food-related content of the words draws the attention and distracts the participant from the primary task, i.e., color-naming. In psychological research, the Stroop task is recognized as a sound measure of attentional bias, and has been frequently used to get insight in the attentional processing of various stimuli, related to different forms of psychopathology (e.g., Dobson & Dozois, 2004; Johansson, Ghaderi, & Andersson, 2005; Robbins & Ehrman, 2004; Williams et al., 1996).

The Stroop task is called an *indirect* measure of attention, because the attentional bias is inferred from participants' performance on a primary reaction time task (i.e., color-naming). A more direct measure of attentional processing is, for instance, the recording of electroencephalographic (EEG) brain activity during stimulus exposure, i.e., event-related potentials (ERPs). ERPs can be defined as time-locked EEG waves that emerge when an individual is exposed to stimuli. Of particular interest are the long-latency positive waves, such as the P300 component. The P300 is a positive peak that emerges at circa 300 milliseconds after stimulus onset, and is located all over the scalp, with maximal amplitudes in the parietal scalp area (Picton, 1992; Polich & Kok, 1995). The P300 is the first of the so-called endogeneous ERPs, which reflect neuroelectric activity related to cognitive processes, such as attention allocation (Polich & Kok, 1995), and is the most widely explored ERP index in selective attention paradigms (Schupp et al., 2007). Emotion and addiction research has yielded convincing evidence that the amplitude of the P300 (and the following Late Positive Potential [LPP] peak is modulated by the emotional content or the motivational significance of the visual information that is processed (for reviews, see Olofsson et al., 2008; Schupp et al., 2006). For example, enlarged P300 (and LPP) waves have been found in response to emotional material (e.g., Cuthbert et al., 2000; Schupp et al., 2000) or, in the case of addiction, to drug-related stimuli (e.g., Herrmann et al., 2000; Herrmann et al., 2001; Littel & Franken, 2007; Lubman et al., 2007), as compared to neutral stimuli. In general, it is assumed that the P300 (and LPP) amplitude directly reflects the degree to which the underlying motivational system in the brain is activated, and as such provides an indication of the intensity by which attentional resources are allocated to certain cues (Cuthbert et al., 2000). In correspondence with this notion, it has been found that the amplitudes of these late positive waves are positively correlated with self-report measures of craving (for a meta-analysis, see Field et al., 2009). Also eating- and body weight-related studies have reported a link between long-latency ERPs and the motivation to eat (Nijs et al., 2008; Stockburger et al, 2008; Stockburger et al., 2009), suggesting that P300 amplitude can be regarded as an index of motivation-related attentional engagement.

While there is general consensus that long-latency ERPs, such as the P300, tap the conscious attentional processing of information, this is less clear for early ERPs (< 300 ms). Until recently, it was assumed that early ERPs reflect the perceptual processing of sensory characteristics of stimuli. However, evidence is accumulating that early ERPs are also modulated by the emotional or motivational content of stimuli (e.g., Franken et al., 2008; Kissler et al., 2006; Schupp et al., 2007). As a consequence, it has been suggested that early ERPs index the automatic orienting of attention towards stimuli (e.g., Pourtois et al., 2004), whereas long-latency ERPs would assess more controlled sustained attention or the delayed disengagement of attention (Schupp et al., 2006).

It is yet unclear which of these attentional processes is reflected in Stroop reaction times. The attentional bias underlying Stroop interference has been assumed to operate on an automatic level (Cox, Fadardi, & Pothos, 2006), but more strategic processes might play a role as well (Phaf & Kan, 2007; Thomas et al., 2007). In the present study, EEG activity was recorded during Stroop task performance in order to examine early and late ERP components in response to the words used in the Stroop task as indices of respectively oriented and maintained attention. Previous studies investigating ERPs during emotional Stroop tasks reported larger amplitudes of early (e.g., P200; Thomas et al., 2007) as well as late (e.g., P300; Franken, Gootjes, & van Strien, 2009) ERP components in response to emotional words relative to neutral words Therefore, we investigated the P200 and P300 ERP-components in response to food-related Stroop words, and explored the association between reaction time scores and both ERP components.

Few studies have examined food-related attentional bias in (non-clinical) obese individuals. Braet and Crombez (2003) reported a specific Stroop interference effect for food-related words in obese children, which was absent in their normal-weight peers. In another study, Soetens and Braet (2007) employed an imbedded word task to examine attentional bias to high-calorie food words in obese and normal-weight adolescents, and found no indication of an attentional bias to food words, in neither of the weight groups. Using ERPs as an index of attention allocation, Nijs et al. (2008) reported enlarged P300 and LPP amplitudes to pictures of food in both obese and normal-weight individuals, with no further between-group differences. A recent study of Castellanos et al. (2009) combined a visual probe task with an eye-movements registration to examine food-related attentional bias in obese and normal-weight females under conditions of hunger and satiety. No between-group differences were found with regard to reaction time measures. However, when attentional bias was directly assessed by means of eye fixation direction and duration, obese individuals appeared to display an enhanced attentional orientation and maintenance to food-related pictures as compared to normal-weight individuals, at least in a state of satiety. Finally, Nijs, Muris, Euser, and Franken (in press) also used various behavioral and electrophysiological measures to examine food-related attention in obese and normal-weight females under conditions of hunger and satiety. Reaction times in a visual probe task revealed a general enhanced automatic orientation towards food cues in overweight versus normal-weight individuals. Maintained attention to pictures of food, as indexed by the P300 amplitude, was only enhanced in normal-weight participants in hunger versus satiety. In hungry overweight participants, the P300 bias for food pictures was not clearly present, although an increased energy intake was observed especially in this group. In sum, the few studies so far have yielded inconclusive findings with respect to food-related attentional bias in relation to obesity. It appears that various measures of attentional processes yield different conclusions, which seems to suggest that they tap different aspects of attention (Mogg & Bradley, 2002; Nijs et al., in press; Pothos, Calitri, Tapper, Brunstrom,

& Rogers, 2009). To get more insight in the exact meaning of and processes underlying -particularly indirect- attention measures (such as the Stroop task), it seems important to combine direct and indirect assessments in attention research, and to explore associations among the outcomes of them.

To summarize, starting from an 'addiction model' of obesity, the present study hypothesizes differences in the attentional processing of food-related stimuli between obese and normals-weight individuals. More specifically, the central hypothesis is that obese individuals display an enhanced automatic and maintained attentional bias to food-related words during a modified Stroop task, as assessed by reaction time scores as well as P200/P300 amplitude scores. In addition, it is expected that attention bias scores correlate positively with food craving scores, and thus indicate approach or wanting tendencies towards food.

Although differences between weight groups are expected, it is acknowledged that obesity is a complex, heterogeneous syndrome. (Over)eating habits are assumed to be influenced by various factors, including biological, genetic, sociocultural, psychological, and environmental factors. Possibly, there is interindividual variability within the group of obese individuals with respect to food-related cue-reactivity, which means that it may well be that only a subgroup of obese individuals is particularly sensitive to environmental food stimuli. In normal-weight individuals, such an interindividual variability in food-cue responsiveness has already been observed. More specifically, in normal-weight individuals, a food-related attentional bias has been related to the tendency to dietary restraint (e.g., Green & Rogers, 1993; Overduin, Jansen, & Eilkes, 1997; Polivy et al., 2008; Tapper, Pothos, Fadardi, & Ziori, 2008), and external eating (Brignell et al., 2009; Johansson et al., 2004; Newman et al., 2008; Nijs et al., 2009). For this reason, a measure of eating styles (assessing restraint, external eating, and emotional eating) was also included in the present study to examine correlations between attentional bias scores and eating styles in both weight groups.

Method

Participants

The study sample was identical to the one used in a previous study. Therefore, for a more detailed description of the participants and in-/exclusion criteria, see Nijs et al., 2008. Twenty obese adults (16 females and 4 males; mean BMI = 36.69, *SD* = 6.47; mean age = 28.65, *SD* = 6.59) and 20 normal-weight controls (16 females and 4 males; mean BMI = 22.68, *SD* = 1.53; mean age = 28.65, *SD* = 6.08) participated in the study. The study was approved by a local ethical committee of Erasmus University, and informed consent was obtained from all participants.

Self-report questionnaires

Because emotions and mood states are known to influence responses to food and the motivation to eat (e.g., Macht, 2008), affect was assessed by means of the Positive Affect Negative Affect Schedule (PANAS; Watson et al., 1988), which consists of 10 items tapping positive affect (e.g., interested, excited) and 10 items tapping negative affect (e.g., distressed, upset). Participants are asked to rate on a scale from 1 (very slightly or not at all) to 5 (extremely) "how they are feeling at this moment". The PANAS has been demonstrated to possess good psychometric properties (Watson et al., 1988).

Food craving was assessed by means of the state version of the General Food Cravings Questionnaire (G-FCQ-S; Cepeda-Benito, Gleaves, Williams et al., 2000; Nijs, et al., 2007), which is a 15-item self-report scale for measuring situational food craving. Briefly, the items refer to (1) an intense desire to eat; (2) anticipation of positive reinforcement that may result from eating; (3) anticipation of relief from negative states and feelings as a result from eating; (4) obsessive preoccupation with food or lack of control over eating; and (5) craving as a physiological state (c.f. hunger). Individuals have to indicate on a Likert scale to what extent they agree with each statement on the moment of completing the questionnaire (1 = strongly disagree; 5 = strongly agree). In the present study, pretest and posttest G-FCQ-S subscale scores (ranging from 3 to 15) were obtained. The G-FCQ-S has been shown to possess good reliability and adequate construct and discriminant validity (Cepeda-Benito, Gleaves, Williams et al., 2000; Nijs et al., 2007).

The Dutch Eating Behavior Questionnaire (DEBQ; van Strien et al., 1986) consists of 33 items that intend to 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 (van Strien et al., 1986).

Food-related Stroop task

Twenty words referring to generally high-calorie, palatable foods (Dutch equivalents of cake, cheese, potato chips, pasta, bonbon, salad, meatball, cookie, ice cream, kebab, bun, yoghurt, whipped cream, chocolate, hamburger, meat, peanut butter, croissant, vanilla custard, treacle waffle) and 20 neutral control (office-related) words (Dutch equivalents of tape, paperclip, cupboard, felt-tip, mobile phone, ball pen, scissors, diary, file, pushpin, printer, monitor, cable, notice board, bookshelf, envelope, stamp, wastepaper bin, punch, stapler) were matched for word length and frequency of use. The mean log word frequencies per million according to the CELEX norms (Baayen, Piepenbrock, & van Rijn, 1993) were 0.44 and 0.40 for the food- and office-related words respectively, $p > .05$. This indicates that there were no differences between the two word categories with regard to frequency of use in the general written Dutch literature.

The Stroop task started with a practice block, including 20 words which were unrelated to food or office items (e.g., hello, football). Subsequently, there were 4 experimental blocks, during which each food- and office-related word was presented 4 times (i.e., once per block), in the centre of a computer monitor, each time in a different color (i.e., blue, red, yellow and green). The order of the words was semi-random, in such that no more than 2 words from the same category, and no more than 2 words of the same color were displayed successively. Participants were instructed to ignore the content of the words and to respond as quickly as possible to the font color of the words by pressing a button in the corresponding color. If the participant did not respond in time, the words disappeared after 2000 ms. The interstimulus interval was set at 1000 ms. To promote learning, participants were informed about correct/incorrect/late responses in the practice block.

Incorrect responses were discarded. Mean reaction times for each group (obese vs. normal-weight) and for each word category (food vs. neutral) were calculated after the deletion of outliers, i.e., reaction times $\leq$ 200 ms or $\geq$ 2000 ms, or reaction times exceeding the individual's mean (2 standard deviations. There were no between-group differences with respect to the total number of trials that were lost due to these procedures (M = 5.20, SD = 3.41 in the obese group vs. M = 5.30, SD = 3.83 in normal-weight controls, $t(38)$ = .09, p > .05).

