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Mood-induced changes in the cortical processing of food images in bulimia nervosa

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ABSTRACT

Background: Negative mood often triggers binge eating in bulimia nervosa (BN). We investigated motivational salience as a possible underlying mechanism using event-related potentials (ERPs) as indicators of motivated attention allocation (P300) and sustained processing (LPP).

Methods: We collected ERPs (P300: 350–400 ms; LPP: 600–1000 ms) from 21 women with full-syndrome or partially remitted BN and 21 healthy women (HC), matched for age and body mass index. Idiosyncratic negative and neutral situations were used to induce corresponding mood states (counterbalanced), before participants viewed images of high- and low-calorie foods and neutral objects, and provided ratings for pleasantness and desire to eat.

Results: P300 was larger for foods than objects; LPP was largest for high-calorie foods, followed by low-calorie foods, then objects. The BN group showed an increased desire to eat high-calorie foods under negative mood and stronger mood induction effects on ERPs than the HC group, with generally reduced P300 and a small increase in LPP for high-calorie foods. Effects were limited to circumscribed electrode positions. Exploratory analyses showed clearer effects when comparing high vs. low emotional eaters.

Conclusion: We argue that negative mood decreased the availability of cognitive resources (decreased P300) in BN, thereby facilitating disinhibition and food cravings (increased desire-to-eat ratings). Increased sustained processing might be linked to emotional eating tendencies rather than BN pathology per se, and reflect approach motivation, conflict, or regulatory processes. Negative mood appears to induce complex changes in food image processing, whose understanding may contribute to the development of tailored interventions in the future.

1. Introduction

Bulimia nervosa (BN) is characterised by recurrent loss of control over eating, resulting in the consumption of large amounts of food in a discrete period of time (binge eating), and compensatory behaviours, such as self-induced vomiting (American Psychiatric Association, 2013). Binge eating is often preceded by negative mood in everyday life (Haedt-Matt & Keel, 2011). The brain mechanisms underlying emotion-induced binge eating remain poorly understood; a better understanding would be important for the improvement of interventions.

In general, acute stress is assumed to decrease eating behaviour through activation of the sympathetic nervous system (Torres & Nowson, 2007). Yet, a subgroup of healthy individuals shows a tendency to overeat in response to negative emotions (van Strien, Frijters, Bergers, & Defares, 1986). Several theories have been proposed to explain emotional eating (for reviews see Reichenberger, Schnepper, Arend, & Blechert, 2020; Vögele, Lutz, & Gibson, 2017). Among others, restraint theory posits that chronic dietary restraint can lead to disinhibited eating under certain conditions, e.g., when experiencing negative emotions (Herman, Polivy, Lank, & Heatherton, 1987; Ruderman, 1985). According to emotion regulation theories, negative emotions increase the motivation to eat, and eating in turn decreases negative emotions (Macht & Simons, 2011). Applying these processes to eating disorders, transdiagnostic theory (Fairburn, Cooper, & Shafran, 2003)

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suggests that BN patients initially binge eat in response to negative emotions because these undermine their ability to restrict food intake. Binge eating is then maintained by an alleviation from negative mood states. In consequence, experiencing negative mood is assumed to increase motivation towards food in BN.

In the substance use literature, the affective processing model of negative reinforcement suggests that negative emotions bias stimulus processing by increasing incentive salience of substance-related stimuli (Baker, Piper, McCarthy, Majeskie, & Fiore, 2004). Food stimuli are associated with high motivational salience in healthy individuals. Several reviews conclude that attentional bias for food stimuli is increased in eating disorders (Aspen, Darcy, & Lock, 2013; Brooks, Prince, Stahl, Campbell, & Treasure, 2011; Giel et al., 2011), but others report mixed results (Stojek et al., 2018; Werthmann, Jansen, & Roefs, 2015). Inconclusive results regarding attentional bias for food in overweight/obese individuals led to the suggestion that momentary factors, e.g., mood, could be more relevant than trait factors in determining attentional bias (Field et al., 2016).

Negative mood induction increases attentional bias (sustained attention) towards unhealthy food in women with food addiction (Frayn, Sears, & von Ranson, 2016), desire to binge in BN (Hilbert, Vögele, Tuschen-Caffier, & Hartmann, 2011), and actual food intake in non-clinical restrained eaters (Evers, Dingemans, Junghans, & Boevé, 2018). In terms of underlying mechanisms, imaging research has found spontaneous negative mood to be associated with increased activity in reward-related brain areas when individuals with BN anticipated food consumption (Bohon & Stice, 2012). Yet, to date, there is no systematic investigation of the effects of experimentally induced negative mood on food-stimulus processing in BN. Event-related potentials (ERPs) offer high temporal resolution and the possibility to investigate sub-processes underlying behavioural and self-report measures.

The processing of motivational salience is, among others, reflected in ERPs occurring after 300 ms after stimulus onset, which are typically larger for emotional than neutral stimuli (Hajcak, Macnamara, & Olvet, 2010; Olofsson, Nordin, Sequeira, & Polich, 2008). The P300 is described as a component peaking at parietal locations between 300 and 500 ms after stimulus onset and reflecting motivated attention allocation, while the ensuing centro-parietal LPP reflects sustained attentional processing and memory encoding (Dolcos & Cabeza, 2002; Hajcak et al., 2010). P300 amplitude is influenced by "task-relevance, motivational significance, arousal level and the influence of these factors on mental resource allocation" (p.7; Olofsson et al., 2008). During the LPP, "top-down processes such as emotional evaluation or suppression appear to interact with affective stimulus activation (…) as do memory encoding processes" (p.8; Olofsson et al., 2008).

Substance users consistently show larger P300 and LPP amplitudes for substance-related than neutral pictures (Littel, Euser, Munafò, & Franken, 2012). ERP amplitudes are correlated with self-reported substance craving (Field, Munafò, & Franken, 2009). It has been suggested that craving is particularly associated with late attentional processing (i.e., LPP), "because it is a form of rumination whereby food/eating-related information is rehearsed in working memory" (p.30; Hardman et al., 2020). In addition, the LPP is sensitive to the regulation of responses to emotional and food stimuli (Giraldo, Buodo, & Sarlo, 2019; Myruski, Bonanno, Cho, Fan, & Dennis-Tiwary, 2019).

Food as a motivationally salient cue elicits larger P300 and LPP amplitudes than neutral stimuli (Carbine et al., 2018; Nijs, Franken, & Muris, 2008; Nijs, Frankena, & Muris, 2010; Nijs, Muris, Euser, & Franken, 2010; Sarlo, Ubel, Leutgeb, & Schienle, 2013). Research on ERPs in eating disorders is scarce, but points towards increased processing of food images (Delgado-Rodríguez et al., 2019; Novosel et al., 2014; Wolz, Fagundo, Treasure, & Fernández-Aranda, 2015; Wolz et al., 2017), also in BN (Blechert, Feige, Joos, Zeeck, & Tuschen-Caffier, 2011), with some evidence that high- and low-calorie foods may be processed differently (Novosel et al., 2014; Svaldi, Tuschen-Caffier, Peyk, & Blechert, 2010), possibly reflecting the tendency of patients to binge on high-calorie foods (Hadigan, Kissileff, & Walsh, 1989). First ERP studies on mood-induced changes in the motivational processing of food stimuli showed that, in healthy women, restrained or emotional eating styles can be associated with increased P300 or LPP amplitudes for food pictures after negative mood induction (Blechert, Goltsche, Herbert, & Wilhelm, 2014; Schnepper et al., 2020).

We used idiosyncratic scripts of recent, aversive events (Blechert, Goltsche, & et al., 2014; Hilbert et al., 2011) to induce moderate levels of negative affect in women with and without BN. We expected this to increase motivational salience of food images in the BN group, as indicated by increased desire-to-eat ratings (Hyp.1). Regarding P300 and LPP, we expected a general differentiation between high- and low-calorie foods and objects (Hyp.2) and a mood-induced change specific for the BN group, in terms of increased amplitudes for high-calorie foods under negative mood (Hyp.3). This allows us to investigate if, analogous to models of substance use (Baker et al., 2004), negative mood triggers binge eating by increasing motivational salience to food stimuli in BN.

Table 1
Age, BMI, and socioeconomic status of the BN and HC groups.

	BN (n = 21)	HC (n = 21)	
	M (SD) range	M (SD) range	Test statistics
Age	31.71 (11.45) 18–56	31.38 (10.24) 19–56	$t_{40} = 0.099$, $p = .92$, $d = 0.031$
BMI	23.62 (3.37) 19.00–32.70	23.97 (3.20) 19.04–31.68	$t_{40} = -0.35$, $p = .73$, $d = 0.11$
ISCED (participant)[a]	$Mdn = 3.00$ 2–7	$Mdn = 6.00$ 2–7	$U = 199.50$, $p = .58$
Restrained eating (DEBQ)	33.24 (7.11)	23.48 (6.86)	$t_{40} = 4.53$, $p < .001$, $d = 1.40$
Emotional eating (DEBQ)	48.01 (11.75)	28.38 (10.22)	$t_{40} = 5.78$, $p < .001$, $d = 1.78$
External eating (DEBQ)	34.14 (7.40)	30.57 (4.70)	$t_{40} = 1.87$, $p = .069$, $d = 0.58$
Drive for Thinness (EDI-2)	31.33 (7.84)	15.71 (4.21)	$t_{30.63} = 8.04$, $p < .001$, $d = 2.48$
Bulimia (EDI-2)	28.05 (8.63)	10.33 (2.67)	$t_{23.80} = 8.99$, $p < .001$, $d = 2.77$
Body Dissatisfaction (EDI-2)	36.24 (11.17)	27.33 (8.71)	$t_{40} = 2.88$, $p = .006$, $d = 0.89$
CES-D	8.29 (6.83)	5.38 (2.09)	$t_{23.70} = 1.87$, $p = .075$, $d = 0.58$
STAI-T	49.62 (14.11)	37.67 (10.07)	$t_{40} = 3.16$, $p = .003$, $d = 0.98$

Note. Effect size is Cohen's d.
BN = bulimia nervosa, HC = healthy control, BMI = body mass index, ISCED = International Standard Classification of Education (United Nations Educational Scientific and Cultural Organization, 2012), DEBQ = Dutch Eating Behaviour Questionnaire, EDI-2 = Eating Disorder Inventory-2, CES-D = Center for Epidemiologic Studies Depression Scale, STAI-T = State-Trait Anxiety Inventory-Trait.
[a] As ISCED scores are ordinally scaled, the median is reported and group differences were tested with the Mann-Whitney-U test.

