Changes in visual attention towards food cues after obesity surgery: An eye-tracking study

Running head: Visual attention towards food cues after OS

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Abstract

Research documented the effectiveness of obesity surgery (OS) for long-term weight loss and improvements in medical and psychosocial sequelae, and general cognitive functioning. However, there is only preliminary evidence for changes in attentional processing of food cues after OS. This study longitudinally investigated visual attention towards food cues from pre- to 1-year post-surgery. Using eye tracking (ET) and a Visual Search Task (VST), attentional processing of food versus non-food cues was assessed in *n*=32 patients with OS and *n*=31 matched controls without weight-loss treatment at baseline and 1-year follow-up. Associations with experimentally assessed impulsivity and eating disorder psychopathology and the predictive value of changes in visual attention towards food cues for weight loss and eating behaviors were determined. During ET, both groups showed significant gaze duration biases to non-food cues without differences and changes over time. No attentional biases over group and time were found by the VST. Correlations between attentional data and clinical variables were sparse and not robust over time. Changes in visual attention did not predict weight loss and eating disorder psychopathology after OS. The present study provides support for a top-down regulation of visual attention to non-food cues in individuals with severe obesity. No changes in attentional processing of food cues were detected 1-year post-surgery. Further studies are needed with comparable methodology and longer follow-ups to clarify the role of biased visual attention towards food cues for long-term weight outcomes and eating behaviors after OS.

Keywords: obesity surgery; eye tracking; visual attention; food cues; decision making; impulsivity

Introduction

In recent decades, the prevalence of obesity (body mass index [BMI] ≥ 30 kg/m^2) has risen rapidly worldwide (Chooi et al., 2019), making obesity-related comorbidities (e.g., type 2 diabetes) becoming the diseases of the 21st century (Rössner, 2002). Recent research puts individuals' impulsivity center stage in terms of weight gain and weight-loss failure due to its effects on cognitive, emotional, and behavioral control in response to food cues (Lowe et al., 2019; Stice and Burger, 2019). Impulsivity describes rash-spontaneous behavior without consideration of its consequences and subsumes diverse facets, such as inhibitory control and reward sensitivity (Sharma et al., 2014). Studies using functional magnetic resonance imaging (fMRI) revealed that individuals with obesity compared to those with normal weight show both food-specific hyper-activation in brain areas linked to reward processing (orbitofrontal cortex, OFC) and visual attention (posterior cingulate cortex, inferior parietal lobe), as well as hypo-activation of areas related to inhibitory control (prefrontal cortex, PFC), resulting in lower dietary self-regulation and increased risk for overeating (Devoto et al., 2018; Lowe et al., 2019; Stice and Burger, 2019). Notably, experimental evidence indicated greater impulsivity the higher the BMI with pre-bariatric adults showing lower inhibitory control than patients with obesity undergoing behavioral weight-loss treatment (Kulendran et al., 2016). At the same time, the odds for recurrent binge eating, characterized by experiencing loss of control over eating, are 13 times greater in those with obesity class III (BMI≥40 kg/m^2) relative to those with obesity class I (BMI=30-34.9 kg/m^2; Duncan et al., 2017).

Currently, obesity surgery (OS) is the most effective treatment in individuals with BMI≥35 kg/m^2 for achieving long-term weight loss and medical and mental health improvements (Lindekilde et al., 2015; Shoar and Saber, 2017; van Hout et al., 2006). Besides the anatomical restriction of the stomach, OS has profound effects on individuals' hormonal and neuronal mechanisms controlling homeostatic and hedonic eating. For example, fMRI studies revealed decreased OFC activity (Baboumian et al., 2019; Faulconbridge et al., 2016) and increased PFC activity (Baboumian et al., 2019; Zoon et al., 2018) in response to high- versus low-caloric food pictures after OS. Additionally, gut-brain communication normalized post-operatively, thereby reducing hunger responsiveness to visual food cues and uncontrolled high-energy food intake (Le Roux et al., 2006; Le Roux et al., 2007; Ochner et al., 2011).

Despite these extensive effects of OS on brain areas driving food-specific inhibitory and attentional processes, only little is known about their behavioral presentation, including OS-induced changes of individuals' eye-movement pattern on food cues. The tracking of patients' eye movements during free exploration of food versus non-food picture pairs enables the identification of biases in attentional processing, i.e., the preferential attention paid to food compared to neutral cues (Bunge et al., 2009). Attentional biases can be conceptualized based on two complementing theories of selective attention (Desimone and Duncan, 1995) and information processing stages (Shiffrin and Schneider, 1977). Accordingly, attentional biases involve early automatic ("bottom-up") and later voluntary ("top-down") processes represented by deviations in attentional engagement to and disengagement from salient stimuli. During eye tracking (ET), facilitated engagement to food cues, i.e., speeded attention allocation towards salient stimuli, is indicated by a greater percentage of initial fixations onto food versus non-food cues, commonly termed 'direction bias'. Difficulties in attentional disengagement from food, i.e., impairments in shifting attention away from salient stimuli, is indicated by longer gaze duration onto food versus non-food cues, termed 'gaze duration bias'. At the same time, there may be a facilitated disengagement or voluntary attentional avoidance of salient stimuli, depicted by shorter gaze duration onto food versus non-food stimuli. Essentially, attentional biases towards food stimuli may be a cognitive marker and predictor of deficient inhibitory control and dysfunctional eating behavior, at least in the short term (Field et al., 2016; Stojek et al., 2018; Werthmann et al., 2015).