EEG recording, EEG analyses, and definition of ERP components

EEG signals were recorded over 64 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 in 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, and to the supraorbital regions of the left and right eye (VEOG). 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 offline re-referenced to the mathematically linked mastoids. EEG and EOG activity was filtered with a bandpass of 0.1-30 Hz (phase shift-free Butterworth filters; 24dB/octave slope). After ocular correction (Gratton et al., 1983), epochs (segments from 200 ms prestimulus to 600 ms poststimulus) that included an EEG signal exceeding $\pm$100 μV were eliminated. Data of 5 participants (3 normal-weight and 2 obese) were excluded from further analyses, because more than 50% of the epochs contained artifacts. The mean number of included food epochs was 70.00 (SD = 6.86), and the mean number of office epochs was 71.63 (SD = 6.54). The mean 200 ms prestimulus period served as baseline. After baseline correction, average ERP waves were calculated for each participant, at each scalp site, for the two stimulus conditions. Based on visual inspection of the grand average waveform (Figure 1) and the existing literature (e.g., Franken et al., 2003), P200 was defined as the average amplitude (μV) within the 185-300 ms time window, and P300 as the average amplitude (μV) within the 300-550 ms time window. In order to reduce the number of statistical analyses, average P300 amplitudes were calculated for a frontal cluster (containing 17 frontal electrode sites: Fp1, AF7, AF3, F7, F5, F3, F1, Fp2, AF8, AF4, F8, F6, F4, F2, Fpz, AFz, Fz), a central cluster (27 central electrode sites: FT7, FC5, FC3, FC1, T7, C5, C3, C1, TP7, CP5, CP3, CP1, FT8, FC6, FC4, T8, C6, C4, C2, TP8, CP6, CP4, CP2, FCz, Cz, CPz), and a posterior cluster (20 parietal-occipital sites: P9, P7, P5, P3, P1, PO7, PO3, O1, P10, P8, P6, P4, P2, PO8, PO4, O2, Pz, POz, Oz, Iz).

Procedure

The procedure of this study is described in more detail in Nijs et al. (2008). In order to bring all participants in a comparable hunger state and to preclude direct effects of food intake on ERP responses (Geisler & Polich, 1992), participants were requested to eat a light meal two hours before the start of the experiment, and subsequently to abstain from any food or caloric drinks until the experiment was finished.

As part of an additional survey, completed at home, all participants filled out a number of questionnaires, including the DEBQ. At the start of the experimental session, participants completed self-report questionnaires to assess pretest food craving and affect. They also indicated the exact time that they had last eaten, their present body weight, and height. Subsequently, they were seated in a comfortable chair in a dimly-lit, sound-attenuated room and EEG electrodes were attached. Each participant first performed the food-related Stroop task, followed by a task, during which pictures of food and non-food items were presented (for detailed results, see Nijs et al., 2008). At the end of the experiment, participants filled out the food craving scale for a second time. All subjects received a financial remuneration for their participation.

Statistical analyses

Independent samples *t*-tests were conducted to examine between-group differences with regard to age, elapsed time since last eaten (in minutes), positive and negative affect, various types of food craving as indexed by the averaged pre- and posttest G-FCQ-S subscales, as well as the DEBQ subscales of external eating, emotional eating, and dietary restraint.

With respect to Stroop-related reaction times, a 2 × 2 repeated measures analysis of variance (ANOVA; with Greenhouse-Geisser corrected *df*'s; uncorrected *df*'s are reported) was conducted with word category (food vs. neutral) as within-subjects factor and group (obese vs. normal-weight) as between-subjects factor. To analyze Stroop-related P200 and P300 amplitudes, 3 × 2 × 2 repeated measures ANOVAs were conducted with electrode cluster (anterior, central, posterior) and word category as within-subjects factors and group as between-subjects factor. In case of significant effects, post-hoc *t*-tests were conducted with Bonferroni adjustments for multiple comparisons. To evaluate the relationship between self-reported food craving, eating style, reaction times, and amplitudes of the ERP components in both groups, Pearson correlations were calculated.

Results

Pre-experimental differences and self-report measures

There were no statistically significant differences (all ps > .05) between the obese and normal-weight participants with regard to age, elapsed time since last eaten ($M = 114.00$, $SD = 25.06$ vs. $M = 127.50$, $SD = 44.74$), positive affect ($M = 31.26$, $SD = 7.29$ vs. $M = 30.10$, $SD = 5.22$), and negative affect ($M = 14.05$, $SD = 6.20$ vs. $M = 13.25$, $SD = 4.85$). In Table 1, the G-FCQ-S and DEBQ scores of both groups are displayed.

On average, normal-weight participants had significantly higher scores on the G-FCQ-S subscale 'craving as a physiological state' (c.f., hunger) as compared to obese participants, $t(37) = 2.33$, $p < .05$. Normal-weight participants also displayed a tendency to report more 'desire to eat' as compared to obese participants, $t(37) = 1.75$, $p = .09$. There were no further significant between-group differences with respect to G-FCQ-S subscale scores. Also, no significant between-group differences were found with respect to external eating, emotional eating, and dietary restraint, although obese participants tended to report a higher level of dietary restraint,$t(37) = 1.82$, $p = .08$.

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Stroop-related reaction times

Reaction times to the color of food-related and neutral words of obese and normal-weight participants are displayed in Table 2. A main effect of word category was found, $F(1,38) = 18.22$, $p < .001$, indicating that reaction times in color-naming of food-related words were generally slower than reaction times to neutral words ($M = 757.83$, $SD = 102.90$ vs. $M = 740.63$, $SD = 103.40$. In other words, a general Stroop interference effect was observed, indicating a general attentional bias toward words with a food-related content. The word category $\times$ group interaction did not attain significance, suggesting that the attentional bias to food-related words was similar in both weight groups.

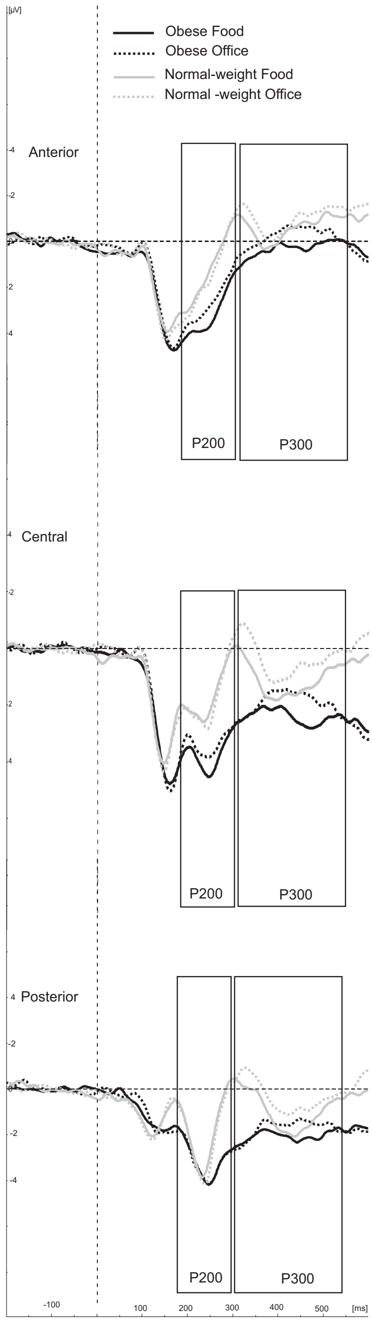

Figure 1: *Grand average ERP waveforms to food-related and neutral control (office-related) words in the anterior, central, and posterior electrode clusters of obese and normal-weight individuals. Positive waves are displayed downwards.*

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Table 1: *Mean scores on eating style- and food craving-related measures (standard deviations) in obese and normal-weight participants.*

	Obese	Normal-weight
DEBQ External	3.16 (.63)	3.29 (.60)
DEBQ Emotional	2.85 (.99)	2.45 (.77)
DEBQ Restraint	2.84 (.61)	2.47 (.68)
GFCQS Desire	7.05 (3.05)	8.50 (2.05)
GFCQS Positive	6.11 (2.23)	6.95 (2.33)
GFCQS Negative	5.87 (2.41)	6.20 (1.95)
GFCQS Control	5.68 (2.45)	5.30 (1.62)
GFCQS Physical *	5.37 (2.50)	7.15 (2.27)

Note. DEBQ = Dutch Eating Behaviour Questionnaire, G-FCQ-S = the state version of the General Food Cravings Questionnaire, * significant between-group difference, $p < .05$

P200 amplitude

Mean P200 and P300 amplitudes to food-related and control words, as assessed at the anterior, central, and posterior electrode clusters, in obese and normal-weight participants are displayed in Table 2. For the P200 amplitudes, a significant electrode cluster x word category × group interaction effect was found, $F(1,66) = 3.39$, $p < .05$. Post-hoc *t*-tests revealed that the anterior (borderline significant; $p = .08$) and central ($p < .05$) P200 waves to food words were larger in obese than in normal-weight participants, whereas there were no significant between-group differences in P200 amplitude to neutral control words (all *p*s >.05). In addition, only in obese participants a marginally significant difference between P200 amplitudes to food-related and neutral control words (food > neutral , i.e., an attentional bias to food words) was found[3], which was situated in the anterior cluster, $p = .06$. This result indicates that in an early latency window (i.e., on a automatic, perceptual level), obese individuals tended to allocate more attention to food-related words than neutral words, and this was not observed in normal-weight participants.

P300 amplitude

With respect to the P300 data, a significant main effect of cue was found, $F(1,33) = 4.54$, $p < .05$, indicating that the P300 amplitudes to food words ($M = .80$, $SD = 3.25$) was generally larger than to neutral words ($M = .20$, $SD = 3.82$), which reflects a bias in the conscious, maintained attention to food words. The word category × group interaction did not attain significance, suggesting that the P300 bias to food-related words was similar in both weight groups. There was also a significant main effect of cluster, $F(1,33) = 24.27$,

[3] When G-FCQ-S hunger was included as covariate in statistical analyses, this exclusive food-related P200 bias in obese individuals was still observed.

Table 2: *Mean scores on attention-related measures (standard deviations) in obese and normal-weight participants.*

	Obese		Normal-weight	
	Food	Office	Food	Office
RT	756.6 (85.26)	744.5 (86.64)	759.1 (120.3)	736.8 (120.0)
RT Bias	12.04 (27.98)		22.35 (22.71)	
P300 Anterior	-.28 (4.21)	-.93 (4.17)	-1.24 (2.95)	-1.57 (3.55)
P300 Central	2.43 (4.47)	1.78 (4.53)	1.03 (3.07)	.20 (4.32)
P300 Posterior	1.94 (3.42)	1.56 (3.92)	.80 (2.23)	.04 (3.75)
P300 Anterior Bias	.66 (1.54)		.33 (2.14)	
P300 Central Bias	.65 (1.42)		.83 (2.23)	
P300 Posterior Bias	.38 (1.14)		.76 (2.23)	
P200 Anterior	3.56 (3.89)	2.97 (4.35)	1.49 (2.72)	1.84 (2.62)
P200 Central	3.97 (3.22)	3.53 (3.55)	1.72 (3.25)	1.84 (2.95)
P200 Posterior	3.28 (2.67)	3.31 (2.89)	1.90 (3.21)	2.11 (3.23)
P200 Anterior Bias	.59 (1.07)		-.35 (1.44)	
P200 Central Bias	.45 (1.30)		-.12 (1.69)	
P200 Posterior Bias	-.03 (1.04)		-.21 (1.74)	

Note. RT = mean reaction times (in ms) to the color of food-related and neutral (office-related) words in the food-related Stroop task, P200/P300 Anterior/Central/Posterior = mean P200/P300 amplitudes (in μV) to food-related and neutral (office-related) words of the anterior, central, and posterior scalp electrode clusters.

$p < .001$. This result indicates that the frontal P300 amplitude was generally significantly smaller than the central ($p < .001$) and posterior ($p < .001$) P300 amplitude.

Correlational analyses

Pearson correlation coefficients among the food-related Stroop reaction time bias, the P200 and P300 bias (averaged over the whole scalp), food craving scores, and eating style scores are displayed in Table 3. Remarkable between-group differences in correlational patterns were observed. In obese participants, significant positive correlations were found between the Stroop interference effect (reaction time bias score) and food craving-related scores (i.e., on the subscales ‘a desire to eat’ and ‘the expectance of a positive outcome from eating’), which were not documented in normal-weight participants. On the other hand, in normal-weight participants positive correlations were observed between P200/P300 bias scores and food craving-related scores (i.e., on the subscales ‘expectance of relief from negative states and feelings as a result from eating’ and ‘hunger’), which were not found in obese participants. There were no significant correlations between reaction time bias and P200/P300 bias scores, while in normal-weight participants a strong positive correlation emerged between the P200 and P300 bias scores. Finally, there appeared to be positive relationships between food-related Stroop reaction

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time bias, food craving, and external eating, but only in obese participants. In normal-weight participants, no significant correlations between any of the attentional bias scores and eating style scores were found.