2. Method

2.1. Participants

Adult, non-underweight, female participants were recruited from the general population. Exclusion criteria included neurological disorders, pregnancy and breast feeding, medical conditions or medication affecting eating behaviour. All participants were interviewed individually with the Eating Disorder Examination (EDE; Fairburn & Cooper, 1993) and the Structured Clinical Interview for DSM-IV (SCID-IV; First, Spitzer, Gibbon, & Williams, 2002). We tested 22 women with current full-syndrome or partially remitted BN according to DSM-5 criteria (American Psychiatric Association, 2013) and age- and BMI-matched healthy control women (HC), without lifetime ED and current mental

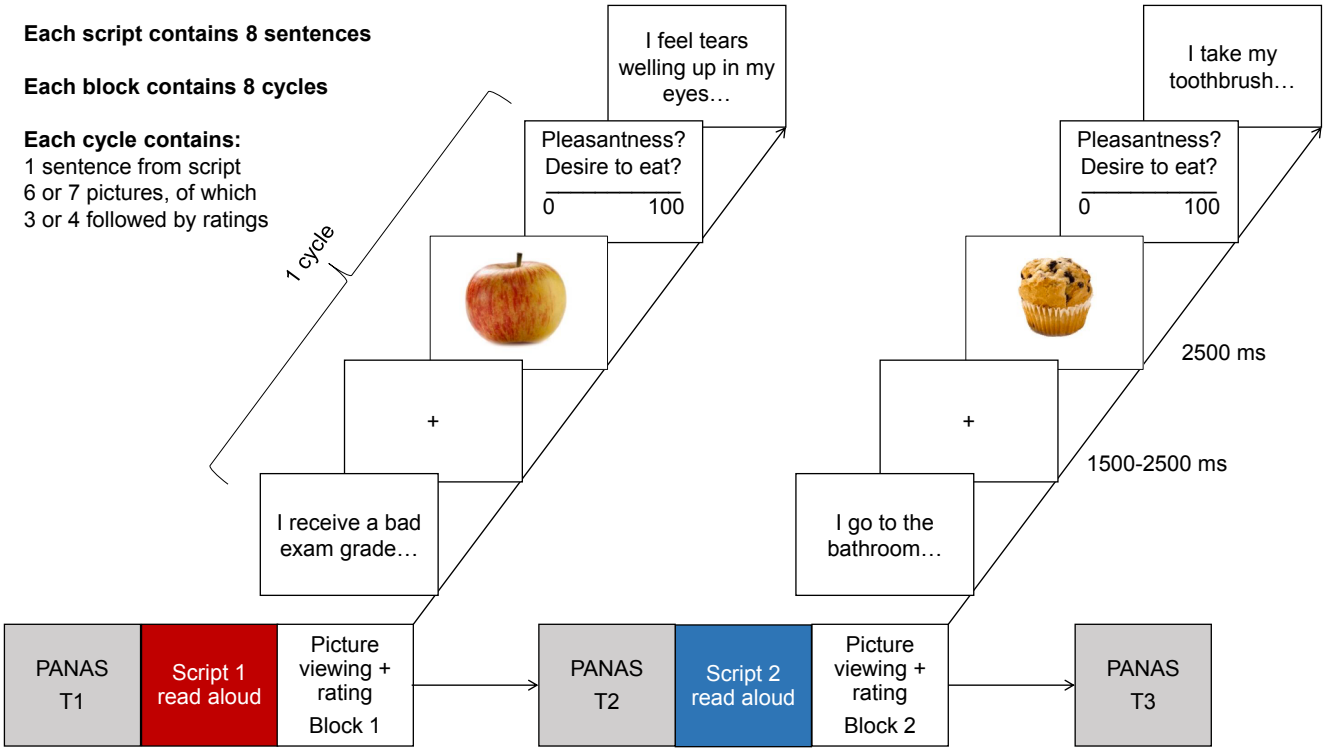

Fig. 1. Flow chart of the experimental paradigm. First, mood was assessed with the Positive and Negative Affect Schedule (PANAS), see Appendix A. Then, the experimenter read the first mood induction script aloud to the participant. The following screen presentation contained eight cycles. Each cycle started with a sentence from the script. Participants were asked to read the sentence and continue once they vividly remembered the situation. This was followed by 6 or 7 pictures (the total number of pictures did not divide evenly). Half of the pictures, i.e. 3 or 4, were followed by pleasantness and desire-to-eat ratings (each picture was presented twice, but only rated once). The order, in which negative and neutral mood were induced, was counterbalanced across participants. Practice trials of picture viewing and rating were performed before the first mood induction. The PANAS was repeated after the first and after the second block.

disorder. Two data sets had to be excluded (flat line on EEG reference channel, outlier on the P300 and LPP components), resulting in 21 women in the BN and HC groups respectively ($N = 42$; 12 with full-syndrome and 9 with partially remitted BN). Three BN patients were currently under psychoactive medication and nine had comorbid mood and/or anxiety disorders, and/or partially remitted posttraumatic-stress disorder. The BN group had significantly higher scores than the HC group (large effect sizes) on restrained and emotional eating, eating disorder pathology (drive for thinness, bulimia, body dissatisfaction), and trait anxiety. External eating and depressive symptoms showed non-significant differences of medium effect size. See Table 1 for an overview of sample characteristics and Appendix A for information on the questionnaires. The subgroups of full-syndrome vs. partially remitted BN and with vs. without comorbid disorders did not differ significantly on any of the trait questionnaires (see Appendix B).

2.2. Procedure

The University of Luxembourg's Ethics Review Panel approved the study. Participants provided written informed consent. The data were collected as part of a larger project, see Appendix C. Participation was reimbursed with gift vouchers (EUR 150). Participants were instructed to consume a standardised meal (~550 kcal) three hours prior to testing and to consume nothing but non-carbonated water afterwards. The experiment was presented with E-Prime 2.0 (Psychology Software Tools, Sharpsburg, PA).

The experimental procedure was based on Blechert, Goltsche, and et al. (2014) and is depicted in Fig. 1. First, an idiosyncratic mood induction was performed, following Hilbert et al. (2011). Participants reported a recent situation, which had elicited negative emotions/distress and was well remembered, excluding traumatic events. The experimenter scripted eight sentences on the situation, thoughts, emotions, and sensations. Participants chose one of two pre-scripted neutral situations (brushing their teeth or going to work/school) of eight sentences and adapted the sentences according to their memory. It was verified that the neutral situation was well remembered and did not elicit negative mood or distress (see Appendix D).

Following a one-minute guided relaxation, the experimenter read out the negative and neutral scripts via intercom in counterbalanced order. After each script, 104 pictures were presented in random order: 2 × 26 food items (13 high-calorie, 13 low-calorie foods) and 2 × 26 household objects. Images were taken from the food pics database (Blechert, Meule, Busch, & Ohla, 2014) and matched for colour, luminance, and complexity. Each image was rated for pleasantness (food, objects) and desire to eat (food) on a visual analogue scale ranging from 0 (*very unpleasant / no desire to eat*) to 100 (*very pleasant / strong desire to eat*). The sentences, which had previously been read out, were repeated interspersed between the pictures to refresh the mood induction. The laboratory session ended with a debriefing, during which participants had the possibility to discuss their experiences during testing with the

Table 2
ANOVA results for positive and negative affect (PANAS).

Effect	*F*	*df*	*p*	η_p^2
Affect	37.37	1, 38	<0.001	0.50
Affect × Time	5.45	1, 76	<0.01	0.13
Affect × Time × Order	7.71	1, 76	<0. 01	0.17
Affect × Time × Order × Group	0.28	1, 76	0.76	0.007

Note. The table summarises significant effects ($p < .05$) and the four-way interaction, indicating that mood induction was successful and did not differ between groups.
PANAS = Positive and Negative Affect Schedule.

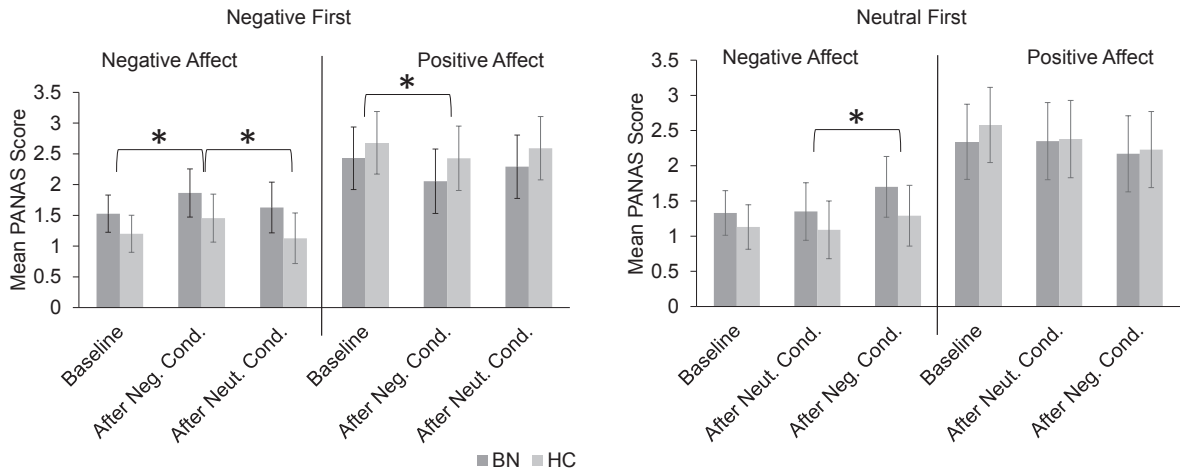

Fig. 2. Mean scores for negative and positive affect (PANAS). The left panel shows the results for participants who received the negative situation first. The right panel shows the results for participants who received the neutral situation first. The results are displayed separately for the BN (dark grey bars) and the HC (light grey bars) groups; note that there was neither a main effect for group, nor a four-way interaction with group. The PANAS was scored from 1 (*very slightly or not at all*) to 5 (*extremely*). For each participant, an average score was calculated over the 10 positive and 10 negative affect items, respectively. Asterisks indicate significances for the post-hoc tests of the three-way interaction Affect × Time × Order. Error bars represent 95% CI. BN = bulimia nervosa group; HC = healthy control group; PANAS = Positive and Negative Affect Schedule.

experimenter, who ensured that participants left the laboratory in a neutral mood state.