The few studies using ET in adults with excess weight revealed inconsistent results regarding attentional biases to food cues (Baldofski et al., 2018; Castellanos et al., 2009;

Graham et al., 2011; Nijs et al., 2010; Sperling et al., 2017; Werthmann et al., 2011) which may be due to the variability of methodology, including the aggregation of overweight and obesity into one group, the control for eating disorders, differences in stimulus material (e.g., high- versus low-caloric food, high-caloric versus neutral stimuli), and analyses (bias score versus raw eye-tracking scores, inter- versus intra-group biases), see Table S1 in online supplementary material. Studies solely including individuals with obesity showed a non-significant direction bias for food versus non-food cues and a significant gaze duration bias for non-food versus food cues indicating voluntary avoidance of attention to food cues during a free exploration paradigm (Baldofski et al., 2018; Sperling et al., 2017). Notably, previous studies included samples with a mean BMI up to 38.7 kg/m^2; thus, it is inconclusive whether the findings are actually transferable to patients with severe obesity. The only longitudinal, but uncontrolled study (*N*=17) on attentional processing of visual food cues using ET in patients with OS suggested a gaze duration bias for non-food versus food stimuli 6 months after sleeve gastrectomy, while this bias was absent pre-surgery (Giel et al., 2014). Overall, there is a lack of evidence from prospective, controlled studies on changes in food-related attentional processing from pre- to post-OS.

In addition to the direct, objective, and highly temporal-resoluted assessment of attentional biases using ET, visual attention can be measured via indirect, reaction-time (RT) based approaches. Due to short presentation times of stimuli and performance orientation, RT tasks tap into different attentional processes than ET which might explain why previous studies did not show significant correlations between direct and indirect measures of attentional biases (e.g., Schmidt et al., 2016). RT tasks, for example, spatial attentional paradigms, require individuals to quickly detect visual target stimuli (e.g., words, pictures), either with probe stimuli (visual probe task, VPT) or distractor stimuli (visual search task, VST) being present or not. In most studies of individuals with overweight and obesity versus normal-weight controls, food-specific visual probe tasks revealed no significant group differences regarding RTs (Hendrikse et al. 2015; Werthmann et al., 2015). Using the more complex VSTs (Werthmann et al., 2015), it is possible to assess facilitated engagement (speeded detection) to food targets among non-food distractors and/or delayed disengagement from food distractors while searching for non-food targets. Previous studies found that a higher BMI in individuals with overweight and obesity was associated with speeded detection of fried versus low-caloric food cues (Gearhardt et al., 2012), while no specific group differences were found in the detection of food versus non-food cues between those with obesity and normal weight (Bongers et al., 2015) and eating disorders (Baldofski et al., 2018; Sperling et al., 2017). Currently, VSTs have never been conducted in samples undergoing OS, but would provide valuable information on attentional biases to food cues after OS, complementing ET findings.

In this context, the aim of this prospective longitudinal study was to assess alterations in attentional processing of visual food cues from pre- to 1-year post-OS using ET and VST. For the first time, these findings were compared to an age-, sex-, and BMI-matched control group without OS. It was hypothesized that both groups with severe obesity show a direction bias to food versus non-food cues and a duration bias for non-food versus food cues during ET and attentional biases towards food cues in the VST at baseline. This pattern was expected to be maintained in controls, while those with OS were assumed to show both direction and duration biases towards non-food versus food cues during ET and no more biased attentional processing of food cues in the VST 1-year post-OS. Secondary hypotheses were that attentional biases towards food cues would be linked to higher BMI, impulsivity, and greater eating disorder psychopathology pre-and post-OS. Uniquely, the predictive value of post-OS changes in attentional processing on percentage of total body weight loss (%TBWL) and eating disorder psychopathology after OS was examined, hypothesizing that reductions in food-related attentional biases will predict greater %TBWL and decreased disordered eating 1-year post-OS.

Materials and Methods

Participants

A total of 72 participants with severe obesity were included. The experimental group (EG, *n*=36) was recruited from Leipzig University Medical Center, mainly from the longitudinal Psychosocial Registry for Bariatric Surgery (PRAC; Baldofski et al., 2015). The control group (CG, *n*=36) was matched to the EG by age, sex, BMI, and socio-economic status, and was recruited from the same clinical institution and the population. Inclusion criteria for the EG were being scheduled for OS (gastric bypass or sleeve gastrectomy, thus BMI≥35 kg/m^2) within the next 3 months, and not undergoing pre-surgery protein diet. Inclusion in the CG required BMI≥35 kg/m^2 and absent intensive weight-loss treatment (i.e., ≤four nutritional consultations per year). Exclusion criteria for both groups included uncorrected visual impairment, serious physical and mental disorders (e.g., current psychosis), and medication intake with substantial effects on cognitive functioning. The study was approved by the local Ethics Committee of the University of Leipzig. Written informed consent was obtained prior study participation. All participants were informed that the results were analyzed pseudonymously and would not influence treatment.

A priori sample size calculation revealed that, given a small-to-medium effect size (*f*=.20) for changes in attentional processing of food cues (Giel et al., 2014), a total sample size of *n*=54 participants was required for detecting within-between interactions in repeated measures analyses of variance (ANOVAs) with adequate power of 95%. Considering data loss due to drop-out and invalid data in 30% (Giel et al., 2014), study enrollment was set to *n*=35 individuals per group. Of the initial 72 participants, 4 EG and 5 CG participants did not provide follow-up data (*n*=6 were not reachable, *n*=1 discontinued study participation, *n*=2 CG participants were excluded due to OS or pregnancy between assessment points), leaving a final EG of *n*=32 and CG of *n*=31 participants. In the EG, *n*=25 received gastric bypass and *n*=7 sleeve gastrectomy.