Discussion

The primary purpose of the present study was to investigate differences in the attentional processing of food-related words in a Stroop task, as assessed by means of behavioral (reaction times) and electrophysiological (P200 and P300 amplitudes) indices, between obese and normal-weight individuals. Most importantly, the amplitude of the P200 wave in response to food-related words was significantly larger (at central scalp positions) in obese participants as compared to normal-weight controls, whereas the P200 amplitude to neutral words did not differ between weight groups. In addition, only in obese participants there was evidence for a P200 bias to food-related (relative to neutral) words. These results indicate that, in early, preconscious, automatic stages of information processing, obese individuals already tend to allocate more attention towards food-related stimuli than normal-weight individuals. This result is in line with findings from previous studies investigating automatic food-related attentional biases in relation to obesity. For instance, Castellanos et al. (2009) reported a preferential initial orientation of eye movements towards food pictures (as compared to control pictures) in satiated obese participants, which was not seen in satiated normal-weight participants. In a similar vein, using a visual probe task (with 100 ms lasting trials), Nijs et al. (in press) found that overweight/obese females demonstrated an enhanced attentional shift towards food pictures (relative to control pictures) as compared to normal-weight females.

Table 3: *Pearson correlations among attentional bias scores (difference scores), food craving-related measures, and eating styles, in obese and normal-weight participants.*

	Obese						Normal-weight					
	RT	P300	P200	DEBQ External	DEBQ Emotional	DEBQ Restraint	RT	P300	P200	DEBQ External	DEBQ Emotional	DEBQ Restraint
RT	.	-.07	.24	.50*	.30	.21	.	-.39	-.20	.27	-.05	-.14
P300	.	.	.44	-.27	.29	.07	.	.	.61**	.10	.23	.18
P200	.	.	.	.25	.18	-.01	.	.	.	.23	.24	.08
G-FCQ-S Desire	.62**	.08	.21	.50*	.37	.13	.05	.29	.15	.21	.26	-.20
G-FCQ-S Positive	50*	.15	.18	.61**	.52*	.27	.05	.34	.18	.39	.46*	.08
G-FCQ-S Negative	.39	.21	.12	.48*	.47*	.29	.11	.72**	.81**	.16	.08	.14
G-FCQ-S Control	.30	.32	-.05	.38	.36	.01	.04	.22	-.01	.14	-.06	.42
G-FCQ-S Physical	.10	.05	-.19	.11	.17	-.10	.04	.41	.60*	.07	-.06	-.11

Note. RT = attentional bias score as assessed by means of reaction times (in ms) in the Food Stroop Task, i.e., the mean reaction time to food-related words minus the mean reaction time to neutral control words, P200/P300 = attentional bias score as assessed by means of P200/P300 amplitudes (in μV), i.e., the mean P200/P300 amplitude to food-related words minus P200/P300 amplitude to neutral control words, DEBQ = Dutch Eating Behaviour Questionnaire, G-FCQ-S = the state version of the General Food Cravings Questionnaire.

$^{*}p < .05$, $^{**}p < .01$

With respect to P300 amplitude, which indexes the more conscious and controlled, motivation-related attentional processing of information, a general food word-related bias was found. That is, larger P300 amplitudes to food than control words were observed in both obese and normal-weight participants, with no between-group differences in intensity or magnitude of this attentional bias effect. This result is in line with findings from previous studies, reporting enlarged P300 amplitudes to pictures of food than control pictures across weight groups (Nijs et al., 2008), or general food-related biases using other behavioral measures of conscious attention (i.e., a visual probe task with 500 ms lasting trials and the duration of eye fixations to food-related pictures; Nijs et al., in press). However, between-group differences in outcomes of these maintained attentional bias measures have been reported as well, in both states of hunger (Nijs et al., in press; using P300 amplitude) and satiety (Castellanos et al., 2009; using eye fixation duration). Similar to the P300 results, a Stroop interference effect of food-related words (i.e., slower reaction times to food-related than control words) was observed in both obese and normal-weight participants. These results contradict those of Braet and Crombez (2003), who reported an exclusive attentional bias to Stroop food words in obese children, which was not seen in normal-weight peers.

Not only in the field of obesity but also in the field of addiction, various studies using different tasks to measure similar attentional constructs, have documented diverging results, suggesting that different tasks may tap different mechanisms of attention. In general, it can be assumed that direct measures of attention, such as ERPs, but also the monitoring of eye movements are more sensitive measures of information processing than indirect tasks, such as the Stroop task. Applying direct and indirect measures of attention simultaneously within one study and examining associations between the outcomes of these measures provides the opportunity to get more insight in underlying mechanisms of indirect attention measures. In the present study, an attempt was made to unravel whether the Stroop interference effect is related to the automatic or strategic attentional processing of information. No significant correlations were found between Stroop reaction time bias and ERP biases, in neither weight group, suggesting that Stroop reaction times do not directly reflect P200 nor P300-related activity. In a recent emotion-related Stroop-ERP study, Franken et al. (2009) also did not find an association between Stroop reaction times and amplitudes of an early ERP-component and the P300, but significant positive correlations were observed between Stroop reaction time bias and the amplitude of the LPP ERP-component, indicating that LPP amplitude and Stroop interference may at least in part tap a similar construct. LPP is assumed to reflect conscious, more voluntary motivation-related attention. This finding suggests that Stroop reaction times reflect a controlled rather than an automatic process (Phaf & Kan, 2007).

An additional purpose of the present study was to investigate the relationship between food-related attentional bias on the one hand, and overeating tendencies and food craving on the other hand, in obese and normal-weight samples separately. Only in obese individuals, the Stroop reaction time bias was positively associated with external eating and food craving. That is, the more obese individuals reported a general tendency to eat in response to food-related cues, the more they reported craving during the experiment, and the more their color-naming responses to food-related words in the Stroop task were slowed. Thus far, to our knowledge, food-related attentional bias in relation to external eating has only been investigated in normal-weight individuals. Both attentional approach (Nijs et al., 2009; Brignell et al., 2008) and avoidance (Johansson et al., 2004) have been observed in normal-weight external eaters. In the present study, no significant relationship was found between indices of food-related attentional bias and external eating in normal-weight participants. Moreover, the present study demonstrates that correlational patterns differ between weight groups, suggesting that findings in normal-weight individuals cannot be generalized automatically to overweight individuals and vice versa.

Only in normal-weight participants, a significant positive association was observed between ERP amplitudes and measures of food craving. Previous eating- and body weight-related studies have reported a link between long-latency ERPs and the motivation to eat (Nijs et al., 2008; Stockburger et al., 2008; Stockburger et al., 2009). However, the present study demonstrates that this finding might be confined to normal-weight individuals, and cannot automatically be generalized to overweight samples. Moreover, the present results are remarkably in accordance with a previous study (Nijs, et al., in press), which also reported a significant positive correlation between hunger ratings and food-related P300 bias in normal-weight females, but not in overweight females, and a significant positive correlation between hunger ratings and a behavioral measure of attention in overweight females, but not in normal-weight females. It is a challenge for future research to discover which attentional task can best be employed to predict further motivation to eat, in both normal- and overweight groups.

One reason why a straightforward explanation with regard to the relation between attention and craving/eating tendencies is problematic may have to do with the reliability and validity of self-report measures. For instance, despite the fact that there were no between-group differences in the time since last eaten, normal-weight individuals did report more hunger and desire to eat during the experiment than obese participants. Also, no significant differences were found in dietary restraint, external eating, or emotional eating. Starting from an addiction model of obesity with enhanced cue-reactivity as the central mechanism underlying overeating, it was expected that obese participants would especially report more food craving and external eating tendencies than normal-weight participants. It is well-known that self-report measures are generally susceptible to social desirable response tendencies, and that particularly obese individuals tend to underreport on eating-related issues such as energy intake (Goris, Westerterp-Plantenga, & Westerterp, 2000; Schoeller, 1995) and body weight (Dauphinot et al., 2009). It is possible that the obese individuals in the present study underreported their food craving/hunger state (Stunkard, 1959) or tendency to overeat, and this may have influenced the results of the correlational analyses.

In sum, the current study provides preliminary support for the idea that obese individuals do seem to demonstrate a specific automatic attentional orientation bias towards food-related stimuli. This increased attentional orientation may be regarded as the first expression of a general enhanced reactivity to food-related stimuli, which probably has its neural origin in the brain reward system. An enhanced food-cue-reactivity may play an important role in the maintenance of the problematic eating behavior. However, in the present study no indications were found for a further enhanced food-related cue-reactivity in obese individuals, as they did not display greater difficulty to disengage attention from food words, or self-reported food craving during the experiment. Replication studies are needed before more definitive conclusions can be drawn.

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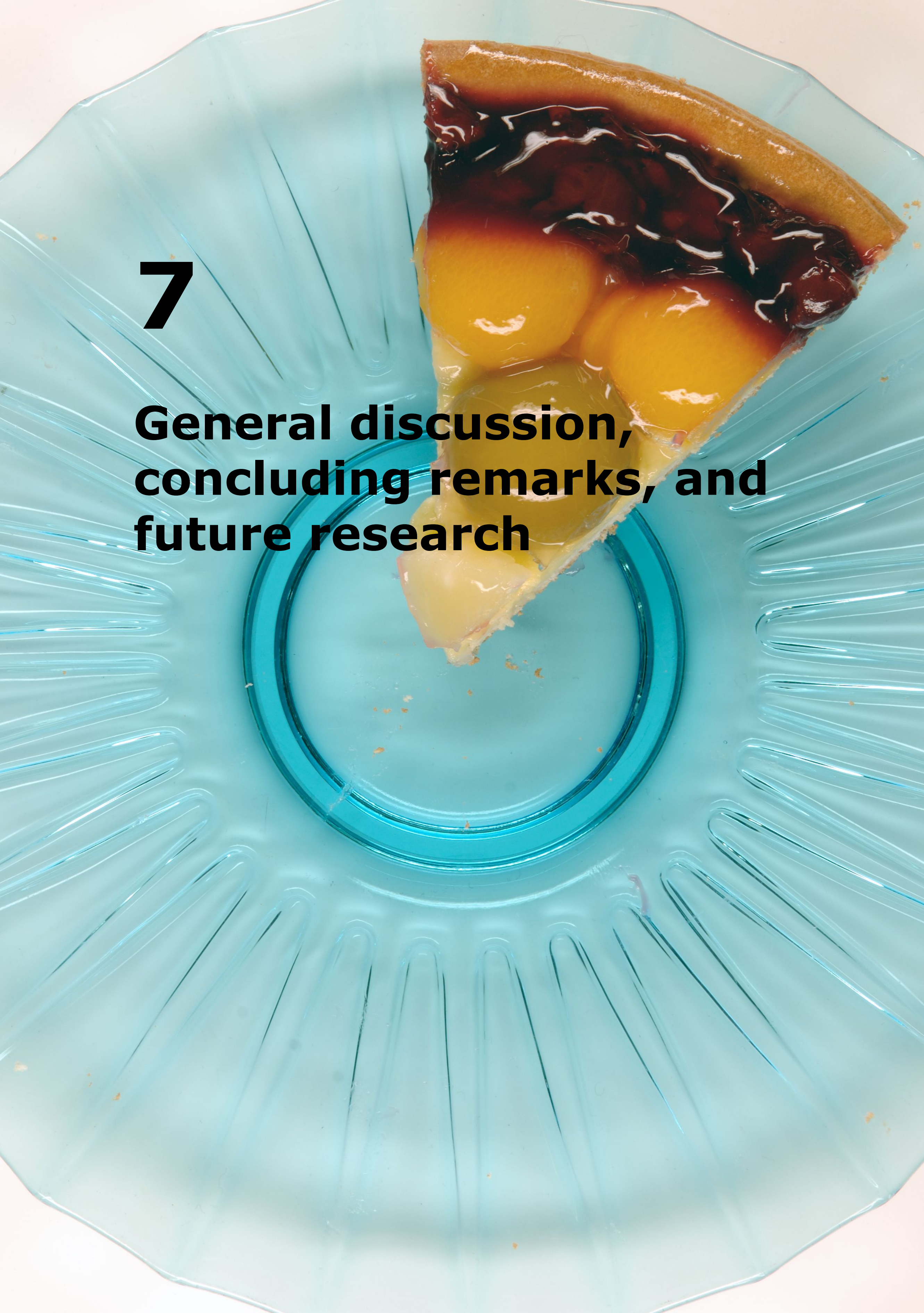
General discussion, concluding remarks, and future research



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The aim of the present studies was to test a number of hypotheses, which were derived from an addiction-based neurocognitive model of obesity. An overview of study results regarding these postulated hypotheses is given in Table 1. The main conclusion is that no straightforward answer can be given yet to the question whether overweight/obese persons are more responsive to (high-calorie) food-related stimuli as compared to normal-weight individuals, as reflected in an enhanced attentional bias to food pictures and words, subjective reports of a more intense desire to eat, and an enlarged amount of food eaten during a bogus taste test. This is mainly due to the fact that too few studies on this matter have been conducted yet, and that various measures have yielded various results, questioning the validity of some of these measures. However, the present studies did yield a number of interesting findings, which might be taken into consideration in future replication studies. These findings are discussed in the following paragraphs.