2.3. EEG recording and analysis

Data was recorded with a 64-channel actiCAP electrode system (Ag/AgCl electrodes, 10/20-system, reference FCz, impedances <20 kΩ) with BrainAmp amplifiers (Brain Products, Gilching, Germany), at a sampling rate of 1000 Hz and high-pass filtered at 0.016 Hz, including horizontal and vertical EOG channels (Ag/AgCl). BrainVision Recorder and Analyzer were used for data recording and processing (Brain Products, Gilching, Germany).

Offline, data were resampled at 250 Hz and re-referenced to mathematically linked mastoids (TP9-TP10). A 50 Hz notch filter was applied, as well as a 24.5 Hz high-cutoff half-power filter (24 dB/octave slope), which is equivalent to a 30 Hz half-amplitude filter (Luck, 2014). A semi-automatic raw data inspection and ocular correction independent component analysis (ICA) were performed (see Appendix E). Faulty EEG channels were excluded before, and interpolated after ICA (36 channels in total). Segments (−500 to +2500 ms) were semi-automatically checked for artefacts. The remaining segments (≥40 for objects; ≥20 each for the high- and low-calorie foods; percent of missing data 3.11–6.59%, see Appendix E) were baseline corrected (−200 to 0 ms), shortened to −200 to +2000 ms, and averaged.

For the identification of relevant components, grand average waveforms and topographies were visually inspected and the extant literature was consulted. The P300 component is known to have a parieto-occipital maximum between 250 and 400 ms (Polich & Kok, 1995). In the present data, it was identified at 350–400 ms (electrodes P3,Pz,P4, and PO3, POz,PO4), which is consistent with previous studies using food picture stimuli (Lahtinen et al., 2019; Leland & Pineda, 2006; Nijs, Muris, & et al., 2010; Schwab, Giraldo, Spiegl, & Schienle, 2017; Svaldi et al.,

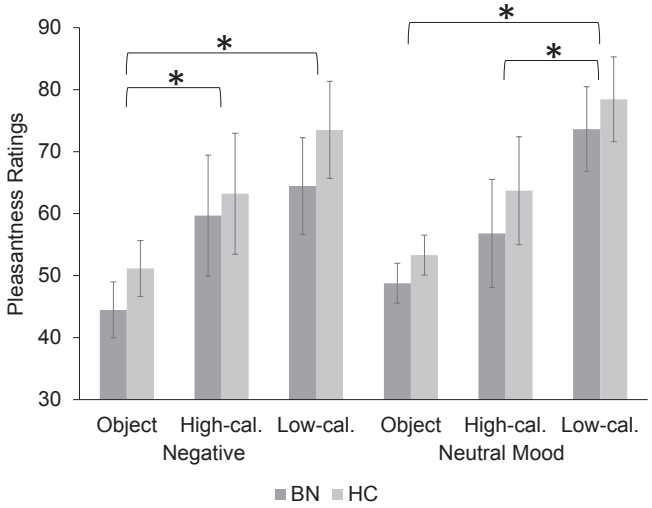

Fig. 3. Pleasantness ratings for object images and high- and low-calorie food images in the negative and neutral mood conditions for the BN (dark grey bars) and HC (light grey bars) groups. Asterisks indicate significances for the post-hoc tests of the two-way interaction Condition × Picture category. Error bars represent 95% CI. BN = bulimia nervosa group; HC = healthy control group.

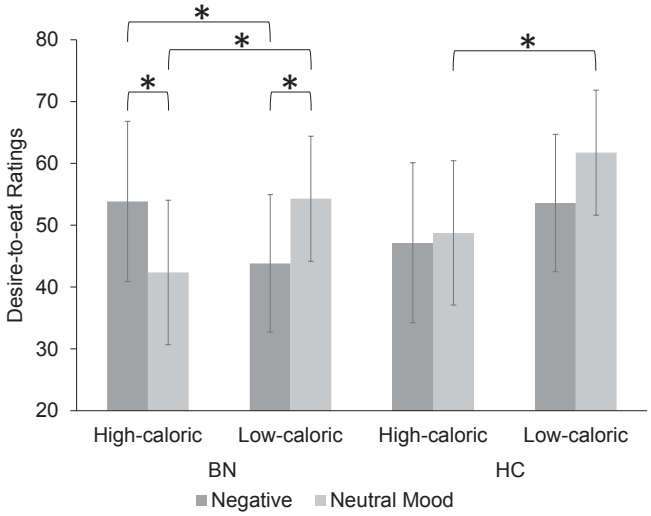

Fig. 4. Desire-to-eat ratings for high- and low-calorie food images in the BN and HC groups for the negative (dark grey bars) and neutral (light grey bars) mood conditions. Asterisks indicate significances for the post-hoc tests of the three-way interaction Group × Condition × Picture category. Error bars represent 95% CI. BN = bulimia nervosa group; HC = healthy control group.

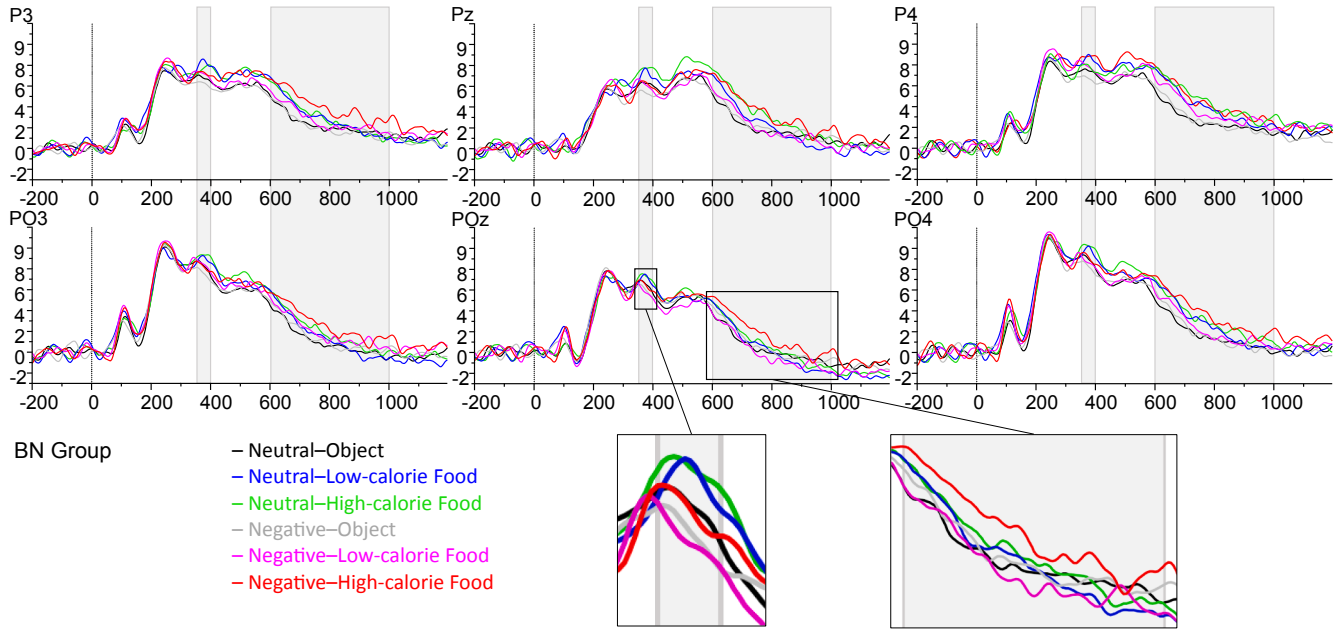

Fig. 5. Grand average waveforms for the bulimia nervosa (BN) group on electrodes P3, Pz, P4, PO3, POz, PO4. Grey boxes indicate P300 (350–400 ms), and LPP (600–1000 ms).

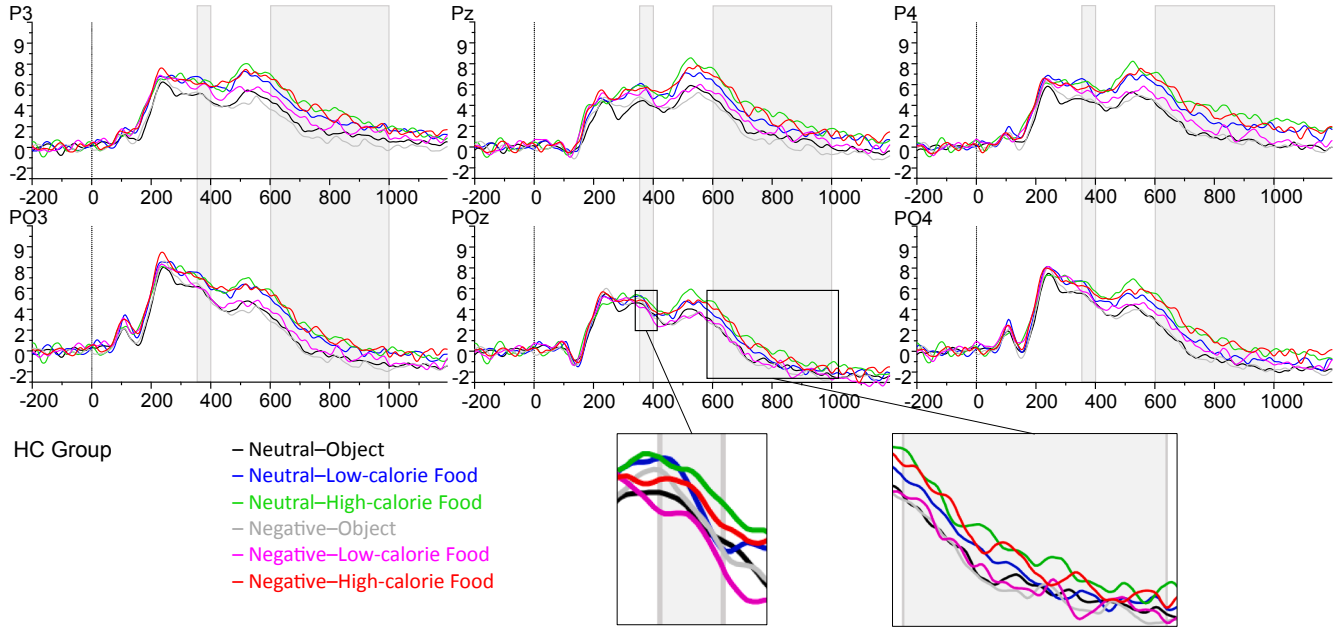

Fig. 6. Grand average waveforms for the healthy control (HC) group on electrodes P3, Pz, P4, PO3, POz, PO4. Grey boxes indicate P300 (350–400 ms), and LPP (600–1000 ms).

