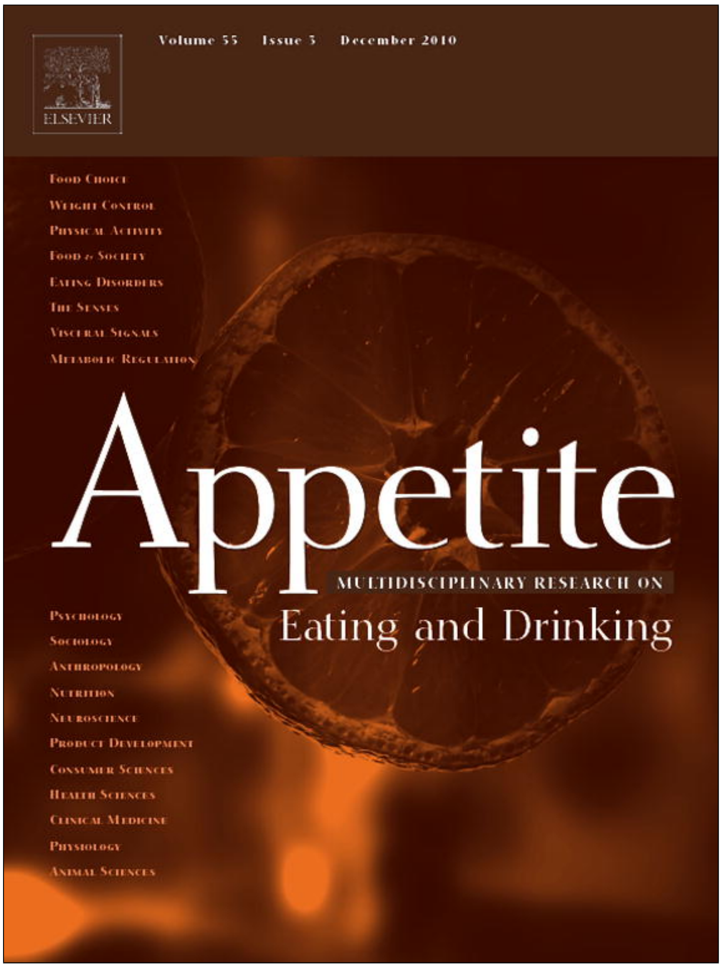
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Research report

Information processing of food pictures in binge eating disorder

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A B S T R A C T

Previous research has yielded evidence of attentional biases for food-related cues in binge eating disorder (BED) using behavioural measures such as the Stroop and dot probe paradigm. Being a more direct measure of attentional processing, the present study used event related potentials (ERPs) to test reactivity to high caloric and low caloric food pictures in women with BED compared to overweight healthy female controls (HC). In order to detect a possible motivational ambivalence, self-report and psychophysiological measures of the sympathetic and parasympathetic response system were assessed additionally. The main results yielded evidence that in women with BED high caloric food pictures elicit larger long latency ERPs compared to HC. By contrast, no such group difference was found for low caloric food pictures. Peripheral measures did not yield any group differences with respect to the processing of the caloric value of food. The results suggest that for women with BED, high caloric food may have high motivational properties and consume large parts of attentional resources. In the context of an environment in which high caloric food is omnipresent, such an abnormal processing may be relevant for the maintenance of the disorder.

Binge eating disorder (BED) is characterized by recurrent binge eating episodes and loss of control in the absence of compensatory behavior. Even though cognitive behavioral therapy (CBT) has proven to be effective with regard to the reduction of binge frequency (Brownley, Berkman, Sedway, Lohr, & Bulik, 2007; Reas & Grilo, 2008; Vocks et al., 2009; Wilfley & Cohen, 1997; Wilson & Shafran, 2005; Wonderlich, de Zwaan, Mitchell, Peterson, & Crow, 2003), 30–50% of treated individuals do not sustain from binge eating in long-term follow-up assessments (Brownley et al., 2007; Vocks et al., 2009; Wonderlich et al., 2003). Therefore there is a further need for more research focusing on mechanisms contributing to the aberrant eating behavior in BED.

In the past two decades, several studies yielded evidence of an attentional bias for food related cues in eating disordered and obese individuals by means of the Stroop task (Channon, Hemsley, & de Silva, 1988; Cooper, Anastasiades, & Fairburn, 1992; Fairburn, Cooper, Cooper, McKenna, & Anastasiades, 1991; Green & Rogers, 1993; Long, Hinton, & Gillespie, 1994), the visual dot probe task (Kemps & Tiggemann, 2009; Leland & Pineda, 2006; Nijs, Muris, Euser, & Franken, 2010; Rieger et al., 1998; Shafran, Lee, Cooper, Palmer, & Fairburn, 2007), the visual search paradigm (Smeets, Roefs, van Furth, & Jansen, 2008), and eye movement monitoring (Castellanos et al., 2009; but see also Nijs et al., 2010). With the exception of eye tracking studies however, these paradigms are behavioral and thus reflect a more indirect measure of attention allocation or information processing. In addition, the interpretation of Stroop and dot probe effects are difficult as results may stem from sensory inhibition or response competition effects (Dobson & Dozois, 2004; Lee & Shafran, 2004).

A more direct approach to assess food-related information processing is the measurement of event-related potentials (ERPs) by means of electroencephalography (EEG). With regard to motivated attention, the P300 component, and the following Late Positive Potential (LPP) and Slow Positive Wave (SPW) are of particular interest. Recent studies indicate that emotionally arousing pictures (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Palomba, Sarlo, Angrilli, Mini, & Stegagno, 2000) are associated with enlarged LPP amplitudes. In longer presentation of emotional pictures (6 s), LPP amplitudes are followed by SPW, which are thought to be a marker of sustained attention (Schupp, Flaisch, Stockburger, & Junghofer, 2006). For example, larger LPP and SPW have been demonstrated in subjects with specific phobias for fear relevant stimuli (Miltner et al., 2005) and in heroin dependent men for drug-associated cues compared to healthy controls (Franken, Hulstijn, Stam, Hendriks, & van den Brink, 2004; Franken, Stam, Hendriks, & van den Brink, 2003).