Attentional bias to food and overweight/obesity

The central assumption of the present thesis was that biases in the initial orientation and maintenance of attention to food-related stimuli (relative to neutral stimuli) would be found in all participants, but would be enhanced in overweight/obese as compared to normal-weight individuals in both conditions of hunger and satiety. Regarding the orientation of attention, it might be cautiously concluded that, indeed, overweight/obese individuals generally tend to direct their initial focus of attention to food-related stimuli, to a greater extent than normal-weight individuals. This was observed using two different indices of oriented attention, i.e., the reaction time bias score of the visual probe task with 100 ms lasting trials (particularly during hunger, see Chapter 5) and the P200 amplitude bias in a food-related Stroop task (which was exclusively seen in obese participants, after 2hr food deprivation, see Chapter 6). To our knowledge, only one study (Castellanos et al., 2009) also investigated the initial orientation towards food-related stimuli in obese and normal-weight individuals. These authors also found that obese participants were more likely than normal-weight participants to direct their initial eye fixation to pictures of food items, but only in a state of satiety. That is, during satiety, there was no food-related bias in the attentional orientation in normal-weight participants, whereas in the obese participants, this bias was as pronounced during satiety as during hunger. It should be noted that we (in Chapter 5), as Castellanos et al. (2009), used the initial eye fixation direction as index of oriented attention, but were not able to find any differences in bias magnitude between weight groups, nor conditions with that index. As will be discussed later in this chapter, there are various reasons why results may be inconsistent across studies and why it is particularly difficult to draw general conclusions from studies using different measures of similar attention-related constructs.

Regarding maintained attention, as expected, a general bias to food-related stimuli (relative to neutral stimuli) was observed in all participants, regardless of weight group. This was demonstrated using various indices of maintained attention, i.e., P300/LPP amplitude in a passive (Chapter 3) and more active (Chapter 5 and 6) paradigm, eye fixation duration (Chapter 5), and reaction times in a visual probe task with trials of 500 ms duration (Chapter 5). Differences between weight groups in bias scores were only found using the P300 amplitude index (see Chapter 5). That is, an unexpected significant between-group difference in P300 bias score was found only in the hunger condition, in such that the P300 bias score was *reduced* in overweight/obese as compared to normal-weight participants. This intriguing finding was speculatively and cautiously interpreted as that overweight/obese females might, consciously and intentionally, use cognitive strategies to limit their maintained attention bias to high-calorie food stimuli when hungry, possibly because they might, particularly when hungry, be tempted to (over)eat when exposed to such stimuli. In line with this interpretation, hungry overweight/obese participants were the ones eating most kilocalories during the bogus taste task (see paragraph 3 of this chapter). However, as was discussed in Chapter 5, results from the other used measures of conscious or maintained attention conflicted with this line of thinking, as they did not yield any indication that overweight/obese individuals had a desire to avoid gazing at the food-related stimuli. Also, in the study of Castellanos et al. (2009), the obese participants were actually found to gaze for a *longer* duration at food-related pictures as compared to normal-weight participants in a satiated state, and no differences in gaze duration between weight groups were found during hunger. In sum, also with regard to maintained attention to food, results of few studies were mixed and rather difficult to reconcile.

Finally, an attempt was made to get more insight in the (oriented or maintained) attention process underlying the reaction times during a Stroop task, which is the most frequently used measure in attention-related research. Participants generally demonstrated slower responses to food-related words as compared to neutral words, indicating that the food-related content of words interfered more with color-naming performance than the neutral content of control words. No differences between weight groups in reaction time bias scores were observed. This finding contrasts with study results from Braet and Crombez (2003), who found an attentional bias to food-related words in a Stroop task to be exclusively present in obese children, and not in their normal-weight peers. In our study, electro-encephalographic (EEG) brain activity was recorded during Stroop task performance to examine associations between reaction times and P200/P300 amplitudes elicited by the words, the latter being indices of respectively oriented and maintained attention. No meaningful associations were found. However, a recent study (Franken et al. Strien, 2009) did report significant associations between reaction times in an emotion-related Stroop task and the amplitude of the Late Positive Potential (LPP), suggesting that these might tap a similar underlying construct or process. The LPP is the event-related potentials (ERP) component which follows the P300 and is assumed to reflect the voluntary allocation of attentional resources to certain stimuli. Interestingly, this finding (as well as findings of other studies, for reviews, see Phaf & Kan, 2007; Thomas et al., 2007) questions the automaticity of Stroop-related reactions, which had been assumed before. The issue whether Stroop reaction times are associated with automatic or intentional attentional processes should be topic for future studies.

As mentioned, for a number of reasons, it is difficult to compare the outcomes of different attention-related measures with each other, and to draw general conclusions from them. In Chapter 5, multiple attention-related measures were employed within the same study sample. As it turned out, no consistent meaningful associations were found between the outcomes of various measures, even if these intended to measure a similar underlying attention process (i.e., attentional orientation or engagement). This lack of a clear relationship between various attention-related measures has been reported before in the addiction (e.g., Mogg & Bradley, 2002) as well as food-related (Pothos et al., 2009) attention literature. Apparently, various attention measures tap (subtly) different underlying mechanisms.

Rather than reaction time tasks, more direct measures, such as ERPs and eye-tracking lately seem to have become the measures of preference in attention research, because they are assumed to yield more sensitive indices of attentional stimulus processing. The monitoring of eye movements allows us to pronounce on the direction and duration of visuospatial attention, and has the advantage that it is possible to examine whether attention is directed toward or away from stimuli. Amplitudes of ERPs give an index of the intensity by which attentional resources in the brain are being allocated to certain stimuli, and have the advantage of a good temporal resolution, which means that changes in brain activity during information processing can be monitored up to a millisecond. Though these direct indices of attention are valuable and recommended tools to investigate attention, they have the disadvantages of being rather time-consuming, requiring particular expert equipment and skills, and sometimes the purpose of applying these techniques might be too obvious to the participants. Behavioral measures, on the other hand, are easier to apply and participants may be less aware of their purpose, and for that reason, they may not be undervalued as tools to get insight in attention processes. Moreover, the application of behavioral measures has yielded an enormous body of knowledge regarding the cognitive processing of relevant information in several psychopathologies and conditions (e.g., Dobson & Dozois, 2004; Johansson et al., 2005; Mogg et al., 1998; Robbins & Ehrman, 2004; Williams et al., 1996). So, it seems useful and important for future studies to further examine the relationships between direct and indirect measures of attention, and to unravel their exact underlying processes and mechanisms.

In sum, the choice of attention measure seems to be an important factor moderating study results. However, using a similar study design with similar (direct) measures of attention does not seem to guarantee similar outcomes or the comparability of findings, as many other factors might influence results as well. For instance, our study, as described in Chapter 5, and the study of Castellanos et al. (2009) both employed a visual probe task and eye movements to test similar hypotheses. Various small differences between the study designs, however, may have accounted for the different results. For instance, Castellanos et al. (2009)

monitored eye movements during performance of a visual probe task, whereas our participants were required to look passively to (a smaller number of) pairs of food-related and neutral pictures while their eye movements were recorded. In the visual probe task, used by Castellanos et al. (2009), picture pairs were displayed for a duration of 2000 ms to assess maintained attention, whereas in our study a trial duration of 500 ms was chosen for this purpose. Castellanos et al. (2009) included obese male and female adults to participate in their study, whereas we chose to conduct our study exclusively in overweight/obese females. Importantly, Castellanos et al. (2009) included a time delay between satiation and the performance of the first attention task, whereas we started with the tasks immediately after milk shake consumption. Moreover, Castellanos et al. (2009) used a within-subjects design and tested participants at various times of day after 10-11 hours food deprivation, whereas we chose a between-subjects design to test all our participants at lunch time, after 17 hour food deprivation. Finally, we used a fixed amount of milk shake which contained around 600 kilocalories to achieve satiation in our participants, and Castellanos et al. (2009) gave their participants the opportunity to drink as much milk shake as they liked (until satiation) which resulted in an amount with an average energy content of 300-400 kilocalories. Similarly, such study design-related differences may explain differential results using the Stroop task in our study (Chapter 6) and the one of Braet and Crombez (2003). Braet and Crombez (2003) conducted their study in obese children, who were in cognitive-behavioral treatment for their weight problem, whereas our study concerned female adults who explicitly reported not to be currently engaged in a diet or any other treatment with the purpose of losing weight. In sum, the study of attention appears to be a complex matter, and, when designing a study, researchers have to take several methodological issues into consideration, which might influence results. Therefore, multiple replication studies seem necessary before definitive conclusions can be drawn.

The relationship between attention to food and the desire to eat

Starting from the model presented in the introduction of this thesis (Chapter 1), positive associations were expected between food-related attention outcomes and the desire to eat. A positive association between attentional bias and motivational indices (craving) has been also found in the addiction field (Field et al., 2009). Also, it was assumed that overweight/obese participants would report more intense food craving and hunger as compared to normal-weight participants. With regard to this latter assumption, results were unequivocal: if between-weight group differences were found in VAS hunger or G-FCQ-S scores (Chapter 3, 5 and 6), it were the normal-weight participants who reported more intense hunger or desire to eat as compared to overweight/obese participants. This finding is contraintuitive and in conflict with the general underlying idea of this thesis, namely that the brain reward system, which regulates the cue-elicited motivation to eat, is sensitized in overweight/obese relative to normal-weight individuals.

However, in the 1950's, it was already mentioned that in normal-weight individuals, physiological 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: obese women consistently denied being hungry even when their stomachs showed normal hunger-related contractions (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 (and thus had to rely more on external eating-related signals to decide when and what to eat, 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. Moreover, in this study, the general increase of the subjective experience of hunger during food deprivation was similar in obese and normal-weight individuals, which was also suggestive of the idea that obese individuals *are* sensitive to internal signs of hunger (Lowe et al., 2000). A similar increase of hunger and a desire to eat in overweight/obese and normal-weight individuals was also seen during the experiments described in the present thesis.

As was already pointed out by Stunkard, as early as in 1959, reports of less hunger (or a desire to eat) 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 et al., 2000; Schoeller, 1995). Also in line with this view is the fact that in the present studies between-group differences (i.e., normal-weight > overweight/obese) in self-reports of hunger or a desire to eat were particularly found in states of relative satiety (in Chapter 5 after milk shake consumption, and in Chapter 3/6 after 2hr food deprivation). Particularly when supposed to be satiated, obese individuals may feel a disinclination to acknowledge being (still or again) hungry, whereas after long-term food deprivation (see e.g., Chapter 5), when they are supposed to be hungry, they may feel less inhibited to admit a desire to eat. Unlike energy intake and body weight, which can be assessed by means of direct objective techniques, there are no unambiguous assessments of subjective experiences, such as hunger or desire (Mattes, Hollis, Hayes, & Stunkard, 2005). Researchers should always keep in mind that any self-report measure is unlikely to give a pure readout of the subjective state it aims to measure (Sayette et al., 2000), and that this might distort study results.

It should be noted that the above-mentioned between-weight group differences in hunger and desire scores were for the greater part seen using a one-item visual analogue scale (VAS) asking about the momentary degree of hunger (Chapter 3 and 5). Generally, VASs are assumed to be less valid assessments of subjective states than multi-item questionnaires, and to be sensitive to the chosen terminology

(Sayette et al., 2000; Stubbs et al., 2000). As discussed in the general introduction of this thesis, there were various reasons to choose both VASs and multi-item scales for indexing the subjective desire to eat. Moreover, though not reported in the previous chapters, correlational patterns were examined between various measures of hunger and desire to eat. Similarly to research concerning the validity of measures of drug craving (e.g., Rosenberg & Mazzola, 2007; Sussner et al., 2006), significant positive correlations were generally observed among the outcomes of VASs using different terminologies of hunger/desire (i.e., the Dutch terms ‘’honger’,‘trek’, ‘verlangen’, ‘zin’), and also between the outcomes of these VASs and scores on the G-FCQ-S, which is demonstrated to be a valid and reliable multi-item questionnaire of food craving (see Chapter 2). This suggests that the used VASs and G-FCQ-S (sub)scales both measure a similar construct of food motivation. Moreover, in Chapter 5, significant positive correlations were found between VAS hunger reports and the amount of kilocalories consumed during the bogus taste task, in both weight groups. Again, this suggests that the VAS hunger we used in our studies generally gives a fair index of the motivation to eat. In sum, it remains unclear why normal-weight individuals should report more intense hunger or food craving than overweight/obese individuals, and this might be due to an inability or unwillingness of obese individuals to accurately report on internal sensations of hunger or desire, or to the chosen measurement instruments. This might be an interesting topic for more systematic studies in future.