2015). For the LPP, we chose a time window of 600–1000 ms at electrodes P3,Pz,P4, and PO3,POz,PO4, which is in line with previous studies on emotion regulation (Hajcak & Nieuwenhuis, 2006), craving regulation (Sarlo et al., 2013), and the processing of food images (Asmaro et al., 2012; Wolz et al., 2015).

2.4. Statistical analyses

Statistical analyses were performed with SPSS 26 (IBM SPSS Statistics, New York, NY). The manipulation was checked with a mixed-design analysis of variance (ANOVA) on PANAS scores: Group (BN vs. HC) × Affect (positive vs. negative) × Condition (negative mood first vs. neutral mood first) × Time (T1-before block 1, T2-after block 1, T3-after block 2). Pleasantness and desire-to-eat ratings (Hyp.1) were analysed with ANOVAs: Group (BN vs. HC) × Condition (negative vs. neutral mood) × Picture category (object vs. high- vs. low-calorie foods). ANOVAs were conducted for each of the ERP components (P300, LPP; Hyp.2,3): Group (BN vs. HC) × Condition (negative vs. neutral mood) × Picture category (object vs. high- vs. low-calorie foods) × Laterality (3/z/4) × Area (P/PO). Laterality and area localise the scalp electrode positions from left to right and front to back, respectively (Giraldo et al., 2019). To control for anxiety and depression, the analyses were repeated as anlayses of covariance (ANCOVAs) with z-standardised scores on the CES-D and STAI-T.

The significance level was set to $\alpha = 0.05$; only significant effects are reported. Significant interactions were followed up with Bonferroni-corrected *t* tests applying Dunn's procedure, reported with the number of comparisons *C* and the critical difference ψ. Huynh-Feldt correction was applied when Mauchley's test indicated a violation of the sphericity assumption. Effect sizes are partial eta squared.

Using an effect size of $\eta_p^2 = 0.10$ (Blechert, Goltsche, & et al., 2014), we calculated a necessary sample size of $N = 22$ with G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) for the expected three-way interaction of group, condition, and picture category in ERPs, and recruited $N = 44$ to be in line with previous studies using idiosyncratic mood induction (Blechert, Goltsche, & et al., 2014; Hilbert et al., 2011).

3. Results

3.1. Manipulation check

ANOVA statistics for the PANAS are reported in Table 2. Our sample indicated higher levels of positive than negative affect. After the first mood induction, positive affect decreased significantly (Affect × Time; $C = 4$, $\psi = 0.15$). Post-hoc tests for the three-way interaction (Affect × Time × Order; $C = 8$, $\psi = 0.23$) indicated increased negative and decreased positive affect when negative mood was induced first. The subsequent neutral mood induction reduced negative affect. When the neutral condition was presented first, it did not significantly change affect. The subsequent negative mood induction increased negative affect, but did not change positive affect. Both groups responded similarly to the mood induction (see Fig. 2).

3.2. Self-report data (Hyp.1)

The analysis of pleasantness ratings showed a significant main effect for condition ($F_{1,40} = 5.30$, $p = .027$, $\eta_p^2 = 0.12$), with higher ratings under neutral than negative mood. Post-hoc tests ($C = 3$, $\psi = 8.26$) for the main effect picture category ($F_{1.80,71.86} = 26.17$, $p < .001$., $\eta_p^2 = 0.40$) showed that low-calorie foods received the highest positive ratings, followed by high-calorie foods, and objects. There was a significant interaction Picture category × Condition ($F_{2,80} = 10.37$, $p < .001$, $\eta_p^2 = 0.21$). Post-hoc tests ($C = 9$, $\psi = 11.76$; see Fig. 3) showed that the ratings for the individual picture categories did not differ significantly between the mood conditions. Instead, their relative positions changed in that high-calorie foods were rated similarly to objects under neutral mood, but similarly to low-calorie foods under negative mood. The group factor did not interact with the other factors. Ratings did not differ significantly between the groups ($F_{1,40} = 3.95$, $p = .054$., $\eta_p^2 = 0.090$).

For desire-to-eat ratings, there were two significant interactions: Picture category × Condition ($F_{1,40} = 18.56$, $p < .001$, $\eta_p^2 = 0.32$), and Group × Condition × Picture category ($F_{1,40} = 5.44$, $p = .025$, $\eta_p^2 = 0.12$). Post-hoc tests for the latter ($C = 8$, $\psi = 9.54$; see Fig. 4) showed that in BN under negative mood desire to eat increased for high-calorie, but decreased for low-calorie foods. The HC group showed a preference for low- over high-calorie foods under neutral mood, which disappeared under negative mood.

3.3. Event-related potentials (Hyp.2,3)

The following results focus on differences between the picture categories (Hyp.2) and the highest-order interaction with the group factor (Hyp.3). The five-way interaction Group × Condition × Picture category × Laterality × Area signifies that the interaction Group × Condition × Picture category was present only for some electrodes, but not others. Therefore, we include the number of electrodes, for which post-hoc tests were significant. See Appendix F for an overview of all significant effects.

P300. See Figs. 5 and 6 for grand average waveforms. Post-hoc tests ($C = 3$, $\psi = 0.70$) for the main effect picture category ($F_{2,80} = 7.09$, $p = .001$, $\eta_p^2 = 0.15$) show that amplitudes for high- ($M = 6.95$, $SD = 4.35$) and low-calorie ($M = 6.65$, $SD = 4.38$) food pictures did not differ from each other, but were higher than for object pictures ($M = 5.90$, $SD = 4.01$). Post-hoc tests ($C = 54$, $\psi = 0.57$) for the five-way interaction Group × Condition × Picture category × Laterality × Area ($F_{3.44,\ 137.62} = 6.00$, $p < .001$, $\eta_p^2 = 0.13$) indicate that the BN group showed strong mood induction effects for all three picture categories on 5 out of 6 electrodes, with higher amplitudes under neutral than negative mood. The HC group only showed this effect for low-calorie food images on 3 out of 6 electrodes. When comparing the groups directly, the BN group showed a larger mood-induction effect than the HC group on the processing of object pictures (6 electrodes), high-calorie food pictures (4 electrodes), and low-calorie food pictures (2 electrodes). See Appendix F for mean differences. The five-way interaction Group × Condition × Picture category × Laterality × Area was still significant when entering depressive and anxiety symptoms as covariates ($F_{3.43,130.41} = 8.28$, $p < .001$, $\eta_p^2 = 0.18$).

LPP. See Figs. 5 and 6 for grand average waveforms. Post-hoc tests ($C = 3$, $\psi = 0.71$) for the main effect picture category ($F_{2,80} = 15.60$, $p < .001$, $\eta_p^2 = 0.28$) show that amplitudes for all three picture categories differed from each other, with the highest amplitudes for high-calorie foods ($M = 2.73$, $SD = 3.34$), then low-calorie foods ($M = 1.82$, $SD = 2.99$), and then objects ($M = 1.11$, $SD = 2.99$). Post-hoc tests ($C = 54$, $\psi = 0.83$) for the five-way interaction Group × Condition × Picture category × Laterality × Area ($F_{3.26,130.48} = 2.79$, $p = .039$, $\eta_p^2 = 0.065$) indicate that the BN group showed mood induction effects only for high-calorie food pictures (2 electrodes); amplitudes were higher under negative than neutral mood. The HC group showed mood-induction effects for low-calorie food images (1 electrode), with lower amplitudes under negative than neutral mood. When comparing the groups directly, the BN group showed a larger mood-induction effect than the HC group on the processing of high-caloric food pictures (2 electrodes), and low-caloric food pictures (1 electrode). See Appendix F for mean differences. The five-way interaction Group × Condition × Picture category × Laterality × Area was still significant when entering depressive and anxiety symptoms as covariates ($F_{3.40,129.35} = 3.53$, $p = .013$, $\eta_p^2 = 0.085$).

3.4. Exploratory analyses

As ERP effects were small, especially for LPP, we explored the possibility that emotional eating tendencies, rather than BN diagnosis could be driving these effects. To this end, we calculated a median split on the DEBQ subscale emotional eating ($Mdn = 38.00$) and replaced the group factor in the ERP analyses with the factor low versus high emotional eating (EE). The pattern of results was the same as for BN versus HC, both for P300 and LPP, but post-hoc results for the five-way interaction on LPP were much clearer: High EE showed a significant increase in LPP amplitudes under negative mood on 5 out of 6 electrodes. This increase was significantly larger in the high EE group than in the low EE group (who had a small tendency towards the opposite effect) on all six electrodes. The detailed analyses can be found in Appendix G.