With regard to eating disorders, one study (Nijs, Franken, & Muris, 2009) found an enlarged P300 amplitude in response to food

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pictures in high compared to low external eaters. As no group differences were found in response to pictures of babies and office related items, the results suggest that high external eaters display an enhanced processing of food related information. In another study (Nijs, Franken, & Muris, 2008) obese individuals did not display larger P300 and LPP amplitudes to food stimuli when compared to normal weight controls. Thus, rather than being a function of weight, enlarged P300 and LPP may rather reflect an index of eating disorders symptoms. As such, using the Posner paradigm (Posner, Snyder, & Davidson, 1980) one study (Leland & Pineda, 2006) found an increased amplitude of a late positive component (P450) for food compared to neutral cues in subjects under food deprivation, which is an empirically well validated antecedent of binge attacks in bulimia nervosa (BN) and BED (Davis, Freeman, & Garner, 1988; Howard & Porzelius, 1999; Stein et al., 2007; Wilfley, Pike, & Striegel-Moore, 1997). In line with that, food deprivation and hunger have been shown to be associated with enlarged positive potentials to food pictures both at an early stage (~170–300 ms; Stockburger, Weike, Hamm, & Schupp, 2008) and also at a later stage of the processing stream indexed by the LPP in healthy university students (Stockburger, Schmalzle, Flaisch, Bublatzky, & Schupp, 2009). In hungry obese compared to satiated obese participants, by contrast, the P300 for food-related cues was reduced, in spite of the significant positive correlation between hunger reports and the amount of food eaten during a bogus taste task (Nijs et al., 2010). Thus, having more difficulties to keep control of their eating behaviour when confronted with food, hungry overweight individuals may intentionally use cognitive strategies to reduce an attentional bias to food-related stimuli (Nijs et al., 2010).

When looking at the association of ERPs and craving, several studies found a significant positive correlation between P300 and self-reported food craving (Nijs et al., 2009), and between the LPP/P300 and self-reported increases of hunger (Nijs et al., 2008). This is consistent with addiction related studies, which reported long-latency ERPs to be associated with self-reported cocaine craving or the motivation to use drugs (Franken et al., 2004; Lubman, Allen, Peters, & Deakin, 2007). Stronger food cravings have also been shown to be correlated with increased startle responding during food cue presentation in binge and food deprived subjects compared to controls (Drobes et al., 2001). Thus, on the one hand, the confrontation with food elicits an appetitive response as indicated by increased long latency ERPs. On the other hand, appetitive cravings seem to prompt an aversive motivational reaction as indicated by the association of food craving and the increased startle reflex.

This motivational ambivalence becomes apparent when considering two experiments conducted by Drobes et al. (2001). The authors investigated the impact of food deprivation (experiment one), binge and restrained eating patterns (experiment two) on psychophysiological, emotional and behavioural reactions to food-related and other cues (pleasant, unpleasant and neutral). Results of experiment one yielded evidence of an enhanced startle response during food compared to pleasant control cues in food-deprived, but not non-deprived subjects. This is coherent with their self-reported stronger arousal and stronger loss of control feelings to food cues. This stands in contrast though to Hawk, Baschnagel, Ashare, and Epstein (2004), who found a stronger reduction of the startle reflex magnitude in deprived participants during food picture viewing. However, while Drobes et al. (2001) did not allow subjects to consume food immediately after the experiment, participants in the Hawk et al. (2004) were given access to eat the food after the experiment. This suggests that in food deprived subjects food pictures elicit an aversive motivational reaction when food consumption is not possible. In fact, deprived subjects in the Drobes et al. (2001) also showed an elevated heart rate response while viewing appetitive food cues. Nevertheless, there were no group differences with respect to changes in skin conductance. Electromyography (EMG), on the other hand, revealed an increased zygomatic and a decreased corrugator activity in response to food cues in strongly deprived subjects compared to other subjects, which is a facial pattern associated with positive valence. Thus, food pictures seem to have activated an appetitive approach response (EMG). However, because immediate reward (i.e. actual consumption) was not possible, defensive reflexes such as the increased startle response were prompted. Similar conclusions can be inferred for binge subjects. As such, binge and deprived subjects (experiment two) rated food cues as significantly more pleasant and reacted with an increased startle reflex while viewing food pictures compared to undeprived controls and restrained subjects. This is consistent with Mauler, Hamm, Weike, and Tuschen-Caffier (2006) who found increased startle response while viewing food pictures in BN patients when compared to healthy controls. Consistently, food cues – compared to other cues –, elicited stronger increments of currogator activity in BN women, while there was no such difference in healthy controls.

Altogether, evidence from studies using event-related brain potentials and psychophysiological measures suggest that subjects with altered eating behaviours are characterized by a differential processing of food pictures when compared to healthy controls. Also, there seems to be discordance between different response-systems, which may reflect the ambivalent nature of food in eating disturbed individuals. Another important factor seems to be the motivational context of participants. As such, Blechert, Feige, Hajcak, and Tuschen-Caffier (2010) found comparable ERP responses to food cues in restrained and unrestrained eaters during a passive viewing condition. However, restrained eaters who were told that they would have to eat some of the presented food after the experiment (availability condition) showed a reduced LPP amplitude compared to restrained esters who had not previously received this instruction (viewing condition). A possible explanation is that restrained eaters exerted cognitive control over their motivational tendencies by successfully down-regulating the salience of food pictures in the availability condition. In fact, one study showed that exposure to food compared to a control object lead to an increase in heart rate, gastric activity and saliva in unrestrained, but not restrained eaters. As gastric activity significantly correlated with subsequent food intake, it can be concluded that unrestrained eaters prepared for food intake, while restrained eaters may have used some form of cognitive control to block the physiological responding to food exposure.

While the above mentioned studies mainly focussed on clinically healthy subjects brought in a state of food deprivation, overweight individuals or on individuals with bulimic symptoms, the food processing in BED has comparably been neglected. In line with an "addiction model of BED", Davis and Carter (2009) propose that weight cycling in BED patients may be an analogue to craving in drug abusers, as it reflects the repeated defeat of one's effort to refrain from binge eating. Furthermore, the over-consumption of food in BED is regulated by dopamine pathways, which are also responsible for the reinforcing effects of addictive drugs (Corwin, 2006; Kelley, Baldo, Pratt, & Will, 2005). Although studies on the relation between ERPs and craving in BED are still pending, neuroimaging studies suggest that similar neural mechanisms maintain drug craving and the desire for natural rewards such as food. Recently, Schienle, Schafer, Hermann, and Vaitl (2009) reported an increased activation of the reward-related brain regions (orbitofrontal cortex [OFC]) during the exposure to food stimuli in BED patients compared to BN patients and normal/obese healthy controls. Such increased OCF activity has also been shown to be implicated in drug craving (Volkow & Wise, 2005; Wang, Volkow, Thanos, & Fowler, 2004). Geliebter et al. (2006) used functional neuroimaging to compare neural responses to high-caloric, low-caloric and non-food pictures in a group of obese binge eaters, normal weight binge eaters, obese and normal weight healthy controls. Compared to healthy controls, the presentation of high-caloric food provoked greater right pre-motor activation only in obese binge eaters. The authors interpret this activation as binge eaters' preparation to eat binge food. This again stands in discordance to the lower salivation to food exposure found in obese binge eaters compared to obese healthy controls (Karhunen, Lappalainen, Tammela, Turpeinen, & Uusitupa, 1997). In binge eaters food exposure also elicits an increase of craving (Karhunen et al., 1997) and arousal as expressed by an increase in heart rate and blood pressure (Vögele & Florin, 1997). Therefore, inhibiting salivation may be the result of a cognitive effort to deal with increases in craving.