Procedure

All participants underwent the same assessment at baseline (T0) and 1-year follow-up (T1). Participants were tested individually in standardized sessions and were instructed to eat 1 h before to ascertain satiety. Attentional processing of food cues was assessed via ET during a free exploration paradigm, followed by the measurement of RTs during a VST. Subsequently, impulsivity was experimentally assessed via neuropsychological tasks. Afterwards, participants' binge-eating episodes were evaluated by a clinical interview (Eating Disorder Examination; Fairburn et al., 2014; Hilbert and Tuschen-Caffier, 2016a). A financial compensation was paid for each session (7 EUR/h).

Free Exploration Paradigm (eye tracking)

Detailed descriptions of the experimental procedures can be found elsewhere (e.g., Schmidt et al., 2016). Briefly, during the free exploration paradigm, participants were shown 30 pairs of food and non-food images (see Figure 1). Eye movements were continuously recorded using a desktop-mounted, video-based infrared eye-tracking system (Eyelink 1, SR Research, Ontario, Canada) with a spatial resolution of 0.1° and a temporal resolution of 500 Hz. Data cleaning was conducted according to Schmidt et al. (2016). Due to invalid data, n=1 EG and n=2 CG patients at T0, and n=1 EG patient at T1 were excluded from analysis.

Two attentional bias scores were determined for hypotheses testing: the direction bias displaying initial orientation and the gaze duration bias reflecting attentional maintenance. The direction bias score was calculated as the percentage of trials in which the first fixation was directed onto the food stimulus, with a score of 50% indicating no bias and a score > and <50% reflecting initial orientation bias towards food or non-food stimuli, respectively. The gaze duration bias score (in ms) was calculated by subtracting the mean gazing time on non-food stimuli from the mean gazing time on food stimuli, with positive scores indicating longer maintained attention towards food.

The paradigm has shown convergent and discriminant validity in previous samples. Specifically, gaze durations on food cues were consistently negatively associated with BMI in samples with obesity-related eating disorders across the age range (Baldofski et al., 2018; Schmidt et al., 2016; Sperling et al., 2017). Furthermore, the gaze duration bias distinguished individuals with binge-eating disorder (American Psychiatric Association [APA], 1994, 2013) from controls (Schmidt et al., 2016; Sperling et al., 2017).

Visual Search Task

In the VST, participants were randomly shown matrices of three or six food and/or non-food pictures presented on an imaginary circle in the middle of a computer screen (Figure 2; e.g., Schmidt et al., 2016). The pictures corresponded to the ones used during ET. For each matrix, participants were asked to decide as fast as possible whether all images were of the same category (food only trial, non-food only trial) or not (food target trial, non-food target trial) by pressing a corresponding key. The task started with a training block which was not analyzed, followed by six blocks with 30 trials each.

RTs were determined only in target present trials. Trials with false responses and RTs of 3 *SD*s below or above the group's mean were excluded from analysis. Due to invalid data, n=2 EG patients were excluded from analysis at T0.

For hypothesis testing, the detection bias score (in ms) was calculated by subtracting the mean RTs for food target trials from the mean RTs for non-food target trials, with positive scores indicating speeded detection of food targets and/or delayed disengagement from food distractors.

This paradigm has previously been used in samples with obesity-related eating disorders and discriminated between adolescents with binge-eating disorder (APA, 1994, 2013) and matched controls and showed clinical associations with reward sensitivity (Schmidt et al., 2016).

Clinical Associations and Outcomes

Neuropsychological assessment of impulsivity. The computerized Delay Discounting Task (DDT; Richards et al., 1999; run by Millisecond®) assesses participant's individual tendency to reduce the subjective value of a reward with increasing delay. Participants had to choose between a standard amount of money (10 EUR) with different time delays (0, 2, 30, 180, and 365 days) or a variable amount of money (0-10 EUR) without delay until an indifference point is found for each delay or until the maximum number of 30 trials for each delay has been performed. Based on the indifference points for each delay, the Area under the Curve (AUC, range: 0-1; Myerson et al., 2001) was calculated with lower values indicating higher discounting of delayed rewards; i.e., higher impulsivity.

The Cards and Lottery Task (CLT; Müller et al., 2017) assesses decision making under risk conditions. Participants were instructed to win as much virtual money as possible by making a series of decisions (i.e., choosing cards from two possible decks in 36 rounds) with conflicting short-term and long-term consequences. Decision-making behavior and reward sensitivity were determined by the Number of Advantageous Decisions (NAD, range: 0-36), with lower scores indicating more short-term oriented decision making and lower reward delay.

Self-report questionnaires. Non-food related impulsivity was evaluated via the Barratt Impulsiveness Scale - short version (BIS-15; Spinella, 2007; Meule et al., 2011) assessing non-planning, motor, and attentional impulsivity. The total sum score (range: 15-60; Cronbach's α=.80) was computed with higher scores indicating higher impulsivity. For eating disorder psychopathology, the global score (range: 0-6; α=.90) of the Eating Disorder Examination-Questionnaire (EDE-Q; Fairburn and Beglin, 2008; Hilbert and Tuschen-Caffier, 2016b) was assessed, with higher scores indicating greater eating disorder psychopathology.

Clinical interview. The binge-eating disorder module of the Eating Disorder Examination interview (EDE; Fairburn et al., 2014; Hilbert and Tuschen-Caffier, 2016a) was applied to determine the mean number of objective and subjective binge-eating episodes over the past 3 months to control for previously found effects of binge eating on attentional processing of food cues (Schmidt et al., 2016; Sperling et al., 2017; Stojek et al., 2018).