Despite the above-mentioned considerations concerning the validity of self-report measures, it is of notice that significant positive associations were found between some, but not all, attention-related outcomes and hunger/desire self-reports. Whereas in the first experiments (Chapter 3 and 4), these associations were assumed to be applicable to both weight groups, later studies (Chapter 5 and 6) demonstrated that the correlational patterns were actually weight group-dependent. For instance, in Chapter 5, exclusively in overweight/obese females, a positive association was observed between the reaction time bias score of the visual probe task with 100 ms lasting trials (reflecting automatic orienting of attention) and VAS hunger scores, and, in Chapter 6, between the reaction time bias score of the food-related Stroop task (presumably reflecting the voluntary allocation of attention) and the G-FCQ-S subscale scores of desire and positive reinforcement from eating. Exclusively in normal-weight females, positive associations were seen between the P200 (Chapter 6; oriented attention) and P300 (Chapter 5 and 6; maintained attention) amplitude biases on the one hand, and VAS hunger as well as G-FCQ-S subscale scores on the other hand. Also in addiction research, the presence and strength of the relationship between drug-related attentional bias and subjective craving appears to depend on several factors (for a meta-analysis, see Field et al., 2009), such as the type of attention measure and the study sample. It is a challenge to future studies to get more insight in which measures of attentional bias provide the most reliable predictors of subsequent food craving and food intake, in both weight groups.

The relationship between attention to food and food intake

In the study described in Chapter 5, an assessment of food intake was included to explore the relationships between attention to food pictures, the desire to eat, and the amount of food eaten. To prevent unnatural or contrived behavior during the experiment (particularly in obese participants, see previous paragraph), participants were initially misled with regard to the purpose of the study. That is, participants were told that the study concerned the general influence of food deprivation on task performance and taste perception, and we concealed the fact that we were interested in differences between weight groups. We believe that such 'white lies' were a particular strength of the studies described in Chapters 4 and 5, and that food cue-elicited responses particularly in these studies may be regarded as spontaneous and genuine. For this reason, also a bogus taste task was chosen to examine food intake. In this task, participants were required to evaluate the taste of a number of snack foods. From answers on a subsequent evaluation form, it appeared that participants were not aware of the fact that their food intake was weighed and their calorie intake was calculated afterwards. Results were -again- rather surprising. Only overweight/obese females ate significantly more of the snack foods during hunger than after satiation, and only in the hunger condition the food intake of overweight/obese females was significantly greater than the food intake of normal-weight females. Thus, at first sight, our data suggested that, particularly during hunger, overweight/obese females were *hyper*sensitive to food stimuli: not only did they orient their attention to a greater extent to the food pictures when hungry (see paragraph 1), they also ate more of the snack foods in the bogus taste task as compared to normal-weight participants. However, it should be noted that, whereas there was a significant positive association between VAS hunger and food intake in both weight groups, there was no convincing evidence for a direct positive association between the attentional orientation to food pictures and food intake. Only in normal-weight participants a positive association was observed between the P300 amplitude bias (which is an index of conscious, maintained attention) and food intake, strengthening the idea that long-latency ERP amplitudes may be an adequate index of food motivation in normal-weights.

Surprisingly, there was no significant difference in the energy intake of normal-weight participants between states of hunger and satiety. This finding suggests that there might be an alternative explanation for the between-weight group difference in the hunger condition. Instead of overweight/obese participants being hypersensitive to snack foods during hunger, hungry normal-weight participants might have intentionally limited their food intake, perhaps because they did not want to spoil their actual healthier lunch. This line of reasoning also suggests that overweight/obese individuals might have more difficulties keeping control over their food choices and intake, particularly when hungry. Recent studies indeed suggest that a poor behavioral inhibition (i.e., impulsivity) or reward sensitivity may be a key factor predicting overeating behaviors, and might thus form a vulnerability factor to become obese (Beaver et al., 2006; Davis et al., 2007; Franken & Muris, 2005; Guerrieri, Nederkoorn, & Jansen, 2007; Nederkoorn et al., 2006). The role of decision-making/impulse control in overeating and obesity is a very relevant and interesting matter to further investigate in more depth.

Individual differences in food cue-reactivity: the association with self-reported external eating

To investigate the underlying mechanisms of the construct of external eating, i.e., the self-reported tendency to eat in response to food-related stimuli, one study (see Chapter 4) investigated differences between normal-weight high and low scorers on the DEBQ subscale of external eating in the (conscious, maintained) attention to food pictures, using the P300 amplitude index. Subtle evidence was found for the idea that in high external eaters, attention was more intensely allocated to food pictures than in low external eaters. Moreover, high external eaters reported a higher desire to eat during the experiment, particularly after the exposure to food pictures, suggesting that these food pictures had a larger 'wanting' effect on high than low external eaters. These findings were partly confirmed in the study described in Chapter 5, in which a significant positive association was observed between external eating scores and the P300 amplitude bias, and between external eating scores and food intake in normal-weight participants. The latter association suggests that normal-weight high external eaters do not only pay more attention to food pictures but also eat more in response to snack foods, which supports the validity of the external eating construct, as assessed by means of the DEBQ.

A recent study of Brignell et al. (2009) also found support for the idea that normal-weight high external eaters are more sensitive to food cues in terms of maintained attention (i.e., in a visual probe task with $\geq$ 500 ms trial duration) and the desire to eat as compared to low external eaters. However, other studies have reported rather reverse patterns, in such that high external eaters were also found to have a tendency to *avoid* looking to food-related words (in a visual probe task; Johansson et al., 2004) or to have a *reduced* attentional bias to food words as compared to low external eaters (in a Stroop task; Newman et al., 2008). Moreover, in the study of Brignell et al. (2009), an enhanced attentional bias, but no enhanced *approach* bias to food pictures was seen in high relative to low external eaters. Also, in the studies described in Chapter 5 and 6 of the present thesis, no meaningful associations were observed between external eating scores and the outcomes of the behavioral and eye-tracking measures of oriented and maintained attention, or the P200/P300 amplitude biases to Stroop-related words. In obese participants, a positive association was seen only between external eating and the Stroop-related reaction time bias score (Chapter 6). In sum, again, the outcomes of some, but not all, attention-related measures were associated with external eating scores, and associations seemed to depend on weight group.

From an incentive sensitization view of obesity, it was expected that obese individuals would report to be higher external eaters than normal-weight individuals. However, in general, no differences between weight groups were found in DEBQ external eating scores (Chapter 5 and 6). Other studies have reported significant between-weight group differences (Castellanos et al, 2009; Braet & van Strien, 1997) and no differences (Caccialanza et al., 2004) in DEBQ measures of external and emotional eating. It has been suggested that higher dietary 'disinhibition' scores might only be found in clinical obese samples, characterized by more severe eating problems, such as binge eating (Caccialanza et al., 2004). In general, food-related cue-reactivity may indeed be more explicitly observed in bingeing than non-bingeing obese individuals. This line of reasoning will be further addressed later in this chapter (see paragraph 5).

As mentioned in the introduction of this thesis (Chapter 1), Restraint Theory (Herman & Mack, 1975) has been and still is very influential in obesity and food-related cue-reactivity research. The DEBQ, which was used as measure of eating styles in the present studies, includes a subscale of dietary restraint. Although restraint was not the primary variable of interest during the present studies, it seems appropriate to also discuss results from DEBQ restraint scores and their associations with cue-reactivity measures. Restraint Theory posits that some normal-weight individuals are as responsive to food-related stimuli as obese individuals (and may therefore be obesity-prone), because they do serious cognitive efforts to resist food temptations in order to control their food intake and body weight. Due to this 'chronic dieting' restrained eaters are sensitive to 'forbidden' food cues and to disinhibitory eating. Noticeably, recent evidence has demonstrated that those individuals who report dietary restraint are not actually dieting, and it has been suggested that dietary restraint should be rather seen as 'eating less than wanted' instead of 'eating less than needed' (Lowe & Butryn, 2007; Lowe & Levine, 2005).

In various studies, dietary restraint, at least as assessed by means of the Restraint Scale (which also assesses aspects of disinhibition; Polivy, Herman, & Warsh, 1978) has been found to be associated with a general enhanced responsiveness towards food-related stimuli, and enhanced (high-calorie) preload-elicited or stress-elicited disinhibitory food intake (Herman & Mack, 1975). However, the restraint scale of the DEBQ, which was used in the present studies is assumed to assess 'pure' volitional attempts to restrict food intake. That is, generally it has been found that scores on the DEBQ restraint scale *per se* are not directly associated with disinhibitory (nor restricted) eating behavior in the laboratory (Lowe & Butryn, 2007; Ouwens, van Strien, & van der Staak, 2003; Stice, Cooper, Schoeller, Tappe, & Lowe, 2007). Also in the present studies, it was found that DEBQ dietary restraint scores were not associated with self-reports of hunger or desire to eat during the experiment (see Chapter 6), nor with the amount of food eaten during the bogus taste task (see Chapter 5), in neither weight group.

However, high restrained eaters, as assessed with the DEBQ as well as with other restraint scales, generally seem to be likely to gain weight over time (French et al., 1994; Stice, Cameron, Killen, Hayward, & Taylor, 1999), and to be more vulnerable to binge eating and bulimic pathology (van Strien , Frijters, van Staveren, Defares, & Deurenberg, 1986), suggesting that also normal-weight high DEBQ scorers are susceptible to become obese. In the present studies, as expected, it was found that overweight/obese individuals generally had higher scores on DEBQ restrained eating than normal-weight participants (see Chapter 5 and 6).

Interestingly, in the present studies, there was evidence for a positive association between dietary restraint and the degree of attentional orientation towards food pictures, at least in normal-weight participants. That is, in normal-weight participants a positive association was found between DEBQ restraint scores and the reaction time bias score of the visual probe task with 100 ms lasting trials (Chapter 5). This suggests that the more restrained normal-weight females are, the more they have a tendency to automatically direct their initial attentional focus to food-related stimuli. In the present thesis, the general assumption is that the attentional bias to food-related stimuli is an outcome of dopamine activation in the reward system. The finding of a positive restraint-attention association suggests that possibly the reward system is more responsive to food-related stimuli in normal-weight high than low restrained eaters, as is also assumed to be the case in obese individuals. It seems worthwhile to investigate the association between DEBQ restraint and specifically attentional orientation (as assessed by means of the visual probe task) in future studies. In overweight/obese participants there was no evidence for a direct meaningful association between restraint and the attentional processing of food stimuli (see Chapter 5 and 6). The finding of the presence and absence of an association between restraint and attentional bias in respectively normal-weight and overweight/obese sample suggests that DEBQ restraint might assess a different construct or a different mechanism in different weight samples. For instance, the main difference might be that normal-weight restrained eaters are quite successful in using their restraint strategies to prevent weight gain, whereas overweight/obese restrained are less successful in doing so. So, high DEBQ restraint scores may point to successful and unsuccessful restraint in respectively normal-weight and obese females. It may be regarded as one of the general conclusions of the present thesis that findings of studies in normal-weight individuals may not be automatically generalized to overweight/obese samples and vice versa.