In light of the research just mentioned, the present study sought to assess food-related information processing by means of ERP and the simultaneous assessment of psychophysiological measures. By doing so, we hoped to assess multiple aspects of the ambivalent motivational state that food pictures would supposedly induce in BED patients. Given the methodological difficulty to implement central and peripheral nervous system parameters assessment in the same experiment, we decided to focus on large and enduring ERP components, namely the SPW - which has a latency window comparable to that of a skin conductance response or a change in heart rate—and the LPP, which occurs earlier but is large enough to "survive" the temporal and spatial filtering (see below).

As in the context of BED binge attacks mainly consist of high caloric food with high fat and sugar content (de Zwaan, Nutzinger, & Schoenbeck, 1992; Yanovski et al., 1992), we hypothesized that compared to overweight healthy controls, BED patients display an enhanced processing of high-caloric food pictures, as indexed by a larger SPW and LPP. By contrast, we expected similar SPW and LPP to low-caloric food pictures across the two groups. Analogue to that we expected BED patients to rate high caloric food pictures significantly more palatable than healthy controls. However, because high caloric food is the main food target when engaging in binge attacks we expected high caloric food pictures to prompt a state of motivational ambivalence. Therefore, we expected BED individuals to classify high caloric food pictures more often as forbidden than healthy controls, while no between group differences were expected for low caloric food pictures. We expected increased levels of heart rate, skin conductance, currogator activity and a decreased level of pulse transit time (corresponding an increase in vasoconstriction and blood pressure) in response to high-caloric pictures in BED patients compared to healthy controls, while we did not expect such group differences on low caloric food pictures. As context and availability of food have shown to modulate the emotional response in restrained eating (Blechert et al., 2010; Drobes et al., 2001; Friederich et al., 2006; Mauler, Hamm, Weike, & Tuschen-Caffier, 2006), we expected these differences to be particularly prominent in a condition where food items would be made available for participants compared to a passive viewing condition.

Method

Participants

Recruitment involved advertisements in local newspapers and ads in internet websites asking for overweight subjects with and without binge attacks. Our clinical group (BED) consisted of 22 female participants meeting the criteria of the *Diagnostic and Statistical Manual for Mental Disorders DSM-IV – Text Revision* (DSM-IV-TR; American Psychiatric Association APA, 2000) for BED. Exclusion criteria were the presence of substance abuse or addiction, bipolar disorder, current or past psychosis, schizophrenia, current suicidal ideation, pregnancy or lactation. As recent studies found evidence for an enhanced food-related cue reactivity in overweight/obese individuals compared to healthy controls (Castellanos et al., 2009; Nijs et al., 2010; Stoeckel et al., 2009, 2008) and women with BED are mostly overweight or obese (Cachelin et al., 1999; Striegel-Moore & Franko, 2003), the comparison of our BED sample to a normal weight group would not have given us the possibility to make assertions on the psychopathology of BED. Because we were interested in mechanisms concerning the psychopathology of BED and not the psychopathology of weight, women in our control group (HC; $n = 22$) were included if their Body Mass Index (BMI = weight/height^2) was ≥ 25; they also had to have an absence of a current or lifetime DSM-IV-TR diagnosis of a mental disorder, pregnancy or lactation. Diagnoses for eating disorders were established by means of the Eating Disorder Examination (EDE; Cooper & Fairburn, 1987; German version: Hilbert, Tuschen-Caffier, & Ohms, 2004). Diagnoses of all other disorders were determined by administration of the Structured Clinical Interview for DSM-IV Axis I (Spitzer, Williams, Gibbon, & First, 1992; (SCID); German version: Wittchen, Zaudig, & Fydrich, 1997). The study was approved by the ethics committee of the University of Freiburg.

Table 1
Participant characteristics.

Measure	BED ($n=22$)	HC ($n=22$)	Statistics	
	M (*SD*)	*M* (*SD*)	F^a	p^b
Age (years)	41.9 (13.9)	37.5 (13.6)	1.14	0.291
BMI (kg/m^2)	36.5 (6.85)	30.5 (3.88)	13.1	0.001
BDI	14.9 (8.58)	2.86 (2.83)	38.8	<0.001
$DEBQ_{RE}$	26.0 (6.12)	25.5 (6.88)	0.66	0.789
$DEBQ_{EE}$	39.4 (6.96)	20.6 (6.81)	16.0	<0.000
$DEBQ_{EX}$	37.0 (8.12)	28.2 (5.65)	16.0	<0.000
$DEBQ_{GLOBAL}$	104 (10.2)	75.9 (16.9)	40.1	<0.000
Binges/last month	13.7 (5.57)	–	–	–

Note: BED = group of women with binge eating disorder; HC = group of healthy controls; BDI = Beck Depression Inventory; DEBQ = Dutch Eating Behavior Questionnaire; GLOBAL = global score; RE = restraint eating subscale; EE = emotional eating subscale; EX = external eating subscale.
[a] *df*(1,43).
[b] $p < 0.05$.

Groups did not differ in age and self reported dieting on the restrained eating subscale of the Dutch Eating Behavior Questionnaire (DEBQ; Van Strien, Frijters, Bergers, & Defares, 1986). However, BED women scored higher on overall eating pathology and severity of depression as assessed by means of the DEBQ and the BDI (Beck, Steer, & Garbin, 1988), respectively. In addition, BMI was higher in women with BED than HC (see Table 1 for means [*M*] and standard deviations [*SD*]). Consistent with others (e.g., Hudson, Hiripi, Pope, & Kessler, 2007; Telch & Stice, 1998; Wilfley, Schwartz, Spurrell, & Fairburn, 2000; Yanovski, Nelson, Dubbert, & Spitzer, 1993), comorbidity in this group was high: 65.6% had a lifetime major depression, 15.5% a current major depression, 9.4% a panic disorder with agoraphobia, 6.3% a social phobia, 6.3% a generalized anxiety disorder, 3.1% a post traumatic stress disorder and 3.1% a somatization disorder.