Weight status. BMI (kg/m^2) was calculated from objectively measured weight and height at T0 and T1. The percentage of total body weight loss (%TBWL) from T0 to T1 was determined as %TBWL=100–(100*weight at T1/weight at T0).

Control Variables

Hunger levels were assessed before sessions using a 7-point Likert scale, ranging from 1=*not at all hungry* to 7=*extremely hungry* (Hilbert et al., 2010).

For assessing the individual valence of food stimuli used in the experimental paradigms, all stimuli were presented on a computer screen after each session and pleasantness was rated on a visual analogue scale ranging from 0=*not at all pleasant* to 400=*very pleasant*. Based on a median split of participants' food ratings, the two categories 'attractive food' and 'unattractive food' were formed and each attentional bias score was additionally determined for each of these categories (Schmidt et al., 2016).

Data Analytic Plan

Post-OS changes in attentional processing of food cues based on ET (direction bias, gaze duration bias) and VST (detection bias) were evaluated with repeated measures ANOVAs including the factors Group (EG, CG; between-subjects)×Time (T0, T1; within-subjects). All dependent variables met the assumption of normal distribution and sphericity. For evaluating the presence of attentional biases towards food cues, one-sample *t* tests against 50% and zero, respectively, were conducted for each group separately.

Two-tailed Pearson correlations were performed to determine associations between ET and VST data and clinical variables (binge-eating episodes, EDE-Q, BIS-15, DDT, CLT) and BMI in the EG for each time point separately.

For predicting clinical outcomes at T1 (%TBWL, binge-eating episodes, EDE-Q) by changes in attentional bias scores from pre- to post-OS, linear regression analyses were conducted, controlled for baseline values of clinical variables. Effect sizes (*d* or partial η^2) were interpreted as small (.20 or .01), medium (.50 or .06), or large (.80 or .14; Cohen, 1988). All statistical tests were carried out using SPSS Version 23.0. A two-tailed significance level was set at α=.05.

Results

Sample Description

The final EG (*n*=32) and CG (*n*=31) did not significantly differ in sociodemographics (Table 1). While groups did not differ in BMI at T0, the EG had a significantly lower BMI due to significant %TBWL at T1 compared to the CG (*p*<.001). No group differences were found in pre-experimental hunger ratings at T0 and T1 and valence ratings of food stimuli at T0 (*ps*>.05). At T1, the EG rated food stimuli as less pleasant than the CG (*ps*<.05).

Free Exploration Paradigm (Eye Tracking)

Direction bias. No significant effects of group, time, or Group×Time (*ps*>.05; small effects) were found for initial direction bias (Table 2). Against expectation, the direction bias scores of the EG did not significantly differ from a test score of 50% at any time point (*ps*>.05; small effects), indicating no attentional bias for any stimulus category. As expected, the CG showed a significant direction bias towards food cues (*p*=.038; small effect), particularly for attractive (*p*=.015; medium effect), but not for unattractive food cues (*p*=.419; small effect) at T0. Unexpectedly, no significant direction bias for any stimulus category was detected at T1 in the CG (*ps*>.05; small effects).

Gaze duration bias. No significant effects of group, time, or Group×Time (*ps*>.05; small effects) were detected for gaze duration (Table 2). As expected, within each group and for both time points, gaze duration bias scores significantly differed from zero (EG: *ps*<.001, large effects at T0 and T1; CG: *ps*<.05, small to medium effects at T0; *ps*≤.001, medium to large effects at T1), indicating that non-food stimuli were fixated longer than food stimuli in both groups and at both time points.

Visual Search Task

Detection bias. No significant effects of group, time, or Group×Time (*ps*>.05; small effects) were found for detection bias (Table 2). Contrary to hypothesis, the detection bias scores of both groups did not significantly differ from zero at any time point (*ps*>.05; small effects), indicating no attentional bias for any stimulus category.

Exploratory analyses of raw RTs for food target and non-food target trials revealed a significant Group×Time effect for attractive food target trials (*p*=.011, medium effect; see Table S2 in online supplementary material), modifying a significant main effect of time (*p*=.006, medium effect), while no group effect emerged (*ps*>.05; small effects). The EG showed a greater reduction of RTs at follow-up than the CG. Significant main effects of time were additionally detected for all target categories ($.002 \le ps \le .009$, medium to large effects), except for non-food target trials with unattractive food distractors (p=.059, medium effect). The time effects indicated significant improvements in RTs over time in both groups. Group and Group×Time effects in these stimuli categories were non-significant (ps>.05; small to medium effects).

Clinical Associations

All associations between attentional processing data and clinical variables in the EG before and after OS are displayed in Table S3 (online supplementary material). At T0, the direction bias assessed via ET was positively associated with BMI (r=.43, p=.016). Against expectations, no further significant associations were found at T0 or T1 (ps>.05).

Changes in Attentional Processing and Clinical Outcomes

Results of regression analyses are displayed in Table S4 (online supplementary material). Against expectations, changes in attentional bias scores from pre- to post-OS in the EG did not significantly predict patient's %TBWL, binge-eating episodes, or EDE-Q global score measured at T1 (ps>.05).

Discussion

Using established ET and VST paradigms, this controlled study's results indicate that OS does not induce changes in attentional processing of visual food cues, at least not within the first year post-OS. All participants with severe obesity, independent of group assignment, showed a time-robust avoidance pattern of food cues in later, voluntary attentional processes, providing further evidence for a top-down regulation of attentional processes towards non-food cues in adults with severe obesity. However, the expected automatic initial orientation towards food cues was not seen in pre-bariatric patients, although a greater percentage of initial fixations onto food cues was associated with greater BMI. Against expectation, no further clinical associations were found and individual changes in attentional processing of food cues from pre- to post-OS did not significantly predict patients' post-bariatric weight loss, binge eating, and eating disorder psychopathology measured 1-year post-OS.