Table 1: *An overview of hypothesis-relevant study results of the present thesis*

Chapter *Study groups* *Deprivation state*	*Attention-related measure* *Underlying attention process (automatic orientation vs. strategic maintenance)* *Used stimuli*	*Hypothesis 1+2* *Attentional bias to food is enhanced in overweight/obese vs. normal-weight persons, in both states of hunger and satiety*	*Hypothesis 3* *Positive correlation between attention to food and food craving*	*Hypothesis 4* *Positive correlation between attention to food and food intake*	*Hypothesis 5* *Obese have higher scores on DEBQ external eating than normal-weight; positive correlation between external eating scores and food cue reactivity outcomes*
Chapter 3 Obese vs. normal-weight 2 hr food-deprivation	P300/LPP amplitude (whole scalp) Passive paradigm Conscious/maintained attention Pictures of food and (neutral) office items	Cue × cluster: food > neutral at central + posterior cluster Bias score: **no between-group differences**	[VAS hunger + G-FCQ-S total score: main effect time: posttest > pretest, no between-group differences] [VAS hunger: main effect group: normal-weight > obese] General positive association between (posterior/central) P300/LPP amplitudes and *increase* of VAS hunger	N/A	N/A

Chapter 4 Normal-weight: High vs. low external eaters 2 hr food-deprivation	P300 amplitude (posterior) Active paradigm Conscious/maintained attention Pictures of food, (neutral) office items, and (pleasant) babies	N/A	[G-FCQ-S total + subscale scores: main effect time: posttest > pretest; main effect group (total score, desire, positive reinforcement): high > low external; time × group (trend, total score): only at posttest: high > low external] Positive association between (posterior) P300 amplitudes to food pictures and pretest + posttest G-FCQ-S scores	N/A	Exclusively P300 food: group effect: high > low external eaters (at a number of electrode sites) General pattern: high: food=baby; low: food=office
Chapter 5 Overweight/obese vs. normal-weight 17 hr food deprivation vs. satiety	Eye-tracking: Gaze direction Automatic orientation of attention Picture pairs of food and (neutral) office items	Main effect cue: food > neutral Bias score: **no between-group differences** no between-condition differences	[VAS hunger: group × condition: satiated normal-weight > satiated overweight/obese at the end of the series of tasks] No significant association between gaze direction bias and VAS hunger	[Kcal intake: Only in overweight/obese: hunger > satiety; Only in hunger: overweight/obese > normal-weight] No significant association between gaze direction bias and kcal intake	No between-group difference in DEBQ external eating score [nor emotional eating] [but significant between-group difference in DEBQ restraint score] No significant association between gaze direction bias and external eating [nor other eating styles]
	Eye-tracking: Gaze duration Maintained attention Picture pairs of food and (neutral) office items	Main effect cue: food > neutral Bias score: **no between-group differences** no between-condition differences	No significant association between gaze duration bias and VAS hunger	No significant association between gaze duration bias and kcal intake	No significant association between gaze duration bias and external eating [nor other eating styles]

Visual probe task: 100 ms Automatic orientation of attention Picture pairs of food and (neutral) office items	Main effect cue: food > neutral Bias score: main effect weight group (trend): **overweight > normal-weight** main effect condition: hunger > satiety	Exclusively in overweight/obese: positive association between 100 ms RT bias score and VAS hunger	No significant association between 100 ms RT bias score and kcal intake	No significant association between 100 ms RT bias score and external eating [nor emotional eating] [but exclusively in normal-weight: significant association between 100 ms RT bias score and restraint]
Visual probe task: 500 ms Maintained attention Picture pairs of food and (neutral) office items	Main effect cue: food > neutral Bias score: **no between-group differences** no between-conditon differences	No significant association between 500 ms RT bias score and VAS hunger	No significant association between 500 ms RT bias score and kcal intake	No significant association between 500 ms RT bias score and external eating [nor other eating styles]
P300 amplitude (posterior) Active paradigm Conscious/maintained attention Pictures of food and (neutral) office items	Main effect cue: food > neutral Bias score: weight group × conditon interaction **In hunger: normal-weight > overweight** **In satiety: overweight > normal-weight** (trend) In normal-weights: hunger > satiety	Exclusively in normal-weight: positive association between P300 bias and VAS hunger.	Exclusively in normal-weight: positive association between P300 bias and kcal intake	Exclusively in normal-weight: positive association between P300 bias and external eating + positive association between kcal intake and external eating [No significant associations between P300 bias and other eating styles]

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Chapter 6 (= Chapter 3) Obese vs. normal-weight 2 hr food-deprivation	Food Stroop Task: RT ? Words related to food and (neutral) office items	Main effect cue: food > neutral Bias score: **no between-group differences**	[averaged pre-/posttest G-FCQ-S subscale scores: between-group difference hunger + desire: normal-weight > obese] Exclusively in obese: positive association between RT bias score and G-FCQ-S subscale (desire / positive reinforcement) scores	N/A	No between-group difference in DEBQ external eating score [nor other eating styles, but obese tend to have higher restraint scores] Exclusively in obese: positive association between RTbias and external eating + positive association between G-FCQ-S subscales (desire,positive and negative reinforcement) and external eating
	Food Stroop Task: P200 amplitude Automatic orientation of attention Words related to food and (neutral) office items	Exclusively in obese: cue-effect: food > neutral Exclusively P200 food: obese > normal-weight	Exclusively in normal-weight: positive association between P200 bias and G-CQ-S subscale (negative reinforcement / hunger) scores	N/A	No significant association between P200 bias and external eating [nor other eating styles]
	Food Stroop Task: P300 amplitude Maintained attention Words related to food and (neutral) office items	Main effect cue: food > neutral Bias score: **no between-group differences**	Exclusively in normal-weight: positive association between P300 bias and G-CQ-S subscale (negative reinforcement) score	N/A	No significant association between P300 bias and external eating [nor other eating styles]

Future directions

In addition to the future research directions mentioned in the sections above, some general recommendations for future studies may be given. These will be addressed below.

Binge eating

Wang et al. (2001) reported a reduced density of dopamine receptors, indicative of an altered reward system functioning, in morbidly obese individuals (i.e., BMI $\geq$ 40 kg/m^2). In the present studies (see Chapters 3,5,6), participants were overweight (BMI 25-30 kg/m^2) or moderately obese (BMI $\geq$ 30 kg/m^2). Possibly, addiction-like mechanisms, such as incentive sensitization, might play a more prominent role in the excessive food intake of morbidly obese than overweight individuals. In the same vein, results of various addiction-related studies suggest that the degree of the substance-related attentional bias is directly proportional to the quantity and frequency of the substance use (Field & Cox, 2008). Thus, a hyperreactivity to the hedonic properties of substance-related cues might particularly be present in those individuals who have the greatest problem with keeping their substance intake under control. In this perspective, in recent literature, it has been suggested that particularly binge eating disorder, an eating disorder that is generally regarded as being a specific subtype of obesity, has commonalities with classic addictions (e.g., Davis & Carter, 2009; Sobik et al., 2005). Binge eating refers to recurring episodes during which large amounts of food are consumed in a short period of time. The food binge is explicitly accompanied by the experience of loss of control and negative affect, and often occurs after a period of food restriction. Unlike non-clinical obesity, attentional biases to food-related stimuli have been investigated quite extensively in clinical eating disorders, primarily by means of behavioral tasks, such as the food-related Stroop task. Although there were a lot of inconsistencies in research outcomes, meta-analytic investigations of Stroop performance in eating disorders (Dobson & Dozois, 2004; Johansson et al., 2005) concluded that food-related Stroop interference effects were enhanced in eating-disordered samples, particularly in those characterized by binge eating (Dobson & Dozois, 2004). In line with this view, obese bingeing females have been found to report more craving than obese non-bingeing females after being exposed to food-related stimuli (Karhunen, Lappalainen, Tammela, Turpeinen, & Uusitupa, 1997). In future studies investigating food-related cue-reactivity in obesity, it would be interesting and relevant to include a measure of binge eating to further examine the relationship between bingeing and the degree of responsiveness to food-related stimuli. Furthermore, it would be interesting to replicate earlier studies regarding the role of food-related attentional biases in (binge) eating disorders, using more direct measures of attention, such as eye-tracking or ERPs.

Negative affect and stress

In a recent study, Jansen et al. (2008) demonstrated that non-eating disordered overweight/obese females with high negative affect displayed a tendency to overeat in response to a negative mood induction and to food exposure, whereas overweight/obese participants with low negative affect and normal-weight participants ate a similar amount of food after both manipulations as compared to a control condition in which there were no triggers for overeating. It was concluded by these authors that being characterized by high negative affect might make it extra difficult for overweight/obese individuals to resist food temptations.

In a similar vein, obese individuals with a high sensitivity to stress might be particularly vulnerable to eat in response to food-related cues. Chronic as well as acute stress has been associated with the etiology and maintenance of obesity (de Vriendt, Moreno, & De Henauw, 2009), binge eating (Gluck, Geliebter, Hung, & Yahav, 2004; Lo Sauro, Ravaldi, Cabras, Faravelli, & Ricca, 2008) and substance abuse (Goeders, 2002). More specifically, stress seems to be an important common trigger for relapse to substance use in addicted individuals (Sinha, 2008) and binge eating in obese individuals (Hagan, Chandler, Wauford, Rybak, & Oswald, 2003), and has been associated with an enhanced motivation for energy-dense foods (Oliver & Wardle, 1999). The impact of stress on cue-elicited craving and substance use has been suggested to have its origin in neural stress signals interacting with the brain reward system (Adam & Epel, 2007). In sum, the role of stress and negative affect in food-related cue-reactivity and obesity seems to be an important topic for future studies.

Gender

In the present studies, participants were mainly females. However, a number of studies in children has demonstrated that particularly males may be sensitive and responsive to food exposure. For instance, when watching food commercials, boys between 8 and 12 years of age were found to eat more candy as compared to when watching neutral commercials, which was not the case in girls of the same age group (Anschutz, Engels, & van Strien, 2009). In addition, overweight adolescent boys have been found to have particularly high scores on the DEBQ subscale of external eating (Braet et al., 2008). Moreover, there is evidence that a substantial proportion of obese men suffers from binge eating symptoms (Grucza, Przybeck, & Cloninger, 2007). These data suggest that cue-reactivity mechanisms may particularly play a role in the obesity onset and maintenance in men, which should be investigated further in future studies.

Dopamine and food-related cue-reactivity

The neurocognitive model as described in Chapter 1 assumes that differences in food-related cue-reactivity between overweight/obese and normal-weight individuals have their origin in the differential activation of dopamine in the reward system in response to the perception of food stimuli. The present studies focused on the cognitive, subjective and behavioral aspects of the model (i.e., attention, craving, food intake), and no direct measure of dopamine release was included. Various recent neuroimaging have reported changes in general activity in reward-related brain regions (e.g., by means of functional magnetic resonance imaging [fMRI]) during exposure to (high-calorie) food stimuli, and differences in this activity between obese and normal-weight participants (e.g., Rothemund et al., 2007; Stoeckel et al., 2009; Stoeckel et al., 2008). It would be particularly interesting and relevant for future replication studies to study the specific associations between dopamine release in the reward system (e.g., by means of positron emission tomography [PET] scans) and cognitive/subjective/behavioral responses to food-related stimuli (e.g., during attention task performance). Imaging of brain activity during performance of various attention-related tasks could also help to further unravel the differences and similarities in neural generators an processes underlying the (differential) outcomes of these tasks.

Another possibility to study the relationship between dopamine activation and further food-related cue-reactivity is by manipulating dopamine activity within the brain, e.g., by administering participants a dopamine-antagonist (such as haloperidol) or –agonist (such as bromocriptine), and examine influences of this manipulation on the degree of food-related attention, craving and food consumption (Franken, Hendriks, Stam, & van den Brink, 2004; Franken, Nijs, & Pepplinkhuizen, 2008). It would be interesting to find out whether such manipulations have a differential impact on food responses in overweight/obese and normal-weight individuals.

Attentional bias to food and the desire to eat: a mutually excitatory relationship?

In the present studies positive correlations were expected and found between a number of attentional bias scores and the degree of desire to eat. The underlying assumption was that the food-related attentional bias and desire are both outcomes of the activation of the reward system, and have an excitatory effect on each other. It would be interesting to further investigate this latter assumption. That is, future studies could focus on the question whether an increase in the intensity of attention to food would result in increased desire and vice versa. Various addiction studies (particularly in smokers and heavy drinkers) have found that manipulations of drug craving (e.g., through deprivation, priming dose, negative mood induction, cue exposure) enhance drug cue-related attention (Field & Cox, 2008). In addition, there is evidence that increasing attentional bias to drug-related stimuli (through attentional training) leads to enhanced craving (Field & Cox, 2008). It would be interesting to find out whether such an ‘attentional training’ could change the intensity of food craving in obese individuals.

7

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Samenvatting

Tijdens de afgelopen paar decennia is de prevalentie van overgewicht en obesitas opvallend gestegen (Schokker et al., 2007). De toegenomen beschikbaarheid van calorierijk gemaksvoedsel in de westerse omgeving lijkt een belangrijke rol te spelen in deze obesitasepidemie (Hill & Peters, 1998). Onderzoek suggereert dat het overvloedige aanbod van smakelijk voedsel excessief eetgedrag stimuleert bij een groot aantal mensen (Westerterp & Speakman, 2008). Vooral personen met overgewicht lijken moeilijk weerstand te kunnen bieden aan deze voedselverleiding (Flegal & Troiano, 2000).