Materials

Experimental design and picture stimuli

All food pictures were collected from various sources on the Internet and edited to be homogenous with respect to brightness, contrast, viewing distance and complexity (number of food items displayed in one picture). For high caloric food pictures, typical binge food, i.e. high on fat and sugar content (de Zwaan et al., 1992) was selected.[1] Low caloric food pictures mainly depicted fruit, vegetable items and crispbread.[2]

Participants first underwent a viewing section (VS) of food pictures, during which they were told to simply watch the following food pictures. Having watched these pictures, they were instructed to watch another series of food pictures, whereby some of the shown food would have to be tasted afterwards (availability section, AS). To make this realistic, a table with high caloric food items on it was placed next to the EEG cabin (however, after the AS participants did not have to taste any of the presented items). The 8.3×6.25 in. pictures were presented on a 17 in. monitor at 1 m viewing distance (14.25° horizontal and 9.09° vertical visual angle) via Presentation (Neurobehavioral Systems, Inc.: Albany, CA) and arranged in two blocks, each containing 10 high caloric food pictures and 10 low caloric food pictures. Two orders of picture presentation were constructed such that, across participants, each block was seen equally often in the VS and AS. Each picture was presented for six seconds followed by a 10–14 s inter-trial interval. The low number of pictures (and trials) for an ERP analysis represents a trade-off between the need for long stimulus durations and inter-trial intervals when measuring electrodermal activity or heart rate and the maximum tolerable duration of the entire experiment. To address the expected moderate signal-to-noise ratio (SNR) in the ERP – that is to say better than in single trials, but worse than in standard EPRs – without having to rely on calculation intensive wavelet or principal component analysis (PCA) based single-trial classification, we applied temporal and spatial filters which form the basis of many single-trial classification approaches (Dyrholm, Christoforou, & Parra, 2007; Lemm, Blankertz, Curio, & Muller, 2005; Model & Zibulevsky, 2006; Parra et al., 2002; Ramoser, Muller-Gerking, & Pfurtscheller, 2000; Smulders, Kenemans, & Kok, 1994).

Immediately after the experiment, participants rated the previously presented pictures with regard to palatability and forbiddance.

Self-report measures

Subjective feelings of hunger, food craving and emotions. All assessments of self-report were presented on the computer screen on an eight-point Likert-like scale, ranging from one (not at all) to eight (extremely). Self-reported food craving was computed by the sum of the following two items: *At the moment* . . . (1) I would really like to eat something, and (2) I could not resist a tasty meal. Analysis of reliability reached an acceptable Conbach's α of 0.76. Self-reported hunger was assessed by the item 'At the moment I feel hungry'. Assessed emotions included anger, sadness, anxiety, boredom and amusement.

Palatability. Participants rated all presented pictures with regard to palatability on a Likert-like scale ranging form 1 (not at all appetizing) to 9 (very appetizing).

Forbiddance. Forbiddance was presented as a dichotomous item (yes–no). In a second step, we aggregated the number of "yes" across all high caloric food pictures with 0 meaning that none of the presented high caloric food cues were rated as forbidden, and 20 meaning that all high caloric food pictures were rated as forbidden. The same procedure was adopted for the low caloric food pictures.

Psychopyhsiological measures

Electroencephalography

The EEG was recorded continuously with SynAmps ampliers and Scan 4.0 software (Neuro-Scan, Inc., Sterling, VA, USA) at a sampling rate of 500 Hz using 0.1 Hz hardware highpass and 100 Hz hardware lowpass filtering. Data was acquired from 33 Ag/AgCl electrodes of a modified 10–20-System electrode cap (EasyCap, Falk Minow Services, Herrsching-Breitbrunn, Germany; sensors at the sites FP1, FP2, F3, F4, F7, F8, FC5, FC6, Fz, Cz, C3, C4, CP1, CP2, CP5, CP6, FT9, FT10, T7, T8, TP9, TP10, Pz, P3, P4, P7, P8, O1, O2, below each eye (inferior orbital) and on the outer canthi of each eye near F9/F10). The ground electrode was positioned on the midline at AFz and Pz was used as the online reference. The bipolar signals between FP1/FP2 and corresponding inferior orbital sensors were used as VEOG, the bipolar signal between the outer canthi of each eye served as HEOG. Electrode impedance was kept below 5 kΩ (10 kΩ for VEOG and HEOG).

From the raw signals event-related epochs from 500 ms before to 6000 ms after stimulus onset were extracted, 40 Hz lowpass filtered, corrected for eye movement and eye blink artefacts (Gratton, Coles, & Donchin, 1983) and edited for artefacts using a statistical approach (Junghofer, Elbert, Tucker, & Rockstroh, 2000).

Generally, EEG data was of very good quality so that in both BED patients and healthy controls an average of nine epochs remained after artefact correction and could be used for averaging, equally for the high and low caloric picture contents and for the VS and AS section (BED, low caloric, VS: average = 9; min = 7; max = 10; BED, low caloric, AS: average = 8.70; min = 6; max = 10; BED, high caloric, VS: average = 9.33; min = 7; max = 10; BED, high caloric, AS: average = 8.62; min = 7; max = 10; HC, low caloric, VS: avg = 9.13; min = 7; max = 10; HC, low caloric, AS: average = 8.90; min = 7; max = 10; HC, high caloric, VS: average = 9.45; min = 7; max = 10; HC, high caloric, AS: average = 9.13; min = 7; max = 10).

Finally, clean EEG epochs were transformed to an average reference, low-pass filtered at 5 Hz, spatially smoothed using a Gaussian filter (FWHM[°] = 40.0) and averaged by conditions (VS/AS, high caloric food pictures/low caloric food pictures). The lowpass filtering and spatial smoothing was used to optimize signal-to-noise ratio for the SPW wave component. The averaged potentials were baseline corrected using the average level of the 500 ms before stimulus onset.

For statistical analysis of the LPP and SWP regional amplitudes were extracted as averages of the centro-parietal sensors C3, C4, CP1, Cz, CP2 and Pz and the latency windows from 500 to 800 ms (LPP) and 1000 to 6000 ms (SPW).