Free Exploration Paradigm (Eye Tracking)

Adding to the inconsistent evidence in samples with overweight and obesity showing either present (Castellanos et al., 2009; Graham et al., 2011; Werthmann et al., 2011) or absent (Baldofski et al., 2018; Sperling et al., 2017) initial orientation towards food cues, present ET data indicated no initial direction bias to food cues before OS. As expected, avoidance of food cues in later attentional processes was present pre- and post-OS, validating previous ET studies in obesity that used the same paradigm and stimulus material (Baldofski et al., 2018; Sperling et al., 2017). However, the present results contrast with earlier ET findings in a small bariatric sample by Giel et al. (2014) showing food avoidance only 6 months after, but not before OS, although a slight but non-significant preference towards non-food cues was already present before OS. Thus, the idea that OS causes changes in attentional processing of food cues (Giel et al., 2014) cannot be supported by the current well-controlled study. Consequently, altered activation in brain areas associated with reward sensitivity and inhibitory control (Baboumian et al., 2019; Faulconbridge et al., 2016; Zoon et al., 2018) and normalized gut-brain communication (Le Roux et al., 2006; Le Roux et al., 2007; Ochner et al., 2011) found in post-bariatric samples do not appear to be reflected in patients' attentional processing of visual food cues. The time-stable attentional avoidance of food cues in both groups, indicated by voluntary attention maintenance on non-food cues during long stimulus duration, might reflect a cognitive strategy in individuals with severe obesity to avoid triggers of craving and uncontrolled eating (Werthmann et al., 2015). Due to the high BMI at baseline, all participants probably had a deep desire for weight reduction, leading to devaluating food as threat and a stronger top-down regulation of visual attention to non-food cues (Field et al., 2016). Indeed, pleasantness ratings of food were comparatively low in both groups and at both assessment points, in line with Giel et al. (2014), which suggest that the mindsets of these patients were already adapted to the goal of weight loss involving a devaluation of food cues and attentional avoidance to resist temptation (Giel et al., 2014). The food-specific direction bias in the CG, a group of individuals with severe obesity and no current weight-loss treatment, at baseline might mirror a motivational conflict between enjoyment of food and desire for weight loss (Field et al., 2016), leading to experience food as both attractive and aversive (Werthmann et al., 2011).

Visual Search Task

Contrasting hypothesis, but in line with the present ET results, no biased attentional processing of food cues in individuals with severe obesity was found using an indirect measure of visual attention (VST). Relatedly, there were no changes in visual attention towards food cues from pre- to 1-year post-OS. As group differences in the detection of food versus non-food cues have only been found between adolescents with binge-eating disorder versus matched controls (Schmidt et al., 2016), but not between individuals with obesity versus normal weight (Bongers et al., 2015), biases in attentional processing of food cues deteced via RT-based paradigms seem to be a cognitive marker of eating disorders rather than overweight disorders.

Interestingly, exploratory analyses of RTs in the VST revealed that both groups discovered the target faster at T1 compared to T0, regardless of target category. For attractive food targets, improvements in RTs over time were significantly greater in the EG than the CG, suggesting that accelerated target detection results from post-OS improvements in general attention and executive functions (Handley et al., 2016).

Clinical Associations

Attentional processing of food cues was poorly associated with clinical characteristics of bariatric patients. Only a higher BMI in patients before OS was associated with stronger initial orientation towards food cues during ET, which is consistent with most (Castellanos et al., 2009; Graham et al., 2011; Werthmann et al., 2011), but not all previous research (Nijs et al., 2010). There were no further significant associations between directly and indirectly measured attentional biases towards food and experimentally assessed and self-reported impulsivity, and eating disorder psychopathology, consistent with previous research that did not identify clear associations across studies (Baldofski et al., 2018; Schmidt et al., 2016; Sperling et al., 2017). Thus, biased attentional processing of food cues may not be a permanent trait (like impulsivity), but rather a state indicating individual's current physical (e.g., hunger level), motivational (e.g., desire for weight loss), or emotional levels (e.g., negative affect) and, therefore, fluctuates over time (Field et al., 2016).

Changes in Attentional Processing and Clinical Outcomes

Against expectations, individual changes in attentional processing of food cues from pre- to 1-year post-OS did not predict post-bariatric weight loss, eating disorder psychopathology, or uncontrolled eating behavior. The lack of prediction effects in the present study might be explained by post-OS anatomical, physiological, and endocrinological changes leading to extreme weight loss and a reduction of eating disorder pathology in almost all patients within the first two years after OS (Courcoulas et al., 2018; Golomb et al., 2015), regardless of patient's food-cue reactivity.

Strengths and Limitations

Strengths of this study include the prospective, longitudinal design, the adequate sample size with high retention rate (87.5%), and the inclusion of a weight-stable matched control group without current weight-loss treatment. Visual attention and impulsivity were assessed multimodally using experimental and self-report measures. Limitations include that effects of medication intake and physical comorbidities on attentional processing were not systematically assessed. Individual valence ratings of presented food cues were relatively low in the present sample, which might have affected paradigm's sensitivity to detect OS-induced changes in food-specific attentional processing. The use of individualized stimulus material in future studies might overcome this aspect.