4. Discussion

The current study investigated increased motivational salience of food stimuli as a possible mechanism linking negative mood and binge eating in BN. Using idiosyncratic situations, we successfully induced moderate levels of negative vs. neutral mood in women with and without BN (manipulation check). Under negative mood, individuals with BN showed an increased desire to eat high-calorie foods (Hyp.1). Regarding ERPs, P300 was larger for food than object images and LPP was largest for high-calorie foods, followed by low-calorie foods, then objects (Hyp.2). In the BN group, negative mood induction led to reduced P300 for all stimulus categories, and a small increase in LPP for high-calorie foods (Hyp.3). Exploratory analyses showed a clear mood-

induced increase in LPP amplitudes for high-calorie foods only in participants with high EE. Our results do not fully support increased motivational salience of food stimuli after negative mood induction in BN, but suggest that more complex mechanisms are at work.

4.1. Self-report ratings (Hyp.1)

Pleasantness ratings under neutral mood were highest for low-calorie foods, followed by high-calorie foods, and then objects. After negative mood induction, low-calorie foods and high-calorie foods were rated similarly. Negative mood induction *decreased* the desire to eat *low*-calorie foods in both groups, but *increased* desire to eat *high*-calorie foods only in BN.

Preferences for low- over high-calorie foods have been reported in previous studies with young women (Meule, Kübler, & Blechert, 2013). This is in line with reports that women are generally concerned about the healthiness of foods (McKie, Wood, & Gregory, 1993), and that the majority of women in Western societies is dissatisfied with their body image (Rodin, Silberstein, & Striegel-Moore, 1984). Chronically restricting food intake to influence weight and shape is termed restrained eating (Herman & Mack, 1975). When experiencing negative mood, restrained eaters are prone to lose self-regulatory control, resulting in overeating (Evers et al., 2018; Ruderman, 1985). This restraint/disinhibition account of emotional eating could explain why low-calorie foods were preferred under neutral mood, but not under negative mood in our study. As the BN group had higher levels of restraint than the HC group, it seems likely that they experienced stronger disinhibiting effects of negative mood, leading not just to a reduced preference for low-calorie foods, but an increased preference for high-calorie foods. Similar results have been reported for women with food addiction, for whom negative mood induction led to *increased* sustained attention for unhealthy foods and *decreased* attention for healthy foods, using eye tracking over an 8 s period (Frayn et al., 2016).

4.2. ERP effects of picture category (Hyp.2)

We found larger P300 amplitudes for both types of food stimuli compared to objects, which is in line with previous reports (Carbine et al., 2018; Nijs et al., 2008; Nijs, Frankena, et al., 2010; Nijs, Muris, et al., 2010; Sarlo et al., 2013). The LPP differentiated between all three picture categories, with the largest amplitudes for high-calorie foods, followed by low-calorie foods, and the smallest amplitudes for objects. Effect sizes for both P300 and LPP were large (Lenhard & Lenhard, 2016). This indicates that motivated attention allocation was similar for both food categories, but high-calorie foods received increased sustained processing resources. In contrast to LPP results, desire-to-eat and pleasantness ratings were highest for *low*-calorie foods. This suggests that LPP effects were driven by conflict about high-calorie foods, rather than approach motivation (Field et al., 2016). High-calorie foods may have been perceived as tasty, yet fattening. Previous studies found differences between high- and low-calorie foods at much earlier components, i.e. as early as 150 ms after stimulus onset (Blechert et al., 2011; Meule et al., 2013; Toepel, Knebel, Hudry, le Coutre, & Murray, 2009). Differences between studies regarding experimental paradigms, stimulus material, samples, and ERP components investigated may account for diverging results.

This effect did not differ by group, neither for P300 nor for LPP, meaning that the groups experienced similar levels of motivational salience for food stimuli. We assumed increased motivational salience for food cues in BN based on the substance use literature on ERPs (Littel et al., 2012), attentional bias for food cues in eating disorders (Brooks et al., 2011), and ERP studies on eating disorders (Blechert et al., 2011; Novosel et al., 2014; Wolz et al., 2015). Nevertheless, we are unaware of any study investigating the P300 and LPP components elicited by food images in BN. Therefore, our results cannot be directly compared to previous studies. It should be noted that differences between BN and HC regarding attentional bias for food stimuli are not consistently observed (Black, Terence Wilson, Labouvie, & Heffernan, 1997; Stojek et al., 2018; Werthmann et al., 2015), and behavioural attentional bias tasks do not necessarily show the same results as ERP measures regarding motivated attention to food (Nijs, Muris, & et al., 2010). Other studies on eating and weight disorders have failed to find differences between clinical and HC groups regarding P300 and LPP for food stimuli (Nijs et al., 2008; Nijs, Frankena, et al., 2010). Some studies even report attenuated P300 responses to food stimuli in eating and weight disorders (Babiloni et al., 2009; Hill, Wu, Crowley, & Fearon, 2013; Nijs, Muris, & et al., 2010; Nikendei et al., 2012). Study designs and samples are heterogeneous and the cognitive processes underlying food ERPs remain poorly understood.

4.3. ERP effects of mood induction (Hyp.3)

We assumed that negative mood would increase motivated attention to (high-calorie) food images in BN based on the affective processing model of negative reinforcement from the substance use literature (Baker et al., 2004) and the transdiagnostic theory of eating disorders (Fairburn et al., 2003). Yet, our results provide a more complex picture.

In BN, negative mood induction led to a generalised reduction of the P300 for all picture categories, suggesting a different mechanism. P300 amplitude is influenced by "task-relevance, motivational significance, arousal level and the influence of these factors on mental resource allocation" (p.7; Olofsson et al., 2008). We propose that in our experiment, resources were mainly allocated to the regulation of induced negative emotions, thereby detracting resources from stimulus processing. Studies with healthy individuals suggest that emotion induction reduces P300 amplitudes in neutral tasks by reducing the availability of cognitive resources (Kliegel, Horn, & Zimmer, 2003; Meinhardt & Pekrun, 2003). Studies with obese individuals indicate reduced inhibitory processing in the prefrontal cortex (PFC) as a possible explanation for attenuated P300 (Babiloni et al., 2009; Hill et al., 2013). This supports the disinhibition account of emotional overeating in BN, suggesting that experiencing and regulating negative emotions reduces cognitive resources necessary to maintain dietary restraint (Fairburn et al., 2003; Ruderman, 1985).

Results in HC suggest decreased motivated attention allocation for low-calorie foods under negative mood. This is in line with the decrease in desire-to-eat ratings. Healthy individuals are assumed to decrease eating behaviour in response to acute stressors (Torres & Nowson, 2007), and previous studies have shown that attentional bias for food cues disappears under conditions of negative mood, using a visual search task (Donofry et al., 2019). The P300 effects for HC were small (significant on three electrodes), however, and should be interpreted with caution. Although the groups did not differ in levels of negative affect, it is likely that coping took up more cognitive resources for individuals with BN, who are known to exhibit poor emotion regulation (Lavender et al., 2015), thus explaining the stronger, stimulus-independent effects in BN.

P300 effects did not extend to the LPP, which showed a small mood-induced increase for high-calorie foods in BN. As this effect reached statistical significance only on two electrode sites, its clinical significance remains unclear, thus not clearly confirming the hypothesis that negative mood increases sustained motivational processing of food images in BN. This result is at odds with the clear effect of negative mood induction on desire-to-eat ratings. LPP reflects arousal rather than valence (Olofsson et al., 2008). Therefore, it may reflect desire to eat, but also increased aversion or conflict, depending on the goal activated (Field et al., 2016). In BN patients, who wish to control mood-induced binge eating, high-calorie foods might appear ambivalent: on the one hand, they promise relief from negative affect, on the other hand, they conflict with the patient's diet goals. Drawing from the clinical interviews, BN patients in our sample varied strongly regarding their wish to suppress binge-eating episodes (see 4.4 Limitations). This might

explain large interindividual differences, and consequently small effects, regarding LPP for high-calorie foods under negative mood.

The transdiagnostic theory of BN (Fairburn et al., 2003) proposes that only a subgroup of patients experiences mood intolerance as a maintaining mechanism of their BN symptoms. In addition, emotional eating occurs in non-clinical populations (van Strien et al., 1986). Therefore, we conducted an exploratory analysis dividing our sample according to emotional eating scores rather than BN diagnosis. In this analysis, LPP showed much clearer effects; high EE, but not low EE, showed increased LPP for high-calorie foods under negative mood, indicating increased sustained processing. It appears that mood-induced changes in food-image processing might not be related to BN psychopathology per se, but rather to eating behaviour tendencies, such as emotional and restrained eating, which may be present to varying degrees in people with *and* without BN. A similar study (Schnepper et al., 2020), which did not report alterations in ERPs between high and low EE, only included healthy participants. Future studies should investigate mood-induced food-image processing across the spectrum from healthy to disordered eating behaviours.

In summary, HC participants showed a small decrease in the processing of low-calorie foods under negative mood (significant on 3 electrodes for P300 and 1 for LPP), which is in line with a decrease in pleasantness and desire-to-eat ratings and could be interpreted as decreased motivation towards their preferred food category. Participants with BN, however, showed a different pattern. We assume that negative mood induction limited resource availability, thereby reducing motivated attention allocation (P300) to all stimulus categories. Following on in the sequence of information processing, sustained processing (LPP) of high-calorie foods was increased, but only for participants high in emotional eating. The exact nature and significance of this effect needs to be explored in future studies. If confirmed, it could indicate increased motivational salience of high-calorie foods (Hajcak et al., 2010), increased aversion or conflict regarding high-calorie foods (Field et al., 2016), or processes involved in the regulation of food cravings (Meule et al., 2013; Sarlo et al., 2013; Svaldi et al., 2015).

4.4. Limitations

It should be noted that our findings only concern negative emotions of moderate intensity, as induced e.g. by daily hassles. Patients with BN show higher emotional instability and more extreme switches between positive and negative affect in daily life than HC (Houben et al., 2016; Santangelo et al., 2014). It is, therefore, possible that higher levels of negative affect, or larger or more frequent changes in affect, exert stronger or even different effects on the processing of food stimuli in BN. In addition, only certain emotions lead to overeating while others do not, with strong inter-individual variability (Altheimer & Urry, 2019). Therefore, different emotions might lead to different changes in food-image processing. It remains for future research to explore the effects of negative, but also positive affect (Cardi, Leppanen, Leslie, Esposito, & Treasure, 2019; Delgado-Rodríguez et al., 2019) at varying intensities and qualities, as well as the association with actual eating behaviour.