Peripheral measures

Peripheral psychophysiological signals were recorded using a Varioport device (Becker Engineering, Karlsruhe, Germany) at a maximum sampling rate of 2000 Hz.

Electrodermal activity (EDA) sampled at 64 Hz was recorded using two disposable Ag-AgCl electrodes filled with isotonic electrode gel attached to the volar surfaces of the digits two and three of the subjects's non-dominant hand (with a constant-voltage of 0.5 V passed between the electrodes) and manually edited for artifacts.

A standard Lead-II electrocardiogram (ECG) with 3 disposable electrodes sampled at 512 Hz was used to gain a raw ECG signal. R-waves were identified automatically by ANSLAB software (Wilhelm & Peyk, 2005), manually edited for artefacts, false positives or non-recognized R-waves and transformed into instantaneous interbeat intervals (IBI). Cubic spline interpolation

[1] The high caloric food pictures displayed the following items: cakes, chips, salty nuts, sandwiches with sausages and ketchup, mayonnaise, butter, chocolate, muffins, ice cream, etc.

[2] The low caloric food items displayed the following items: oranges, kiwifruit, grape fruit, puffed rice, crispbread, salads, vegetable plates, green squash, bell pepper, carrots, etc.

and resampling at 4 Hz were used to convert the IBI into an equidistant time series.

The pulse wave sampled at 512 Hz was measured by a plethysmograph transducer attached to the fourth digit of the participant's non-dominant hand. Minima, maxima and time points of the steepest upstroke were identified automatically by ANSLAB and also edited manually for artefacts. Pulse wave transit time to the finger (PTT, in milliseconds) was indexed by time elapsed between the closest previous ECG R-wave and the steepest upstroke of the peripheral pulse at the finger. Clean PTT data was transformed into an equidistant time series as described for the IBI.

The corrugator electromyography (EMG) raw recorded at a sampling rate of 512 Hz from 2 Ag/AgCl miniature electrodes filled with electrolyte attached bilaterally of the corrugator supercilii. The signal was 49–51 Hz bandstop filtered offline to minimize power supply interspersion, 22 Hz highpass filtered to remove baseline drifts and low frequency components, rectified, and smoothed using a 50 ms moving average window.

From the clean EDA, IBI, PTT and EMG signal, event-related epochs from 500 ms before to 6000 ms after stimulus onset were extracted, averaged by condition and baseline corrected using the average level of the 500 ms before stimulus onset.

Procedure

In order to bring all participants in a comparable hunger state and to exclude the effects of direct food intake on ERP response, participants were requested to eat a normal size meal (comparable to an average restaurant meal size) 3 h before testing, and to abstain from any food until the experiment was finished. Food intake was assessed in a bogus task, whereby the experimenter announced a saliva test allegedly being sensitive both to recent food consumption and long lasting food restriction (see Blechert et al., 2010; Drobes et al., 2001; Stockburger et al., 2008 for a comparable procedure). The experiment took place in a dimly lit, sound attenuated laboratory room connected to a control room were the experimenters sat. Upon arrival, participants were told that they were going to accomplish a series of experiments involving film clips and pictures, with the aim of learning more about their emotions. They were also told that between the film and picture experiment they would have a short pause. Then, two laboratory assistants attached the electrodes. After instructing participants on the film experiment, the assistants left the room and started with experimental procedures which are unrelated to this paper and were published elsewhere (Svaldi, Caffier, & Tuschen-Caffier, 2010). To ensure that the emotions elicited in the film experiment would not influence food cue responses in the subsequent experiment, participants rated several emotions and food craving four minutes after the film experiment. After this, participants had a pause of seven minutes, during which they remained seated in the lab. Then, they were instructed about the next experiment and were told, that they were going to watch a series of pictures.

Statistical analyses

Hypotheses were tested by means of univariate repeated measures analyses of variance (ANOVAs). If assumption of sphericity was not met (Mauchlys Sphericity Test: $p < 0.05$), degrees of freedom for dependent variables were corrected conservatively by Greenhouse-Geisser. Being exceedingly robust against violation of normality (Tabachnick & Fidell, 2007), univariate analyses were also adopted for variables not normal in distribution. Following Levine and Hullett (2002), effect sizes of the group differences and interactions are reported by eta squared (η^2; not partial η^2), whereby values up to 0.01 refer to small, 0.06 to moderate and 0.14 to large effect sizes (Cohen, 1988). For post hoc tests Cohen's d is reported, whereby values up to 0.2 refer to small, 0.5 to moderate, and 0.8 to large effect sizes (Cohen, 1988).

Results

Subjective feelings of hunger, food craving and emotions

No significant group differences were found with respect to hunger and food craving, neither were there significant group differences for anger, sadness, anxiety and boredom. There were, however, significant differences with regard to amusement, whereby women in the control group self-reported significantly higher amusement scores than women in the BED group (see Table 2 for *M*, *SD* and statistics).

Picture evaluation

Subjective ratings of food pictures revealed that women in the BED group rated high caloric food pictures significantly more often as forbidden than HC, $F(1,42) = 2.19$, $p = 0.024$, $d = 0.70$, while there was no such difference on low caloric food pictures, $F(1,42) = 1.76$, *ns*. There were no group differences with regard to ratings of palatability both for high caloric food pictures, $t = (1,42) = 1.51$, $df = 42$, *ns*, and for low caloric food pictures, $t = 1.80$, $df = 42$, *ns*. Instead, both groups rated high caloric food pictures significantly more palatable than low caloric food pictures, $t = -3.224$, $df = 21$, $p = .004$, $d = -0.90$ for HC, and $t = -2.044$, $df = 21$, $p = 0.050$, $d = -0.70$ for the BED group.

Event-related potentials

Late positive potential

The 2 (Group: BED, HC) × 2 (Picture section: VS, AS) × 2 (Caloric content: high caloric food pictures, low caloric food pictures) repeated measures ANOVA for the LPP revealed a significant main effect for Picture Section, $F(1, 42) = 9.67$, $p = 0.003$, $\eta^2 = 0.20$ (see Table 3 for M and SD and Figs. 1 and 2 for illustration).. Thereby, the LPP was significantly higher in the AS than in the VS. There was also a significant interaction of Group × Caloric Content, $F(1, 42) = 7.52$, $p = 0.009$, $\eta^2 = 0.15$. Post hoc analysis revealed that the LPP for high caloric pictures was increased in the BED group compared to healthy controls, $F(1,43) = 3.96$, $p = 0.053$, $d = 0.60$, while there were no group differences on low caloric food pictures, $F(1,43) = 0.22$, $p = 6.39$, $d = 0.14$. There were no other significant main effects or interactions.