Conclusion

This study provided further support for a voluntary top-down regulation of attentional processes towards non-food cues in adults with severe obesity. At the same time, visual attention did not change from pre- to 1-year post-OS. Considering extant research, biased attentional processing of food cues may be a more prominent feature in individuals with eating rather than weight disorders. Given the profound anatomical and metabolic effects of OS and the related homogeneity of patients' weight loss and eating disorder psychopathology reduction within the first two years after OS (Courcoulas et al., 2018; Smith et al. 2019), further studies with longer follow-ups are needed to ultimately clarify whether inter-individual differences in attentional food cue processing occur in the long term, when surgical effects diminish. As long as findings on attentional processing of visual food cues across the obesity spectrum are heterogeneous and unrelated to clinical outcomes, there is no urgent call for post-OS interventions addressing attentional bias modification (Kakoschke et al., 2014; Kemps et al., 2015).

Ethical Standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent

Informed consent was obtained from all individual participants included in the study.

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Declarations of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Table 1

Sample characteristics of the experimental group (EG) and control group (CG).

	EG (n=32)	CG (n=31)		
	M (SD)	*M (SD)*	Statistics	*p*
Sex: female, *n* (%)	21 (65.6)	21 (67.7)	χ^2 (1, N=63)=0.32	.859
Age T0 (years)	42.3 (10.9)	43.1 (10.2)	F (1, 61)=0.11	.742
BMI T0 (kg/m^2)	49.7 (9.3)	47.7 (6.7)	F (1, 61)=0.87	.355
BMI T1 (kg/m^2)	34.1 (9.5)	47.9 (6.9)	F (1, 61)=43.39	<.001
SES T0 (1-21)	10.1 (3.5)	10.2 (3.1)	F (1, 54)=0.02	.895
Hunger rating T0 (1-7)	1.1 (0.6)	1.1 (0.3)	F (1, 59)=0.00	.972
Hunger rating T1 (1-7)	1.3 (1.0)	1.3 (0.5)	F (1, 61)=0.01	.913
Food rating T0 (0-400)	214.4 (65.5)	222.7 (58.8)	F (1, 61)=0.28	.589
Food rating T1 (0-400)	197.4 (61.2)	229.7 (57.4)	F (1, 61)=4.67	.035
%TBWL T1	31.9 (7.9)	-0.5 (5.1)	F (1, 61)=366.41	<.001

Notes. BMI=body mass index; SES=socio-economic status; T0=baseline, for EG: assessed prior to obesity surgery; T1=1-year follow-up, for EG: assessed 1-year post-surgery; %TBWL=Percentage of total body weight loss from T0 to T1.

Table 2
Attentional biases as a function of group and time.

	EG		CG		Group×Time		
	T0	T1	T0	T1			
	M (SD)		*M (SD)*		*F*(1, 57)	*p*	η^2
Free Exploration Paradigm							
Gaze direction bias (%)							
All food	52.2 (11.5)	50.1 (11.3)	53.5 (8.6)	52.6 (11.3)	0.115	.735	.00
Attractive food	51.5 (13.2)	50.1 (14.1)	55.3 (11.0)	52.2 (14.0)	0.107	.744	.00
Unattractive food	53.1 (15.6)	49.8 (13.2)	52.0 (12.9)	53.2 (12.2)	0.786	.379	.01
Gaze duration bias (ms)							
All food	-340.0 (347.7)	-322.7 (301.4)	-189.9 (340.1)	-267.9 (307.4)	1.425	.238	.02
Attractive food	-372.3 (389.2)	-351.5 (352.2)	-230.5 (387.7)	-294.7 (348.3)	0.973	.328	.02
Unattractive food	-312.8 (382.5)	-295.7 (322.1)	-149.5 (357.5)	-239.3 (355.0)	1.010	.319	.02
Visual Search Task							
Detection bias (ms)							
All food	-6.9 (76.4)	-3.5 (50.0)	-8.2 (48.5)	-4.2 (56.4)	0.000[a]	.717	.00
Attractive food	-16.7 (86.4)	-11.7 (47.5)	-1.3 (48.9)	-17.4 (89.2)	0.745[a]	.392	.01
Unattractive food	4.8 (93.7)	1.8 (73.0)	-11.7 (77.5)	10.5 (50.5)	0.821[a]	.368	.01

Notes. Gaze direction bias scores >50% indicate attentional bias towards food stimuli, <50% towards non-food stimuli, and =50% an absent attentional bias for any stimulus category. Gaze duration bias scores >0ms indicate attentional bias towards food stimuli, <0ms towards non-food stimuli, and =0ms an absent attentional bias for any stimulus category. EG=experimental group; CG=control group; T0=baseline, for EG: assessed prior to obesity surgery; T1=1-year follow-up, for EG: assessed 1-year post-surgery.
[a] df=1, 59