We controlled food deprivation status in our study by asking participants to consume a standardised meal three hours prior to testing and abstain from eating afterwards. Previous research has shown that food deprivation influences ERPs for food stimuli (Stockburger, Schmälzle, Flaisch, Bublatzky, & Schupp, 2009). Relatively high hunger levels after three hours of food deprivation might explain why participants showed strongly enhanced ERPs for food stimuli. We cannot exclude that this manipulation affected participants with BN, who regularly impose periods of short-term food deprivation on themselves, differently from HC.

Ratings and ERPs did not always align in our results. Under neutral mood conditions, low-calorie foods were preferred in the ratings, but not in the ERPs. The P300 did not distinguish calorie type, and LPP showed increased processing of high-calorie foods. As ratings were collected in separate trials from ERPs, we cannot exclude differences in processing between passive viewing and rating trials. We chose this approach to avoid motor confounds in the ERPs, but future studies should compare passive viewing with active conditions, e.g. downregulation of food cravings, in BN. Our stimulus set included low-calorie foods, which has been suggested to bias participants towards a health interpretation (Werthmann et al., 2015). This could explain the positive evaluation of low-calorie food images under neutral mood. In addition, we did not use idiosyncratic food stimuli. It is possible that effects would be stronger when focusing on the patients' favourite binge foods, albeit at the costs of lower experimental control.

We recruited our clinical sample from the general population, not from a treatment centre. Although all women in the BN group showed BN symptoms, they were functioning in everyday life, and some were partially remitted. With a mean age of 32 years, these women had had BN for many years, as the disorder typically begins during adolescence (Nagl et al., 2016). Although the subgroups with partially remitted versus full-syndrome BN did not differ in terms of clinical variables (see Appendix B), it is possible that the inclusion of partially remitted patients weakened the effect size of our results. Similarly, our control group did not show any disordered eating behaviour, such as binge eating or purging (as determined in the clinical interviews), and scored significantly lower on general and eating-specific psychopathology. Notwithstanding, we cannot exclude the possibility that our recruitment for a study on "mood and food" attracted in particular women, who perceived themselves as experiencing problems in that direction. Our exploratory analyses suggest that it is important for future studies to investigate emotional eating across the spectrum of clinical and non-clinical eating behaviour, using continuous, rather than dichotomous sampling. In addition, including a larger number of BN patients would allow investigating the question, if a subgroup is particularly vulnerable to negative mood-induced binge eating and associated changes in stimulus processing. Differences regarding severity, duration, and previous treatment of BN should be examined in larger samples, as previous studies have found attentional bias for food to be related to BN severity (Albery et al., 2016).

4.5. Summary and clinical relevance

In summary, we successfully induced moderate negative mood in participants with and without BN. The BN, but not the HC group, showed the expected increase in desire to eat high-calorie foods under negative mood. We expected this to be accompanied by an increase in motivational salience of high-calorie food stimuli, but were unable to find clear evidence for this in our neurophysiological indicators, P300 and LPP. Instead, in BN, negative mood led to reduced motivated attention allocation (P300) for all stimuli, and weakly increased sustained processing of high-calorie foods (LPP). Although both components are typically sensitive to the motivational significance of a stimulus, this aspect interacts with other aspects of the stimulus and the task, which differ between P300 and LPP (Olofsson et al., 2008). Therefore, we derive the following hypotheses from these results and extant research: (1) negative mood reduces processing resources and thereby contributes to a breakdown of dietary restraint in BN, and (2) only a subgroup of BN patients, with prominent emotional eating tendencies, experiences increased sustained processing of high-calorie foods under negative mood.

To further investigate hypothesis 1 in BN, we propose (1) to apply an oddball paradigm after negative mood induction, as this setup has previously led to reduced P300 in healthy individuals and allows for a clearer interpretation of the component than passive viewing, (2) to assess inhibitory processing after negative mood induction, for example with go/no-go tasks, and (3) to compare negative mood induction with other tasks, which reduce self-regulatory resources, e.g. thought suppression (for an overview, see Hagger, Wood, Stiff, & Chatzisarantis, 2010). Regarding hypothesis 2, we suggest to investigate the LPP component and possible underlying mechanisms (1) across the range of

clinical to non-clinical emotional eating behaviours and in large clinical samples, (2) during the application of different craving and emotion regulation strategies in BN, and (3) in association with measures of approach bias.

A better understanding of the processes underlying food-stimulus processing in general and under negative mood in BN may help improve treatment options. Interventions, such as food exposure, attentional bias modification, and approach bias modification build on the assumption of biased motivational processing of food stimuli. Our results contribute to the mixed literature on food-related attentional bias in BN (Stojek et al., 2018; Werthmann et al., 2015). Recent reviews concluded that there is a lack of attentional bias modification studies in BN (Turton, Bruidegom, Cardi, Hirsch, & Treasure, 2016), and mixed results regarding exposure therapy with binge and purge cues (Butler & Heimberg, 2020). A first trial using approach bias modification also yielded mixed results (Brockmeyer et al., 2019). The latter study found that even before the intervention some participants with binge eating had an *approach* bias and others an *avoidance* bias regarding food. This highlights the need to further investigate interindividual differences for the development of tailored interventions (Butler & Heimberg, 2020). Our results further suggest that training emotion-regulation skills might help increase resource availability when experiencing negative mood, at least in a subgroup of patients. In line with this idea, treatment outcome has been shown to be superior in patients, whose emotion regulation improves rapidly at the beginning of treatment (MacDonald, Trottier, & Olmsted, 2017).

The results of the current study highlight the complexity of cognitive processes involved in food-stimulus processing in people with and without BN. Based on our results, we formulated several hypotheses, which may help guide future basic research and ultimately the development of tailored interventions. These are dearly needed, considering that currently only around 30% of BN patients achieve abstinence from binge-purge behaviours after treatment (Linardon & Wade, 2018).

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CRediT authorship contribution statement

Annika P.C. Lutz: Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Angelika Dierolf:** Methodology, Writing - review & editing, Supervision. **Zoé Dyck:** Methodology, Investigation, Writing - review & editing, Project administration. **Claudio Georgii:** Methodology, Writing - review & editing. **Rebekka Schnepper:** Methodology, Writing - review & editing. **Jens Blechert:** Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition. **Claus Vögele:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Information on psychometric questionnaires

Participants had the option of filling in the questionnaires in German, French, or English, considering the multilingual context in Luxembourg.

Dutch Eating Behaviour Questionnaire (DEBQ). The DEBQ was developed by van Strien et al. (1986) and translated into German (Grunert, 1989) and French (Lluch et al., 1996). It contains three subscales for the assessment of restrained eating (the tendency to limit one's food intake to influence body weight/shape; 10 items), emotional eating (the tendency to eat in response to negative emotions; 13 items), and external eating (the tendency to eat in response to environmental cues, e.g. sight and smell of food; 10 items). Responses are given on a 5-point Likert scale, ranging from 1 *seldom* to 5 *very often*. Sum scores were calculated for each subscale, with higher values indicating a more problematic eating behaviour. Cronbach's alpha in our sample was 0.92, 0.97, and 0.82 for the three subscales.

Eating Disorder Inventory-2 (EDI-2). The EDI-2 (Garner, 1991) is the revised version of the EDI (Garner, Olmstead, & Polivy, 1983), which was translated into German (Paul & Thiel, 2005) and French (Bouvard & Cottraux, 2005). In the current study, we used the first three subscales of the EDI-2, which represent the eating-disorder specific constructs drive for thinness (7 items), bulimia / bulimic tendencies (7 items), and body dissatisfaction (9 items). Responses are given on a 6-point Likert scale ranging from 1 *never* to 6 *always*. Sum scores were calculated for each subscale, with higher values indicating a higher degree of eating-disorder symptoms. Cronbach's alpha in our sample was 0.92, 0.95, and 0.93 for the three subscales.

Center for Epidemiologic Studies Depression Scale (CES-D). The CES-D is a 20-item scale for the assessment of depressive symptoms (Radloff, 1977) with translations into German (Hautzinger, 1988) and French (Fuhrer & Rouillon, 1989). Responses are given on a 4-point Likert scale ranging from 0 *rarely or none of the time (<1 day)* to 3 *most or all of the time (5–7 days)*. Responses for all items are summed up to form a total score, for which higher values indicate a higher level of depressive symptoms. Cronbach's alpha in our sample was 0.93.

State-Trait Anxiety Inventory, trait version (STAI-T). The STAI-T is a 20-item measure of anxiety symptoms on a trait level (Spielberger, Gorsuch, & Lushene, 1970) with translations into German (Laux, Glanzmann, Schaffner, & Spielberger, 1981) and French (Bergeron, Landry, & Bélanger, 1976). Responses are scored on a 4-point Likert scale ranging from 1 *not at all* to 4 *very much so*. Responses for all items are summed up to form a total score, for which higher values indicate a higher level of anxiety symptoms. Cronbach's alpha in our sample was 0.95.

Positive and Negative Affect Schedule (PANAS). The PANAS assesses positive and negative affective states on two subscales with 10 items each (Watson, Clark, & Tellegen, 1988). It was translated into German (Krohne, Egloff, Kohlmann, & Tausch, 1996) and French (Gaudreau, Sanchez, & Blondin, 2006). Responses are scored on a 5-point Likert scale ranging from 1 *very slightly or not at all* to 5 *extremely*. We calculated average scores for each subscale, with higher scores reflecting higher levels of positive and negative affect, respectively. In our sample, Cronbach's alpha for positive affect was 0.91, 0.89, and 0.91 for the three measurements, and 0.86, 0.90, and 0.94 for negative affect.

Appendix B. Comparison of BN subgroups

Table 3 shows that the subgroups of patients with full-syndrome vs.

Table 3
Tests of differences between full-syndrome vs. partially remitted BN patients on psychopathology questionnaires.