Slow positive wave

A 2 (Group: BED, HC) × 2 (Picture section: VS, AS) × 2 (Caloric content: high caloric food pictures, low caloric food pictures) repeated measures ANOVA for the SPW revealed a significant main effect for Group, $F(1,42) = 6.00$, $p = 0.019$, $\eta^2 = 0.14$, whereby SPW amplitudes were larger in the BED group compared to HC (see Table 3 for *M* and *SD*). There was also a significant interaction of

Table 2
Mean (*SD*) of self-report measures on hunger, food craving and emotions.

Measure	BED ($n = 22$)	HC ($n = 22$)	Statistics	
	M (*SD*)	*M* (*SD*)	F[a]	P[b]
Anger	1.55 (1.40)	1.14 (0.64)	1.57	0.217
Sadness	1.90 (1.45)	1.86 (1.42)	0.007	0.935
Amusement	1.10 (0.31)	2.09 (1.82)	5.75	0.021
Boredom	3.85 (2.60)	3.09 (2.22)	1.04	0.314
Anxiety	1.10 (0.31)	1.18 (0.59)	0.309	0.581
Hunger	3.55 (2.61)	2.68 (2.26)	1.34	0.254
Craving	7.35 (4.66)	5.41 (3.90)	2.16	0.150

Note: BED = group of women with binge eating disorder; HC = group of healthy controls.
[a] $df(1,43)$.
[b] $p < 0.05$.

Table 3
Means (*SD*) of subjective and psychophysiological parameters.

	BED $n=22$				HC $n=22$			
	VS		AS		VS		AS	
	HCF	LCF	HCF	LCF	HCF	LCF	HCF	LCF
LPP	0.26 (2.16)	−0.90 (1.55)	0.76 (1.56)	0.50 (1.82)	−0.46 (1.51)	−0.17 (1.32)	−0.24 (1.28)	0.13 (1.50)
SPW	−0.23 (0.95)	−0.37 (0.70)	0.29 (0.97)	−0.16 (0.93)	−0.34 (0.54)	−0.40 (0.71)	−0.26 (0.73)	0.05 (0.80)
EMG	0.42 (1.16)	−0.16 (0.40)	0.18 (0.45)	−0.06 (0.21)	0.27 (0.56)	0.00 (0.42)	0.24 (0.76)	−0.01 (0.31)
IBI	3.32 (13.36)	2.85 (13.94)	4.53 (11.32)	−1.79 (16.02)	4.32 (18.45)	3.67 (11.21)	5.45 (24.81)	−5.19 (26.5)
PTT	0.62(1.17)	−0.19 (3.04)	0.19 (1.55)	−0.67 (3.73)	0.74 (3.29)	−0.70 (2.40)	0.90 (3.30)	0.26 (3.58)
SCL	−0.02 (0.02)	0.01 (0.03)	−0.01 (0.04)	0.00 (0.02)	−0.01 (0.03)	0.02 (.04)	−0.00 (0.04)	0.01 (0.04)
Self-report	HCF		LCF		HCF		LCF	
Forbiddance	7.32 (6.81)		0.05 (0.21)		3.09 (5.07)		0.14 (0.64)	
Pallatability	3.83 (1.19)		2.95 (1.31)		3.98 (1.68)		2.68 (1.18)	

Note: BED = group of women with binge eating disorder; HC = healthy controls; VS = viewing section; AS = availability section; HCF = high caloric food pictures; LCF = low caloric food pictures; LPP = Late positive potential [μV]; SPW = slow positive wave [μV]; EMG = corrugator supercilii electromyogram change [aU]; IBI = cardiac interbeat interval change [ms]; SCR = skin conductance responses [μS]; PTT = Pulse transit time change [ms]; forbiddance = frequency of food pictures classified as forbidden with concern to HCF and LCF; VS = viewing condition; AS = availability condition.

Group × Caloric Content, $F(1,42) = 7.61$, $p = 0.009$, $\eta^2 = 0.15$ (see Figs. 1 and 2). Post hoc tests revealed that the SPW to high caloric food pictures was significantly larger in women with BED compared to HC, $F(1,43) = 12.4$, $p = 0.001$, $d = 1.06$. There was no significant group difference with regard to the SPW in response to low caloric food pictures, $F(1,43) = 0.54$, $p = 0.463$, $d = 0.22$.

Psychophysiological measures

See Table 3 for *M* and *SD*, and Fig. 1 for the illustration. With regard to EMG, the 2 × 2 × 2 repeated measures ANOVA revealed a significant main effect for caloric content, $F(1, 41) = 10.4$, $p = 0.002$, $\eta^2 = 0.203$. Thereby, in both groups EMG activity was significantly increased in response to high compared to low caloric food pictures regardless of viewing condition. The 2 × 2 × 2 repeated measures ANOVA conducted for SCR yielded a significant main effect for Group, $F(1,39) = 4.35$, $p = 0.044$, $\eta^2 = 0.10$, as well as a significant main effect for caloric content, $F(1,39) = 16.2$, $p < .000$, $\eta^2 = 0.29$. Thereby, SCRs were significantly lower in the BED group and significantly reduced in response to high caloric food pictures compared to low caloric food pictures regardless of the viewing condition. With regard to PTT, the 2 × 2 × 2 repeated measures ANOVA revealed a significant main effect for caloric content, $F(1,36) = 3.97$, $p = 0.054$, $\eta^2 = 0.10$, but no main effect for group or any other significant interactions. Overall, PTT was significantly increased in response to high caloric food pictures compared to low caloric food pictures. For IBI, there was a marginally significant main effect for caloric content, $F(1,41) = 2.64$, $p = 0.111$, $\eta^2 = 0.05$; thereby, heart rate responses to high caloric pictures were lower in mean than low caloric pictures, *ns*. There were no other significant main effects or interactions for IBI.

Correlations

Subjective feelings of hunger and subjective craving as assessed prior to the beginning of the experiment were not significantly correlated with SPW and LPP. There were neither any significant correlations between SPW/LPP and the psychophysiological parameters, nor with palatability, forbiddance and BMI.