Figures

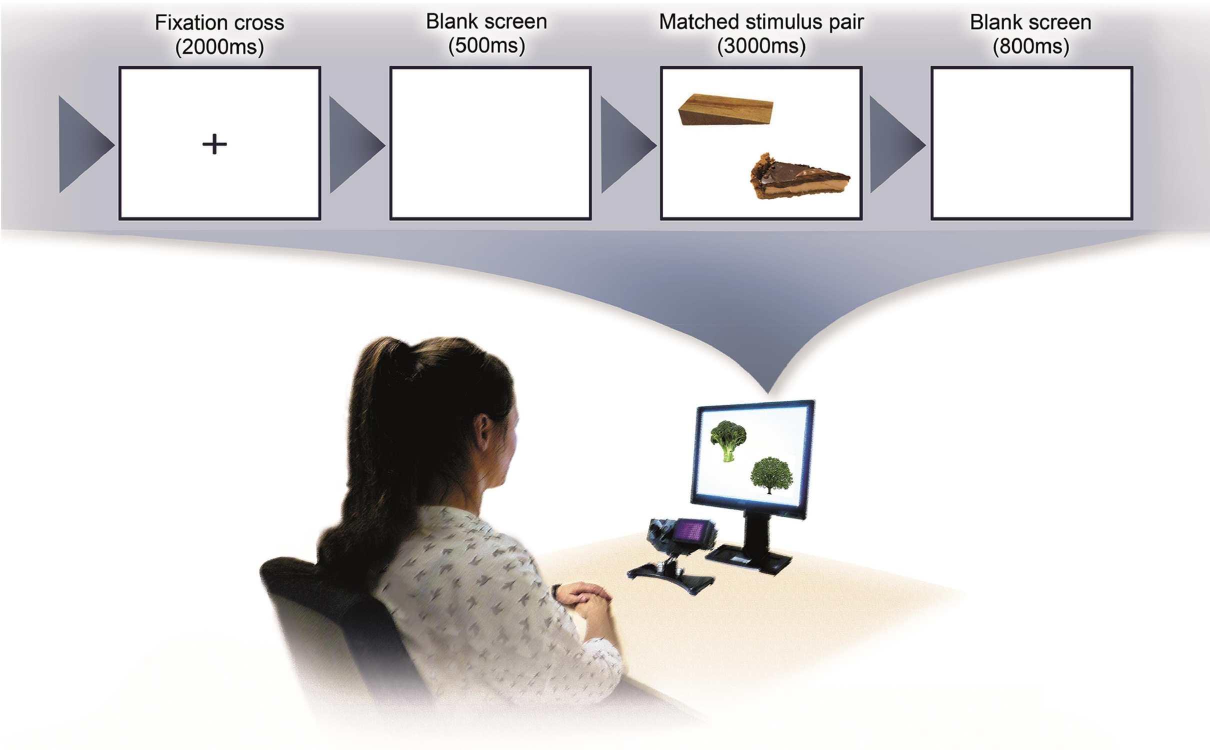

Figure 1. Procedure of the free exploration paradigm. Each trial began with a fixation cross, followed by a blank screen, the picture pair, and ended with a blank screen introducing the next trial. The pairs of food and non-food cues were matched with respect to color, size, complexity, and shape. Food cues included both low-caloric (e.g., carrot, broccoli) and high-caloric food (e.g., pizza, chocolate), while non-food cues depicted everyday objects not associated with eating or food.

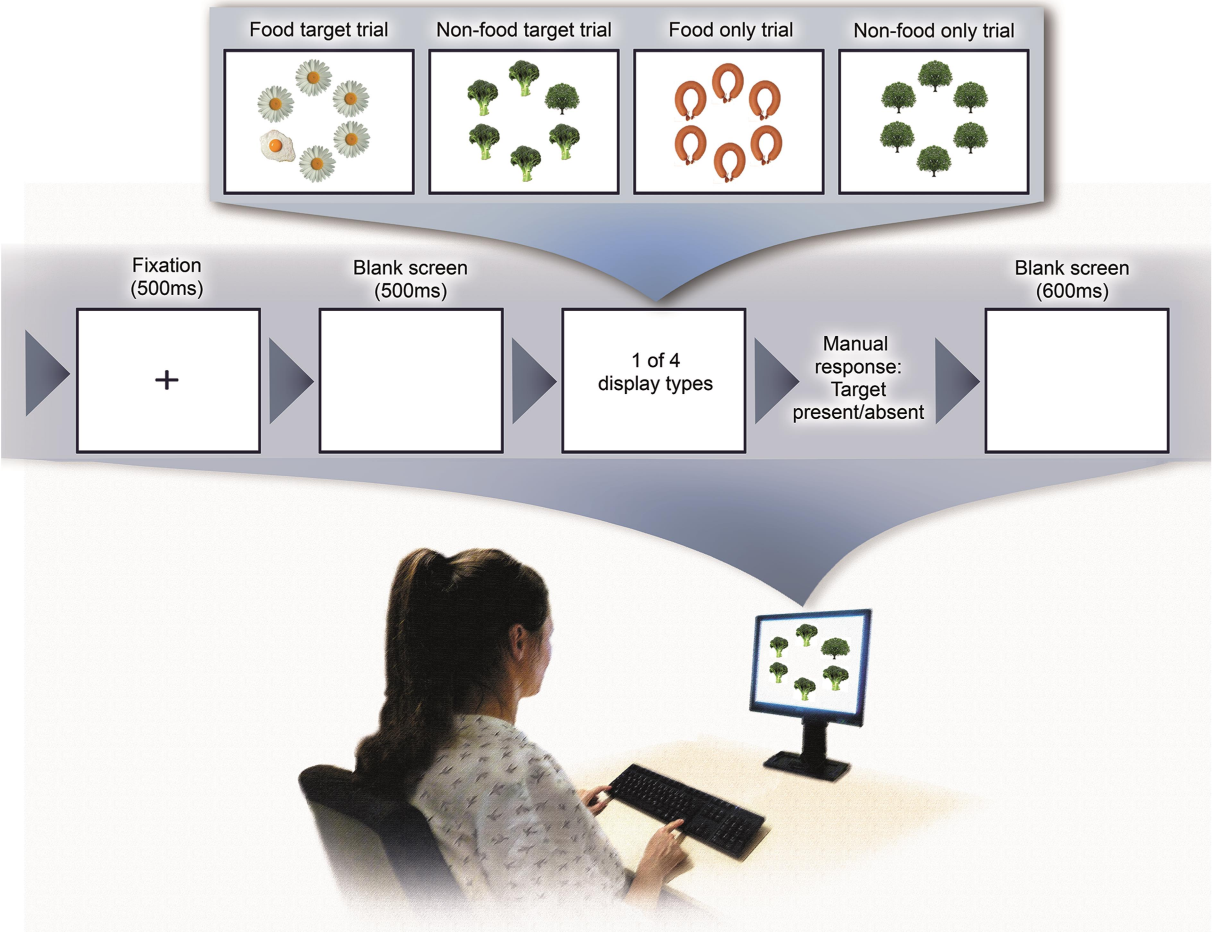

Figure 2. Procedure of the visual search task. Each trial began with a fixation cross, followed by a blank screen, one of four possible trial types, and ended with a blank screen introducing the next trial. Picture matrices remained on the screen until the participant gave a manual response by pressing the left or right key.