Questionnaire	Test statistics
Restrained eating (DEBQ)	$t_{19} = 1.70$, $p = .11$
Emotional eating (DEBQ)	$t_{10.22} = -0.15$, $p = .88$
External eating (DEBQ)	$t_{19} = 1.16$, $p = .26$
Drive for Thinness (EDI-2)	$t_{19} = 1.71$, $p = .10$
Bulimia (EDI-2)	$t_{19} = 1.50$, $p = .15$
Body Dissatisfaction (EDI-2)	$t_{19} = 1.20$, $p = .24$
CES-D	$t_{19} = 0.21$, $p = .84$
STAI-T	$t_{19} = -0.10$, $p = .92$

Note. DEBQ = Dutch Eating Behaviour Questionnaire, EDI-2 = Eating Disorder Inventory-2, CES-D = Center for Epidemiologic Studies Depression Scale, STAI-T = State-Trait Anxiety Inventory-Trait.

Table 4
Tests of differences between BN patients without vs. with comorbid DSM disorders on psychopathology questionnaires.

Questionnaire	Test statistics
Restrained eating (DEBQ)	$t_{19} = 1.79$, $p = .09$
Emotional eating (DEBQ)	$t_{19} = 0.33$, $p = .75$
External eating (DEBQ)	$t_{19} = -0.23$, $p = .82$
Drive for Thinness (EDI-2)	$t_{19} = 0.60$, $p = .56$
Bulimia (EDI-2)	$t_{9.34} = 0.15$, $p = .87$
Body Dissatisfaction (EDI-2)	$t_{19} = -1.31$, $p = .20$
CES-D	$t_{8.31} = -1.74$, $p = .12$
STAI-T	$t_{9.76} = -1.39$, $p = .20$

Note. DEBQ = Dutch Eating Behaviour Questionnaire, EDI-2 = Eating Disorder Inventory-2, CES-D = Center for Epidemiologic Studies Depression Scale, STAI-T = State-Trait Anxiety Inventory-Trait.

partially remitted BN did not differ significantly on any of the questionnaire measures, and Table 4 shows the same for patients with vs. without comorbid DSM disorders. In a German validation study of the EDI-2 (Paul & Thiel, 2005), patients diagnosed with BN scored on average 33.5 (*SD* = 6.4) on drive for thinness, 31.0 (*SD* = 5.3) on bulimia, and 44.2 (8.9) on body dissatisfaction. The scores of our BN sample were similar (31.33, 28.05, 36.24, respectively), with perhaps slightly lower body dissatisfaction scores (although within 1 *SD* of the mean). In the same validation study, women without eating disorders scored on average 17.3 (*SD* = 6.8) on drive for thinness, 10.6 (*SD* = 3.4) on bulimia, and 30.2 (10.3) on body dissatisfaction. The scores of our HC group were similar (15.71, 10.33, 27.33, respectively).

Appendix C. Information regarding the larger project

The study presented in the current paper was part of a larger project. Female participants were recruited from the general population in Luxembourg through flyers and announcements in local media (newspapers, magazines, radio, television, and social media). In total, 341 interested persons were screened for inclusion and exclusion criteria with a custom-made telephone screening. Of these, 26 individuals presumably meeting criteria for current BN, according to the Diagnostic and Statistical Manual of Mental Disorders, fifth edition, (DSM-5), were invited for participation in the study. In addition, 28 women presumably *not* meeting DSM-5 criteria for current or past EDs were selected from the screened women to match the participants of the BN group in age and body mass index (BMI).

All participants were then interviewed in person with the Eating Disorder Examination (EDE; Fairburn & Cooper, 1993) to assess diagnostic criteria for current DSM-5 EDs, and with the Structured Clinical Interview for DSM-IV (SCID-IV; First et al., 2002) to assess diagnostic criteria for past EDs and current or past other mental disorders. Four women had to be excluded from the BN group after the diagnostic interviews because they did not fulfil DSM-5 criteria for current full-syndrome or partially remitted BN. In the HC group, five individuals had to be excluded because of current or past ED other than BN (full- or partial-syndrome current or past BED). One participant could not participate in EEG testing because of braided hair (cornrows), which would have interfered with a correct fit of the EEG cap. One dataset had to be excluded post-hoc due to insufficient quality of EEG data (flat signal on offline reference electrode). One participant was identified as an outlier (≥1.5 interquartile ranges above the mean) or extreme value (≥3 interquartile ranges above the mean) on almost all variables for the P300 and LPP components and was hence excluded. The final sample consisted of 21 women with current full-syndrome (n = 12) or partially remitted (n = 9) BN and 21 HC women.

Project participation began with a diagnostic session, in which participants were interviewed with a custom-made socio-demographic interview, the EDE, and the SCID-IV. After the diagnostic session, participants completed nine days of smartphone-based ecological momentary assessment (data will be reported elsewhere). This was followed by a laboratory session. Trait questionnaires were filled in online. After completing all parts of the study, participants were invited for an optional, individualised feedback on the results of the diagnostic interviews.

At the end of the diagnostic session, participants received written and verbal instructions to consume a standardised meal on the day of the laboratory session, three hours prior to testing. They received a list of five meal choices, each containing approximately 550 kcal. Participants were asked to prepare and consume one of the choices at home or their workplace. All were simple, common dishes, such as spaghetti with tomato sauce or cereals with milk. They were further instructed not to consume anything other than non-carbonated water in the three hours between the standardised meal and laboratory testing. The experimenter enquired after compliance with these instructions at the beginning of the laboratory session. Afterwards, a semi-structured interview was conducted to prepare the mood induction scripts. The participants were then seated in the EEG chamber and the psychophysiological recording equipment was prepared. The experimental tasks began with resting-state measurements. Then, participants completed an interoceptive task (heartbeat perception; data will be reported elsewhere). Afterwards, the task described in the current manuscript took place. This was followed by a computerized food-choice task and a bogus taste test (data will be reported elsewhere).

Appendix D. Additional information on idiosyncratic scripts

The idiosyncratic mood induction procedure was based on Hilbert et al. (2011). Using a custom-made semi-structured interview, participants were asked to report events from the previous four weeks, which had made them feel down, frustrated, sad, or had elicited any other negative emotions, excluding traumatic events. These situations were then rated on a 9-point Likert scale regarding how well the participant remembered the event (1 = *not at all*, 9 = *very well*), how negative or positive she felt when recalling the event (self-assessment manikin scale, SAM, with 1 = *very negative* and 9 = *very positive*; Bradley & Lang, 1994), and how stressful it was to recall the event (1 = *not at all*, 9 = *very much*). The experimenter then chose the situation with the highest scores on all variables. This situation was further explored regarding what had happened, when, where, with whom, and which thoughts, emotions, physical sensations, behaviours, and consequences occurred. Subsequent to the interview, the experimenter formed a set of eight sentences

Table 5
Percent of missing EEG data after artefact rejection, separated by picture categories, mood conditions, and groups.

	Objects		High-calorie foods		Low-calorie foods	
	Negative	Neutral	Negative	Neutral	Negative	Neutral
BN $n = 21$	3.75	4.95	3.85	3.11	4.21	6.59
HC $n = 21$	3.11	5.31	4.21	2.93	4.03	4.95
Total sample $N = 42$	3.43	5.13	4.03	3.02	4.12	5.77

Note. BN = bulimia nervosa group, HC = healthy control group.

Table 6
ANOVA results for P300.

Effect	F	$df1$, $df2$	p	η_p^2
Picture category	7.09	2, 80	0.001	0.15
Laterality	12.61	2, 80	<0. 001	0.24
Picture category × Laterality	2.64	3.34, 133.63	0.046	0.062
Picture category × Area	10.31	2, 80	<0. 001	0.21
Laterality × Area	26.73	2, 80	<0. 001	0.40
Picture category × Laterality × Area	2.98	4, 160	0.021	0.069
Group × Condition × Picture category × Laterality × Area	6.00	3.44, 137.62	<0. 001	0.13

Note. The table summarises significant effects ($p < .05$). All other effects were non-significant.

out of this information, which included thoughts, emotions, sensations, and a short description of the situation.

For the neutral situation, participants were asked to choose one of two pre-scripted situations (brushing their teeth or going to work/school), as piloting had shown that it was difficult for most individuals to recall neutral situations. Each pre-scripted situation consisted of eight sentences. Participants were asked to order and adjust the sentences so that they best matched their memory of the situation. The neutral situation was rated for memory, emotions, and stress on the same scales as the negative situation, to ensure that it was easy to remember and did not elicit strong emotions or stress.

Appendix E. Parameters used for artefact rejection and ocular correction ICA

After rereferencing and filtering, we ran a semi-automatic raw data inspection to identify major artefacts, such as muscle movements or non-physiological glitches. The algorithm detected voltage steps above 100 μV/s, voltage differences above 400 μV over 200 ms intervals, and activity below 0.5 μV over 100 ms intervals, which was then verified by visual inspection and adjusted, if necessary. Ocular artefacts were not included, but removed subsequently with ocular correction independent component analysis (ICA), using a restricted infomax algorithm. The meaned slope algorithm was used for blink detection. ICA training continued until the modifications made to the matrices were below $1e^{-07}$, or until the maximum of 512 steps was reached. ICA components reflecting vertical and horizontal ocular activity were identified based on relative VEOG and HEOG variance, respectively. Components with relative VEOG/HEOG variance over 30% were marked for deletion. The components to be deleted and the correction of the data were visually inspected and adjusted, if necessary. EEG channels with excessive noise or flat line, as identified during raw data inspection, were excluded from ocular correction ICA and interpolated after ICA using spherical splines (order of splines = 4; maximal degree of Legendre polynomials = 10; $\lambda = 1e^{-5}$). This concerned 36 channels across all data sets. Data were then segmented from −500 to +2500 ms around stimulus onset. As only major artefacts had been marked during raw data inspection, an additional semiautomatic artefact rejection was applied to the segmented data. The algorithm scanned for voltage steps above 50 μV/s, voltage differences above 150 μV over 200 ms intervals, and activity below 0.5 μV over 100 ms intervals. The result was manually verified and corrected, if necessary. Table 5 provides detailed information on percent of missing data after artefact rejection.

Table 8
ANOVA results for LPP.