Discussion

The main aim of the present study was to assess food-related information processing by means of ERPs and the simultaneous assessment of psychophysiological measures. While long latency ERPs have shown to index attentional processes and motivational properties (Schupp et al., 2006), psychophysiological measures such as heart rate, pulse, electrodermal activity and electromyography reflect an individual's sympathetic and parasympathetic response system. Especially for individuals with disturbed eating patterns, the confrontation with food elicits a strong appetitive response, as shown by heightened ERP amplitudes (Nijs et al., 2008) and correlations with food craving and hunger (Nijs et al., 2008; Nijs et al., 2009). Such increased appetitive reactions have also been demonstrated for healthy individuals brought under conditions of food deprivation and hunger (Stockburger et al., 2009; Stockburger et al., 2008). On the other hand, for individuals with restrained eating and binge eating patterns, the confrontation with food also elicits aversive reactions as shown by increased startle and elevated heart rate responses (Drobes et al., 2001) and increments of the currogator activity (Mauler et al., 2006). On the background of the reported studies, we thought that individuals with BED would as well be characterized by such an ambivalent relation to food. Because during binges BED individuals mostly resort to high caloric food (de Zwaan et al., 1992; Yanovski et al., 1992), we thought that this ambivalence would be mostly present for high caloric food. Specifically, we hypothesized that compared to HC, BED participants display an enhanced processing of high-caloric food pictures as indexed by larger SPW and LPP amplitudes. We also expected BED participants to show an increased sympathetic reaction in response to high caloric food pictures – as expressed by increased levels of heart rate, skin conductance and currogator activity. Because the motivational context has shown to be of relevance (Blechert et al., 2010; Drobes et al., 2001; Hawk, Baschnagel, Ashare, & Epstein, 2004), we expected these differences to be more pronounced when subjects were told that some of the presented food items would have to be tasted after the experiment compared to a condition in which subjects had to just passively watch the food items. By contrast, no group differences in SPW and sympathetic measures were expected for low caloric food pictures. On the self-report level, we expected both groups to evaluate high caloric food pictures being more palatable than low caloric food pictures, but that BED individuals would more frequently classify high caloric food pictures as forbidden compared to overweight healthy controls.

We found evidence that in women with BED high caloric food pictures elicit larger LPPs and SPWs compared to HC. Overall, these effects were large for the SPW and medium for the LPP. By contrast, no such group difference was found for low caloric food pictures. This suggests that for women with BED, high caloric food pictures have strong motivational properties and consume large parts of attentional resources. To ensure that the results would not be due to differences in the level of hunger and craving (Stockburger et al., 2009; Stockburger et al., 2008), we assessed these variables prior to

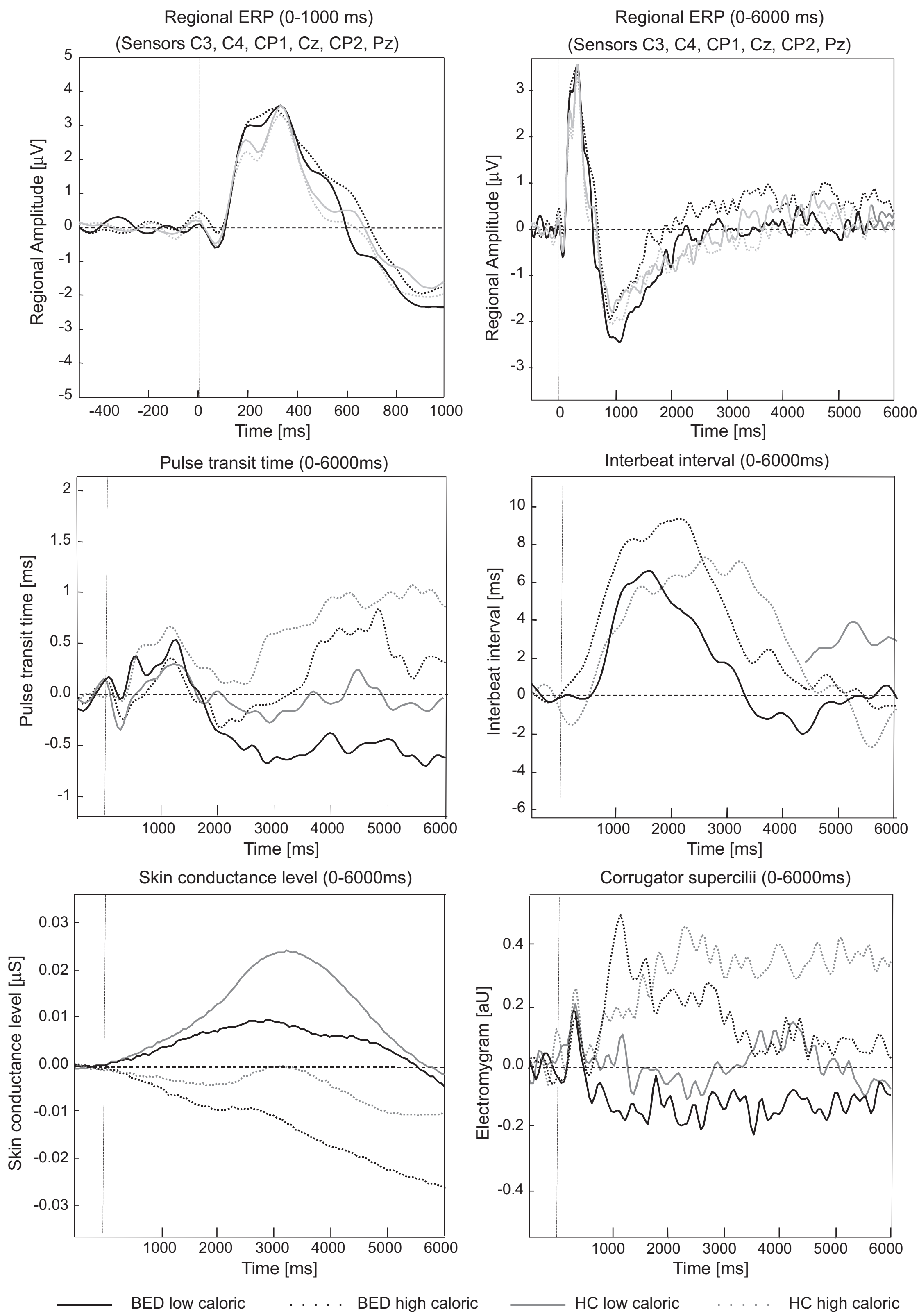

Fig. 1. One and six seconds evoked potentials (regional average across centro-parietal sensors; low pass filtered and spatially smoothed), pulse transit time, ECG interbeat interval, skin conductance response and corrugators supercilii myogram for high and low caloric conditions for BED patients and healthy controls (HC).

the picture presentation, whereby both groups were comparable on actual hunger and craving. Unfortunately, we did not reassess these variables after the experiment. However, on the background of studies which found positive correlations between long latency ERPs and self reported craving and self reported increases of hunger (Nijs et al., 2008, 2009), the increased ERPs in response to high caloric food pictures in our BED group may be interpreted as an index of increased craving. Nevertheless, in addition to the assessment of ERPs in response to food cues, future studies with BED participants should also continuously assess actual craving.