De motivatie om te eten wordt ondermeer gereguleerd in het mesocorticolimbisch beloningssysteem in de hersenen (Berridge, 2009). Dopamine is een belangrijke neurotransmitter in dit systeem en lijkt betrokken te zijn bij verschillende aspecten van reactiviteit ten aanzien van appetitieve stimuli. Dopamine speelt een rol bij cognitieve (b.v. aandacht), subjectieve (b.v. hunkering), fysiologische (b.v. hartslag) en gedragsmatige (b.v. toenadering) reacties op appetitieve stimuli (Franken et al., 2005).

Verschillende studies hebben aangetoond dat de dopaminerge neurotransmissie in het beloningssysteem is verstoord bij aan alcohol en drugs verslaafde personen. Een aantal neurocognitieve modellen van verslaving postuleert dat een sensitizatie van de dopamine-afgifte in het beloningssysteem verantwoordelijk is voor de observatie dat verslaafde personen een verhoogde aandacht hebben voor middelengerelateerde stimuli in de omgeving (Robinson & Berridge, 1993; Franken, 2003). Verondersteld wordt dat deze aandachts*bias* voor middelengerelateerde stimuli samenhangt met de subjectieve ervaring van hunkering (*craving*) naar het middel en deze versterkt (Field & Cox, 2008; Field et al., 2009). Deze hunkering zorgt er op zijn beurt voor dat de aandacht gericht blijft op de stimulus die geassocieerd is met het middelengebruik, waardoor het verlangen nog sterker wordt. De wisselwerking tussen selectieve aandacht voor en hunkering naar het middel zou ertoe leiden dat het individu op zoek gaat naar het middel en zich overgeeft aan het gebruik ervan (Fadardi & Cox, 2008; Cox et al., 2002; Marissen et al., 2006; Waters et al., 2003).

Bij obese personen zijn eveneens afwijkingen in de dopaminerge neurotransmissie aangetroffen (Wang et al., 2001). Dit doet vermoeden dat het hierboven omschreven neurocognitief model van verslaving van toepassing kan zijn op overgewicht/obesitas. Uitgaande van een dergelijk 'verslavings'model van obesitas is de centrale hypothese van dit proefschrift dat personen met overgewicht/obesitas een verhoogde reactiviteit vertonen ten aanzien van calorierijke voedselgerelateerde stimuli vergeleken met slanke personen. Meer concreet zijn de hypothesen als volgt geformuleerd. Ten eerste, obese personen vertonen een aandachtsbias voor voedselgerelateerde stimuli (ten opzichte van neutrale controlestimuli) en dit in sterkere mate dan slanke personen, zowel in een staat van honger als verzadiging. Verschillen tussen obese en slanke personen worden gezien in de initiële richting (*oriented attention*) en in de duur (*maintained attention*) van aandacht. Ten tweede, er is een positieve associatie tussen de uitkomsten van aandachtsbias-maten, het zelfgerapporteerde verlangen om te eten en de hoeveelheid voedsel gegeten tijdens een experiment. Ten derde, obese personen hebben hogere scores op een zelfrapportageschaal voor extern eten, d.i. de neiging om te eten bij bijvoorbeeld het zien of ruiken van lekker voedsel (Schachter, 1971). In het algemeen hangen scores op een schaal voor extern eten op een positieve manier samen met alle directe maten van voedselgerelateerde reactiviteit (d.i. aandacht, hunkering, voedselinname).

In de studies gebundeld in dit proefschrift werden verschillende maten gebruikt om de initiële richting van de aandacht en het vasthouden van de aandacht (of het onvermogen de aandacht af te wenden) te meten. Indirecte, gedragsmaten waren de *visual probe task* (Posner et al., 1980) en de Strooptaak (Williams et al., 1996). Meer directe maten van aandacht waren de registratie van electroencefalografische (EEG) activiteit tijdens de blootstelling aan stimuli (d.i. *event-related potentials*; ERPs) en het monitoren van oogbewegingen. Bij alle aandachtstaken werden foto's van calorierijk voedsel en neutrale controlefoto's gebruikt, behalve bij de Strooptaak, waarin woorden werden gebruikt. Het subjectieve verlangen om te eten werd gemeten met een multifactoriële vragenlijst of met een visuele analoge schaal (VAS). De voedselinname werd bepaald aan de hand van een valse smaaktest, de neiging to extern eten met behulp van de Nederlandse Vragenlijst voor Eetgedrag (NVE; van Strien et al., 1986).

De algemene rationale, hypotheses en methode worden besproken in **hoofdstuk 1** van dit proefschrift. **Hoofdstuk 2** behandelt de ontwikkeling en validering van twee multifactoriële zelfrapportage-vragenlijsten voor het meten van het algemene verlangen om te eten: de '(persoonlijkheids)trek'versie en de 'staat'versie van de *General Food Cravings Questionnaires* (G-FCQ-T en G-FCQ-S). De '(persoonlijkheids)trek' versie van de G-FCQ meet bepaalde eigenschappen van hunkering naar voedsel die stabiel zijn in de tijd en in verschillende situaties. De 'staat'versie meet situatie-afhankelijke hunkering naar voedsel. De factorstructuur van beide vragenlijsten werd onderzocht met exploratieve en confirmatieve factoranalysetechnieken. De interne consistentie, test-hertestbetrouwbaarheid en constructvaliditeit van de vragenlijsten werden eveneens onderzocht. Geconcludeerd werd dat de G-FCQ-T en G-FCQ-S betrouwbare en valide vragenlijsten zijn voor het meten van de stabiele en situatie-afhankelijke hunkering om te eten (Nijs et al., 2007).

In hoofdstuk 3 tot en met 6 worden een aantal studies weergegeven die zijn opgezet om bovengenoemde hypotheses te testen. **Hoofdstuk 3** omschrijft de eerste studie waarin obese en slanke personen, na 2 uur niet te hebben gegeten, werden blootgesteld aan foto's van calorierijk voedsel terwijl de EEG-hersenactiviteit werd geregistreerd. De amplitudes van twee ERP-componenten, namelijk de P300 en de Late Positieve Potentiaal (LPP), werden onderzocht als indices voor de intensiteit waarmee aandacht werd besteed aan de getoonde stimuli (Olofsson et al., 2008; Schupp et al., 2006). Over het algemeen werden grotere ERP-amplitudes geregistreerd in respons op voedselgerelateerde dan neutrale foto's, en deze bleken geassocieerd met de zelfgerapporteerde toename van honger (gemeten met een VAS) tijdens het experiment. De resultaten ondersteunden de hypothese dat ieder mens van nature een aandachtsbias vertoont voor calorierijk voedsel, aangezien dit voedsel van grote natuurlijke motivationele waarde is voor de mens (Gerber et al., 1999). Tegen de verwachtingen in werden geen verschillen gevonden tussen obese en slanke proefpersonen wat betreft de electrofysiologische of subjectieve reacties op foto's van voedsel (Nijs et al., 2008).

De studie die beschreven staat in **hoofdstuk 4** keek naar de onderliggende rol van aandacht voor voedsel bij de zelfgerapporteerde neiging tot extern eten (Schachter, 1971). Hiertoe werden verschillen in aandacht voor foto's van voedsel onderzocht tussen slanke vrouwen met hoge en lage scores op de extern-etensubschaal van de NVE (van Strien et al., 1986). Personen die hoog scoren op deze extern-etenschaal zeggen de neiging te hebben om te (over)eten wanneer zij worden geconfronteerd met voedselgerelateerde stimuli, zoals bij het zien of ruiken van lekker voedsel. De proefpersonen hadden opnieuw 2 uur voor de start van het onderzoek niets gegeten en opnieuw werd de amplitude van de P300-ERP-component gekozen als maat voor motivatiegerelateerde aandacht. In het algemeen ondersteunden de resultaten de hypothese dat hoog externe eters meer aandacht geven aan voedselgerelateerde stimuli (wat werd geobserveerd als een grotere P300) dan laag externe eters, al waren de effecten niet groot. Geen verschillen tussen beide groepen werden gevonden in P300 amplitudes uitgelokt door neutrale of positieve emotionele foto's. Hoog externe eters rapporteerden ook een significant sterker verlangen om te eten na de blootstelling aan de foto's van voedsel dan laag externe eters. Deze bevindingen ondersteunen de validiteit van en geven meer inzicht in het extern-etenconstruct, in ieder geval zoals het zich manifesteert bij slanke vrouwen (Nijs et al., 2009).

Hoofdstuk 5 beschrijft de meest omvattende studie van dit proefschrift. In deze studie werden verschillen in de initiële oriëntatie en het vasthouden van de aandacht op foto's van voedsel onderzocht tussen vrouwen met overgewicht/obesitas en slanke vrouwen, die (random) in een staat van honger (17 uur voedseldeprivatie) of verzadiging (middels een milkshake) waren gebracht. Naast de P300-amplitude werd in deze studie ook de *visual probe task* ingezet als maat voor aandacht én werden de oogbewegingen van de proefpersonen geregistreerd terwijl zij werden blootgesteld aan paren van foto's van voedsel en neutrale objecten. Als maat voor de subjectieve ervaring van honger werd tijdens het experiment herhaaldelijk een VAS voorgelegd aan de proefpersonen. In deze studie ondergingen de proefpersonen ook een "valse" smaaktest. In deze valse smaaktest werd aan de proefpersonen gevraagd een aantal calorierijke snacks te beoordelen op smaak.

In werkelijkheid was niet de smaakbeoordeling, maar de calorie-inname van de proefpersonen tijdens de smaaktest de variabele van interesse. De calorie-inname werd na afloop van de smaaktest bepaald. De neiging tot extern eten werd opnieuw gemeten aan de hand van de NVE.

De studie was bijzonder informatief, aangezien werd aangetoond dat de resultaten met betrekking tot aandachtsbias voor voedsel voor een groot deel afhankelijk zijn van de gekozen aandachtsmaat en gewichtsgroep. Bijvoorbeeld, alleen in de *visual probe task*, en alleen wanneer in deze taak paren van foto's van voedsel en neutrale objecten werden aangeboden voor een duur van *100* ms, werden verschillen tussen de gewichtsgroepen gevonden. Dat is, in deze taak bleken vrouwen met overgewicht/obesitas sterker de neiging te hebben om de initiële aandacht automatisch te richten op foto's van voedsel dan slanke vrouwen. Dit bleek ook het geval te zijn voor vrouwen met honger in vergelijking met vrouwen in een staat van verzadiging. De oogbewegingdata (waaruit een maat voor zowel de richting als de duur van oogfixaties werd gedistilleerd) en de data van de *visual probe task* waarbij de stimulusparen *500* ms werden aangeboden (wat gezien kan worden als een maat voor vastgehouden aandacht) wezen daarentegen op een algemene aandachtsbias voor foto's van voedsel en geen verschil tussen de gewichtsgroepen, noch condities. De resultaten die werden gevonden met de P300 amplitude waren verrassend: de P300 bias voor foto's van voedsel was significant groter in een staat van honger dan verzadiging bij slanke vrouwen, maar niet bij vrouwen met overgewicht/obesitas. Vrouwen met overgewicht/obesitas die ruim 17 uur niet hadden gegeten bleken geen significante aandachtsbias voor voedsel te vertonen, dit in tegenstelling tot de vrouwen met overgewicht/obesitas die een verzadigende milkshake hadden geconsumeerd en de slanke vrouwen in beide condities. Omdat P300 een maat voor vastgehouden aandacht lijkt te zijn die gevoelig kan zijn voor het gebruik van cognitieve strategieën, werd deze bevinding voorzichtig geïnterpreteerd als een neiging van vrouwen met overgewicht/obesitas om de aandacht af te wenden van voedselgerelateerde stimuli wanneer zij in een staat van honger zijn. Gespeculeerd werd dat zij net bij honger extra gevoelig zouden kunnen zijn om te over-eten. Dat vrouwen met overgewicht/obesitas bij honger een neiging hebben tot over-eten bleek op het eerste gezicht uit de resultaten van de valse smaaktest: de vrouwen met overgewicht/obesitas en honger waren degenen die het meest aten tijdens deze test. Het moet evenwel worden benadrukt dat alternatieve verklaringen mogelijk zijn voor zowel de P300-uitkomsten als de resultaten van de smaaktest. Replicatie-onderzoek is noodzakelijk vooraleer definitieve conclusies kunnen worden getrokken.