Effect	F	$df1$, $df2$	p	η_p^2
Picture category	15.60	2, 80	<0. 001	0.28
Laterality	13.21	2, 80	<0. 001	0.25
Area	66.52	1, 40	<0. 001	0.62
Picture category × Laterality	5.66	3.51, 140.46	0.001	0.12
Picture category × Area	5.19	2, 80	0.008	0.12
Laterality × Area	25.34	2, 80	<0. 001	0.39
Group × Condition × Picture category × Laterality × Area	2.79	3.26, 130.48	0.039	0.065

Note. The table summarises significant effects ($p < .05$). All other effects were non-significant.

Appendix F. ANOVA tables and post-hoc test results

The following tables present statistics for significant ANOVA effects for P300 (Table 6) and LPP (Table 8), as well as post-hoc test results regarding the 5-way interaction Group × Condition × Picture category

Table 7
P300: Post-hoc tests for the five-way interaction Group × Condition × Picture category × Laterality × Area. Mean differences for neutral minus negative mood conditions for the BN and HC groups and the difference HC minus BN, for objects, high-caloric foods, and low-caloric foods on the P300 at six electrode sites.

Electrode	Neutral-Negative								
	BN			HC			HC-BN		
	Obj.	High cal.	Low cal.	Obj.	High cal.	Low cal.	Obj.	High cal.	Low cal.
P3	0.57*	0.43	1.02*	−0.019	0.27	0.47	−0.59*	−0.16	−0.55
PO3	0.70*	1.08*	0.53	−0.11	0.13	1.07*	−0.81*	−0.95*	0.54
Pz	0.91*	1.46*	1.05*	−0.25	0.10	0.32	−1.15*	−1.35*	−0.73*
POz	0.54	0.83*	1.25*	−0.13	0.37	0.66*	−0.67*	−0.46	−0.59*
P4	0.77*	1.06*	0.75*	−0.17	0.43	0.64*	−0.94*	−0.63*	−0.12
PO4	0.68*	1.11*	1.07*	0.016	0.39	0.51	−0.67*	−0.72*	−0.56

Note. Following Dunn's procedure for post-hoc tests, we calculated a critical difference of $\psi = 0.57$, which includes correction for multiple testing (number of tests $C = 54$). BN = bulimia nervosa group; HC = healthy control group; obj. = object pictures; high cal. = high-caloric food pictures; low cal. = low-caloric food pictures.
* Differences surpassing the critical difference of $\psi = 0.57$ (i.e., >0.57 or <−0.57).

Table 9
LPP: Post-hoc tests for the five-way interaction Group × Condition × Picture category × Laterality × Area. Mean differences for neutral minus negative mood conditions for the BN and HC groups and the difference HC minus BN, for objects, high-caloric foods, and low-caloric foods on the LPP at six electrode sites.

Electrode	Neutral-Negative								
	BN			HC			HC-BN		
	Obj.	High cal.	Low cal.	Obj.	High cal.	Low cal.	Obj.	High cal.	Low cal.
P3	0.10	−1.06*	0.24	0.70	0.19	0.62	0.60	1.25*	0.38
PO3	−0.25	−0.72	−0.43	0.35	−0.05	0.82	0.60	0.67	1.26*
Pz	−0.19	−0.18	0.27	0.61	0.32	0.58	0.79	0.51	0.31
POz	−0.16	−0.90*	0.38	0.26	0.26	0.48	0.42	1.16*	0.10
P4	−0.10	−0.07	0.33	0.02	0.39	0.94*	0.12	0.45	0.60
PO4	−0.09	−0.54	0.42	0.06	−0.11	0.14	0.15	0.43	−0.29

Note. Following Dunn's procedure for post-hoc tests, we calculated a critical difference of $\psi = 0.83$, which includes correction for multiple testing (number of tests $C = 54$). BN = bulimia nervosa group; HC = healthy control group; obj. = object pictures; high cal. = high-caloric food pictures; low cal. = low-caloric food pictures.
* Differences surpassing the critical difference of $\psi = 0.83$ (i.e., >0.83 or <−0.83).

Table 10
ANOVA results for P300.

Effect	*F*	*df*1, *df*2	*p*	η_p^2
Picture category	7.11	2, 80	0.001	0.15
Laterality	11.88	2, 80	<0. 001	0.23
Picture category × Laterality	2.68	3.35, 134.02	0.044	0.063
Picture category × Area	10.38	2, 80	<0. 001	0.21
Laterality × Area	27.36	2, 80	<0.001	0.41
Picture category × Laterality × Area	3.01	3.72, 148.97	0.023	0.070
Group × Condition × Picture category × Laterality × Area	4.99	3.48, 139.26	0.002	0.11

Note. The table summarises significant effects ($p < .05$). All other effects were non-significant.

Table 12
ANOVA results for LPP.

Effect	*F*	*df*1, *df*2	*p*	η_p^2
Picture category	15.35	2, 80	<0.001	0.28
Laterality	12.52	2, 80	<0. 001	0.24
Area	62.99	1, 40	<0. 001	0.61
Picture category × Laterality	5.54	3.56, 142.47	0.001	0.12
Picture category × Area	5.30	2, 80	0.007	0.12
Laterality × Area	25.31	2, 80	<0.001	0.39
Group × Condition × Picture category × Laterality × Area	2.92	3.26, 130.32	0.033	0.068

Note. The table summarises significant effects ($p < .05$). All other effects were non-significant.

× Laterality × Area for P300 (Table 7) and LPP (Table 9). The comparisons to be calculated in the post-hoc tests were based on a priori hypotheses, that is, the mood-induced changes in image processing for each group and the difference in mood-induced changes between the groups. This resulted in $C = 54$ post-hoc comparisons.

Appendix G. Exploratory analyses: low versus high emotional eaters

On the P300, there was a significant five-way interaction Group × Condition × Picture category × Laterality × Area. Post-hoc tests showed that high emotional eaters (EE) had a generalised amplitude reduction under negative mood (objects: 6 electrodes; high-calorie foods: 5 electrodes; low-calorie foods: 6 electrodes), while low EE showed a much weaker reduction only for high- and low-calorie foods (3 electrodes each), but not objects. In consequence, the group comparison showed larger mood-induction effects for high EE especially for objects (6 electrodes), but less so for high-calorie foods (3 electrodes with positive effects, 1 with negative effect) and low-calorie foods (3 electrodes). ANOVA results for the P300 are displayed in Table 10 and post-hoc results for the five-way interaction are shown in Table 11.

For the LPP, there was also a significant five-way interaction Group × Condition × Picture category × Laterality × Area. Post-hoc tests showed that high EE had increased amplitudes under negative mood only for high-calorie foods (5 electrodes). Low EE showed small effects in the opposite direction, for high-calorie foods (2 electrodes) and low-calorie foods (1 electrode). The group comparison showed that high EE had a larger mood-induced increase in LPP amplitudes than low EE for high-calorie foods (all 6 electrodes), and to a lesser extent for low-calorie

Table 11
P300: Post-hoc tests for the five-way interaction Group × Condition × Picture category × Laterality × Area. Mean differences for neutral minus negative mood conditions for the BN and HC groups and the difference HC minus BN, for objects, high-caloric foods, and low-caloric foods on the P300 at six electrode sites.

Electrode	Neutral-Negative								
	Low EE			High EE			High-Low EE		
	Obj.	High cal.	Low cal.	Obj.	High cal.	Low cal.	Obj.	High cal.	Low cal.
P3	−0.14	0.65*	0.41	0.69*	0.058	1.08*	0.84*	−0.59*	0.67*
PO3	−0.32	0.21	0.98*	0.91*	1.00*	0.62*	1.22*	0.79*	−0.36
Pz	−0.083	0.79*	0.48	0.74*	0.78*	0.88*	0.83*	−0.009	0.40
POz	−0.34	0.29	0.66*	0.75*	0.92*	1.24*	1.08*	0.63*	0.57*
P4	−0.21	0.78*	0.78*	0.81*	0.71*	0.61*	1.03*	−0.070	−0.18
PO4	−0.18	0.36	0.47	0.87*	1.14*	1.10*	1.05*	0.78*	0.63*

Note. Following Dunn's procedure for post-hoc tests, we calculated a critical difference of $\psi = 0.57$, which includes correction for multiple testing (number of tests $C = 54$). BN = bulimia nervosa group; HC = healthy control group; obj. = object pictures; high cal. = high-caloric food pictures; low cal. = low-caloric food pictures.
* Differences surpassing the critical difference of $\psi = 0.57$ (i.e., > 0.57 or <−0.57).

Table 13
LPP: Post-hoc tests for the five-way interaction Group × Condition × Picture category × Laterality × Area. Mean differences for neutral minus negative mood conditions for the BN and HC groups and the difference HC minus BN, for objects, high-caloric foods, and low-caloric foods on the LPP at six electrode sites.

Electrode	Neutral-Negative								
	Low EE			High EE			High-Low EE		
	Obj.	High cal.	Low cal.	Obj.	High cal.	Low cal.	Obj.	High cal.	Low cal.
P3	0.36	0.81	0.74	0.43	−1.68*	0.11	0.07	−2.50*	−0.63
PO3	−0.15	0.25	0.79	0.25	−1.02*	−0.40	0.40	−1.27*	−1.18*
Pz	0.53	1.15*	0.71	−0.11	−1.02*	0.14	−0.64	−2.17*	−0.57
POz	−0.26	0.39	0.45	0.36	−1.03*	0.41	0.62	−1.42*	−0.03
P4	−0.38	0.93*	1.10*	0.30	−0.62	0.17	0.68	−1.55*	−0.94*
PO4	−0.49	0.30	0.14	0.46	−0.96*	0.43	0.95*	−1.26*	0.29

Note. Following Dunn's procedure for post-hoc tests, we calculated a critical difference of $\psi = 0.83$, which includes correction for multiple testing (number of tests $C = 54$). BN = bulimia nervosa group; HC = healthy control group; obj. = object pictures; high cal. = high-caloric food pictures; low cal. = low-caloric food pictures.
* Differences surpassing the critical difference of $\psi = 0.83$ (i.e., >0.83 or <-0.83).

foods (2 electrodes). A small effect in the opposite direction was observed for objects (1 electrode). ANOVA results for the LPP are displayed in Table 12 and post-hoc results for the five-way interaction are shown in Table 13.

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