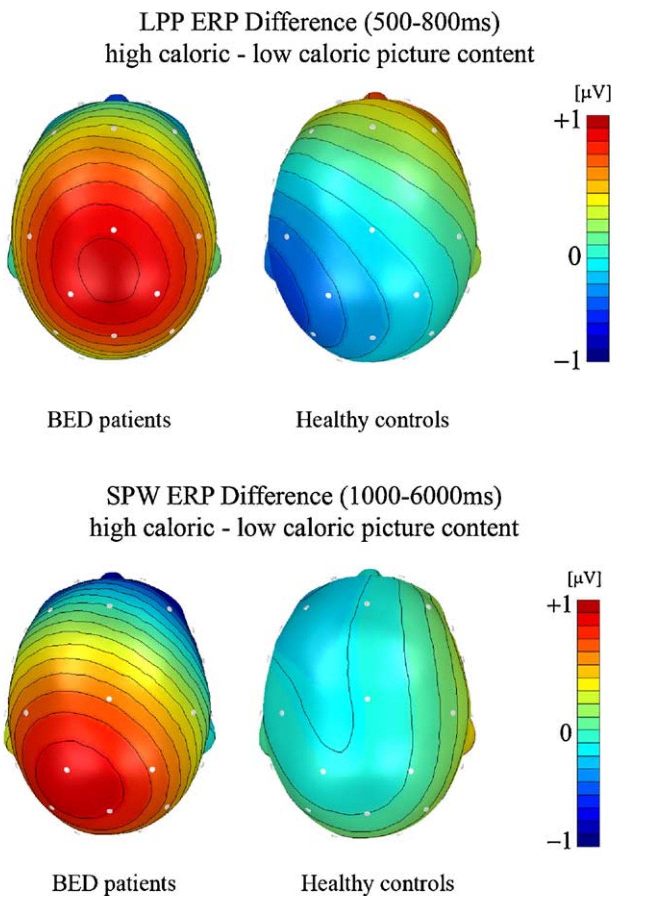

Fig. 2. Topographical maps of potential differences between high caloric and low caloric conditions for LPP (500–800 ms post stimulus onset) and SPW (1000–6000 ms post stimulus onset) for BED patients and controls. Maps indicate a differentiation of caloric content at centro-parietal sites for BED patients but not for controls.

Contrary to restrained eaters (Blechert et al., 2010; Drobes et al., 2001; Friederich et al., 2006; Mauler et al., 2006), availability of food did not modulate the emotional response in the BED group, probably because in BED bingeing occurs within the context of chaotic, less restrained eating (Wilfley et al., 2000). Oddly, the LPP but not the SPW was significantly higher in the condition where participants were told that they would have to eat some of the food after the experiment. A possible reason for this unexpected finding may be that we have not systematically varied the order of the viewing and the availability sections. It would be interesting for future studies to investigate actual food intake (e.g., in a taste task) following the attention task and compare this to the simple presentation of food pictures in a between group design.

Overall, both groups rated high caloric food pictures as more palatable than low caloric food pictures. However, high caloric food pictures were more frequently classified as forbidden in BED participants compared to HC. Hence it is possible that high caloric food may be more forbidden to BED patients because it is highly appetitive and appealing to them (as shown by the increased ERPs). The fact that there was no significant correlation between forbiddance and ERPs, though, speaks against this assumption. On the other hand, a reason for the non-significant correlation could also be the reduced variance given because of our dichotomous – instead of the continuous – assessment of forbiddance.

While ERPs seem to be a measure which differentiates between BED and overweight healthy controls, most peripheral measures did not yield group differences with respect to the processing of the caloric value of food. Skin conductance however revealed interesting decreases for high caloric food, and BED patients showed generally a stronger decrease than HC when viewing any kind of food pictures. As SCR increases with higher stimulus-induced arousal (Boucsein, 1992), this finding seems to suggest a soothing effect of food, which was generally larger in BED patients. The general increment in PTT for high caloric food in both groups can be interpreted in a similar manner, as a decrease in blood pressure indicates a reduction of sympathetic arousal.

However, currogator activity revealed a simultaneous increment of distress elicited by high caloric food pictures in overweight women with and without BED. Contrary to Drobes et al. (2001) who found a facial pattern associated with positive valence, our EMG results possibly indicate a greater aversion which overweight subjects may have learned to associate with the sight of high caloric food. The IBI and PTT patterns found in our study match well with the brief bradycardia one would expect as part of an orienting response towards a stimulus (Barry, 1996), but the influence of caloric content or subject group did not reach significance. Future research will need to investigate reasons behind this contradiction and it may be useful to compare BED subjects to overweight and normal weight individuals in the same study.

The experimental procedure in this study was designed to allow for the assessment of a broad set of physiological parameters. As a consequence, the number of trials was low for an ERP experiment and our findings need replication with better signal-to-noise ratios. This and the applied spatial and temporal filtering made it impossible to analyze earlier ERP components which have been shown to be sensitive for motivational relevance, such as the Early Posterior Negativity (Junghofer, Bradley, Elbert, & Lang, 2001). Moreover, a larger EEG sensor set with better head coverage would be desirable, to better justify the average reference and allow inverse modeling of neuronal generator structures. On the other hand, our filtering approach and reference choice should be statistically conservative and the robustness of the reported effects make us confident about their reliability. Concerning the processing of food pictures by BED patients, our data successfully illustrate the complexity and possible conflicting tendencies in multiple response systems.

Being small in sample size, our data is preliminary; nonetheless we found neurophysiological evidence that information processing of high caloric food pictures is abnormal in women with BED. Even though BMI was not correlated to ERPs, future studies should match the control group on BMI. Last but not least, even though ERPs to high caloric food pictures were increased in BED participants, it remains yet to be studied whether the increased processing is a consequence or an antecedent and whether it is related to the maintenance of the disorder.

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