In deze studie werd ook gekeken naar correlationele patronen tussen de verschillende aandachtsmaten, de subjectieve ervaring van honger, de hoeveelheid gegeten tijdens het experiment en extern eten scores. Ook deze correlationele patronen bleken sterk afhankelijk van de gewichtsgroep. Over het algemeen leek de P300 amplitude een adequate index te zijn voor voedselgerelateerde motivatie bij slanke personen: positieve correlaties werden gevonden tussen de P300 amplitude bias, VAS honger, extern eten scores en de hoeveeldheid voedsel die werd gegeten tijdens de valse smaaktest. Voor de zwaarlijvige groep werden alleen positieve correlaties gevonden tussen de reactietijdbias in de 100 ms *visual probe task* en zelfgerapporteerde honger. Al bij al suggereren deze data dat bevindingen bij slanke populaties niet automatisch kunnen worden gegeneraliseerd naar zwaarlijvige populaties en vice versa. Geen verschil tussen beide groepen werd gevonden in de zelfgerapporteerde neiging tot extern eten (Nijs et al., in press).

In de studie die wordt beschreven in **hoofdstuk 6** werd aan obese en slanke proefpersonen, die 2 uur niet hadden gegeten, gevraagd om een klassieke Stroop-taak met voedselgerelateerde woorden uit te voeren. De Strooptaak is een taak die veel is toegepast in het kader van psychologisch aandachtsonderzoek. In deze studie werd tijdens het doen van de Strooptaak de hersenactiviteit van de proefpersonen geregistreerd middels EEG. Door zowel een vroege (P200; maat voor aandachtsoriëntatie) als een late (P300; maat voor vastgehouden aandacht) ERP-component te onderzoeken werd er naar gestreefd meer licht te werpen op de mechanismen van aandacht die ten grondslag liggen aan het Stroop interferentie-effect.

Een Stroop-interferentie effect (d.i. een tragere reactie bij het benoemen van de kleur van voedselgerelateerde dan neutrale woorden) werd gevonden bij alle proefpersonen, onafhankelijk van het lichaamsgewicht. Ook was de P300 amplitude uitgelokt door voedselwoorden in het algemeen groter dan de P300 amplitude uitgelokt door neutrale woorden, zonder significante verschillen tussen beide gewichtsgroepen. Verschillen tussen de obese en slanke proefpersonen werden gevonden met betrekking tot de amplitude van de P200 ERP-component uitgelokt door voedselwoorden: deze was significant groter voor obese dan slanke personen. Alleen de obese proefpersonen vertoonden een tendens tot een P200-bias voor voedselgerelateerde woorden (ten opzichte van neutrale woorden). Dit gegeven suggereert dat, in een vroeg stadium van informatieverwerking, obese personen sterker de aandacht richten op voedselgerelateerde stimuli dan slanke personen.

Geen significante samenhang werd gevonden tussen de reactietijdbias (het Stroop-intererentie-effect) en de biases in de ERP-amplitudes, zodat geen verdere uitspraak kon worden gedaan met betrekking tot de betekenis van de reactietijden in de Stroop-taak. Desalniettemin werden in de obese groep significante positieve correlaties gevonden tussen de reactietijdbias, het verlangen om te eten en de neiging tot extern eten. Dit duidt erop dat vertraagde reacties op voedselwoorden in een Stroop-taak gerelateerd zijn aan een verhoogde motivatie om te eten bij de blootstelling aan voedingsgerelateerde stimuli, althans bij obese personen. In de slanke groep werden significante positieve correlaties gevonden tussen de P200/P300-biasscores en het verlangen om te eten. De twee groepen verschilden opnieuw niet in de zelfgerapporteerde neiging tot extern eten.

Hoofdstuk 7 geeft een samenvatting en discussie van de resultaten van voorgaande studies. De hoofdconclusie van dit proefschrift is dat het vooralsnog niet mogelijk is om een eenduidig antwoord te geven op de vraag of personen met overgewicht/obesitas sterker reageren op voedselgerelateerde stimuli dan slanke personen in termen van aandacht, hunkering en eetgedrag. Dit is voornamelijk te wijten aan het feit dat er nog weinig onderzoek hiernaar is gedaan. Bovendien lijken onderzoeksresultaten af te hangen van de gekozen aandachtstaak, onderzoeksgroep en andere methodologische keuzes. Een aantal adviezen en ideeën voor toekomstig replicatie-onderzoek wordt hieronder opgesomd.

Het is essentieel dat er meer duidelijkheid komt omtrent welk mechanisme of aspect van aandacht wordt gemeten met verschillende aandachtsmaten. Verschillende aandachtsmaten lijken verschillende resultaten op te leveren, ook wanneer zij eenzelfde aandachtsmechanisme beogen te meten (bijvoorbeeld *oriented* of *maintained attention*). In toekomstig onderzoek lijkt het raadzaam directe en indirecte maten van aandacht te combineren en associaties tussen de uitkomsten van beide te onderzoeken teneinde meer inzicht te krijgen in hun betekenis. Onderzoekers dienen niet alleen na te denken over hun keuze van aandachtstaak bij de opzet van hun onderzoek, maar ook over andere methodologische zaken, die de studieresultaten kunnen beïnvloeden zoals de keuze van onderzoeksgroep (b.v. mannen en/of vrouwen), de duur van voedseldeprivatie (b.v. 2 uur of 17 uur), de wijze van verzadigen (b.v. milkshake of normale lunch), de opzet van een valse smaaktest (b.v. met snacks of gezonde keuzemogelijkheden), het tijdstip van het experiment et cetera. Om tot definitieve conclusies te komen lijkt replicatie-onderzoek noodzakelijk.

Ondanks onduidelijkheid omtrent de validiteit van sommige aandachtstaken kan uit dit proefschrift worden afgelezen dat personen met overgewicht/obesitas de neiging lijken te hebben om hun eerste focus van aandacht spontaan en automatisch te richten op voedselgerelateerde stimuli en dit in sterkere mate dan slanke personen. Dit werd in de studies van dit proefschrift geobserveerd aan de hand van 2 verschillende indices van de initiële oriëntatie van aandacht, namelijk de reactietijdbias in de 100 ms *visual probe task* (hoofdstuk 5) en de P200-amplitudebias voor voedselgerelateerde woorden in een Strooptaak (hoofdstuk 6). Het lijkt de moeite waard deze tendens verder te onderzoeken.

Op het eerste gezicht blijkt uit de studies in dit proefschrift dat er geen verschillen zijn tussen zwaarlijvige en slanke personen in *maintained attention* voor voedsel [zoals gemeten met de P300/LPP amplitude (hoofdstuk 3, 5, 6), de duur van oogfixaties (hoofdstuk 5), en de reactietijden in de 500 ms visual probe task (hoofdstuk 5)]. Toch werd ook enige evidentie gevonden voor de idee dat vrouwen met overgewicht/obesitas de neiging hebben minder aandacht te besteden aan voedselgerelateerde stimuli (d.i. niet méér dan aan neutrale stimuli) wanneer zij lange tijd niet gegeten hebben (zie P300-resultaten in hoofdstuk 5). Voor toekomstig onderzoek is het interessant om uit te zoeken of de P300-resultaten uit hoofdstuk 5 gerepliceerd en direct geassocieerd kunnen worden met mechanismen van bijvoorbeeld cognitieve vermijding.

Onderzoekers moeten bedacht zijn op het feit dat zelfrapportagematen niet altijd een zuivere weergave zijn van de subjectieve staat die ze beogen te meten en dat dit de resultaten kan vertekenen. Bijvoorbeeld, als verschillen werden gevonden in de rapportage van honger of het verlangen om te eten, dan waren het de slanke proefpersonen die meer honger/verlangen rapporteerden dan proefpersonen met overgewicht/obesitas. Het is mogelijk dat personen met overgewicht/obesitas (bewust of onbewust) gevoelens van honger/verlangen naar voedsel onderrapporteren (Stunkard, 1959), zoals zij ook, in sterkere mate dan slanke personen, lijken te doen bij rapportages van hun lichaamsgewicht (Dauphinot et al., 2009) of voedselinname (Goris et al., 2000). Al is dit zeer moeilijk omdat geen directe, objectieve maten voor honger/verlangen voorhanden zijn, toch zou toekomstig onderzoek een poging kunnen ondernemen om de validiteit van zelfrapportage-instrumenten voor honger en het verlangen naar voedsel systematisch te onderzoeken, met name in populaties met overgewicht/obesitas.

Ook voor andere eetgedraggerelateerde zelfrapportagematen, zoals de neiging tot extern eten, lijkt het nodig de validiteit in zowel slanke als zwaarlijvige populaties verder te onderzoeken. In de studies uit dit proefschrift werden geen verschillen gevonden tussen gewichtsgroepen in de zelfgerapporteerde neiging tot extern eten, al werd dit in ander onderzoek wel geregistreerd (b.v. Castellanos et al., 2009). In dit proefschrift werden aanwijzingen gevonden dat extern eten in slanke vrouwen geassocieerd is met een verhoogde aandacht voor voedsel, meer verlangen naar voedsel en een grotere calorie-inname bij de blootstelling aan snacks (hoofdstuk 4 en 5), maar dit wordt door een aantal recente studies tegengesproken (Johansson et al., 2004; Newman et al., 2008). Ook met betrekking to extern eten waren de correlationele patronen verschillend voor de gewichtsgroepen. Bij obese personen werd enkel een positieve associatie gevonden tussen de Stroop-reactietijdbias en extern-etenscores. Extern eten is een interessant en relevant construct in het huidige tijdperk waarin de omgeving een essentiële rol lijkt te spelen in de toenemende obesitascijfers. Daarom is het nodig in verder onderzoek uit te zoeken wat dit construct precies weergeeft en hoe het zich manifesteert in zowel slanke als obese populaties.

Bevindingen in slanke populaties lijken niet zonder meer generaliseerbaar naar obese populaties en vice versa. Dit bleek met name het geval te zijn voor de correlationele patronen die werden gevonden tussen maten van aandacht, verlangen, voedselinname en extern eten. Bijvoorbeeld, in de obese populatie lijken reactietijdmaten en adequate index te zijn voor de motivatie om te eten en in de slanke populatie lijken ERP-maten samen te hangen met honger en verlangen naar voedsel. Toekomstig onderzoek moet uitzoeken welke maten van aandacht de beste voorspeller zijn van hunkering naar voedsel en voedselinname, voor zowel slanke als obese personen.

Tot slot is het belangrijk om de mogelijkheid voor ogen te houden dat slechts een subgroep van obese personen in bepaalde situaties of toestanden in die mate reactief is ten aanzien van calorierijk voedsel dat de vergelijking met verslaving kan worden getrokken. In hoofdstuk 7 wordt voorgesteld om de volgende variabelen in toekomstig onderzoek te betrekken: de mate van impulscontrole, het voorkomen van eetbuien, de neiging tot negatief affect, stress en stressgevoeligheid, en genderverschillen. Voor het doen van uitspraken omtrent causale relaties tussen de dopaminerge neurotransmissie, aandacht, craving en voedselinname volstaat correlationeel onderzoek niet, maar zijn experimentele designs noodzakelijk waarbij de dopamine-afgifte en/of de mate van aandacht voor voedsel en/of het verlangen naar voedsel worden gemanipuleerd.

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Curriculum Vitae

Ilse Nijs was born in Tienen, Belgium, on June 13^{th}, 1974. She completed her secondary education (Latin and Greek) in 1992 at the Onze-Lieve-Vrouwecollege in Tienen. In 1998, she received a degree of 'gegradueerde' (c.f. bachelor; with credits) in Nutrition and Dietetics at the Regaschool Leuven (currently Katholieke Hogeschool Leuven). Few months after graduation, she moved to the Netherlands to start working as a research dietician/assistant at the Department of Human Biology, Faculty of Health Sciences, University of Maastricht. For five years she was actively involved in several research projects with regard to the effectiveness of various nutritional and dietetic interventions in patients with diabetes mellitus and/or obesity. In 2001, she decided to start an education in Mental Health Sciences at the University of Maastricht, in which she graduated cum laude in 2004. By 2004, she had moved to Rotterdam, where she worked, for a period of one year, as a research assistant and teacher at the Institute of Psychology, Faculty of Social Sciences, Erasmus University Rotterdam. Here, she started working as a PhD-student in 2005, studying attentional mechanisms in food craving and overeating in relation to obesity. Being a PhD-student, she followed an education at the Dutch-Flemish post-graduate school for research 'Experimental Psychopathology' (EPP). She also acquired ample experience in several teaching activities, such as supervising tutorial groups and practicals in the field of Clinical and Biological Psychology, giving lectures, and supervising research projects and theses of bachelor and master students. In 2009, she started working as an assistant professor at the Institute of Psychology, Erasmus University Rotterdam.

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Attentional Mechanisms in Food Craving and Overeating

Ilse Nijs