Supplementary Material

Table S1

Summary of eye-tracking studies using free exploration paradigms to assess attentional biases to food cues in adults with overweight and/or obesity and control participants (normal weight, binge-eating disorder, night eating syndrome).

	Sample		**Method**			**Within-group biases**		**Between-group differences**	
Authors	**EG**	**CG**	**Condition**	**ET paradigm and variables**	**Stimuli**	**EG**	**CG**	**Direction bias**	**Duration bias**
Baldofski et al., 2018	NES - *n*=19 - BMI=35.1 ±9.3 kg/m²	Obesity - *n*=19 - BMI=35.4 ±10.3 kg/m²	Satiety	Free Exploration Paradigm	- 30 food cues (high and low caloric) - 30 neutral stimuli (office, household, nature items) - presented for 3s	- gaze direction for food versus non-food cues - gaze duration for non-food versus food cues	- gaze duration for non-food versus food cues		
Castellanos et al., 2009	Obesity - *n*=18 - BMI=38.7 ±6.9 kg/m²	Normal weight - *n*=18 - BMI=21.7± 1.9 kg/m²	Satiety versus hungry	Free Exploration Paradigm within Visual Probe Task	- 20 high-caloric food cues - 20 low-caloric food cues - 20 nature cues - presented for 2s	- gaze direction bias for food versus non-food in hungry condition - gaze duration bias for food versus non-food in satiety and hungry condition	- gaze direction and duration bias for food versus non-food in hungry condition	- EG>CG for food cues in satiety	- EG>CG for food cues in satiety
Giel et al., 2014	Pre-bariatric - *n*=17 - BMI=48.3 ±6.5 kg/m²	- no CG - pre-post (6 month) obesity surgery	Satiety	Free Exploration Paradigm	- 30 low- and high-caloric food cues - 30 non-food cues (household items) - presented for 3s	n.r	n.r.		- Post-surgery>pre-surgery for non-food cues

	Sample		Method			Within-group biases		Between-group differences	
Authors	**EG**	**CG**	**Condition**	**ET paradigm and variables**	**Stimuli**	**EG**	**CG**	**Direction bias**	**Duration bias**
Graham et al., 2011	High BMI - *n*=15 - BMI=28.9 ±5.0	Low BMI - *n*=21 - BMI=21.3 ±2.3 kg/m²	Moderate hunger	Free Exploration Paradigm	- 20 high-caloric sweet food cues - 20 high-caloric savory food cues - 20 low-caloric food cues - presented for 3s		- gaze direction bias for high-caloric sweet food cues versus low-caloric food cues	- EG>CG for low-caloric food cues	
Nijs et al., 2010	Overweight/ obesity - *n*=26 - BMI=30.0 ±4.6 kg/m²	Normal weight - *n*=40 - BMI=20.6 ±1.1 kg/m²	Satiety or hunger	Free Exploration Paradigm	- 15 high-caloric food cues - 15 neutral cues (office items) - presented for 2s	- gaze direction and duration bias for food versus non-food cues	- gaze direction and duration bias for food versus non-food cues		
Schag et al., 2013	BED - *n*=25 - BMI=35.4 ±5.6 kg/m²	CG1: Obesity - *n*=26 - BMI=35.4 ±5.4 kg/m² CG2: Normal weight - *n*=25 - BMI=22.5 ±1.6 kg/m²	Satiety	Free Exploration Paradigm	- 24 low- and high-caloric food cues - 24 non-food cues (everyday objects) - presented for 3s	- gaze direction bias for food versus non-food cues	- gaze direction bias for food versus non-food cues in CG1 and CG2		- EG>CG1, CG2
Sperling et al., 2017	BED - *n*=23 - BMI=32.4± 9.2 kg/m²	Obesity - *n*=23 - BMI=32.7 ±9.0 kg/m²	Satiety	Free Exploration Paradigm	- 30 food cues (high and low caloric) - 30 neutral stimuli (office, household, nature items) - separation into individual attractive and unattractive food cues - presented for 3s	- gaze duration for non-food cues versus unattractive food cues	- gaze duration bias for non-food versus all food cues		- CG>EG for non-food cues

	Sample		Method			Within-group biases		Between-group differences	
Authors	**EG**	**CG**	**Condition**	**ET paradigm and variables**	**Stimuli**	**EG**	**CG**	**Direction bias**	**Duration bias**
Werthmann et al., 2011	Overweight/ obesity - *n*=22 - BMI=28.0± 3.7 kg/m²	Normal weight - *n*=29 - BMI=21.2±2.0 kg/m²	Satiety	Free Exploration Paradigm within Visual Probe Task	- 20 high-caloric food cues - 20 musical instrument cues - 10 neutral, non-food cues (office supplies, traffic objects) - presented for 2s	n.r.	n.r.	- EG>CG for food cues	

Notes. Only significant findings are presented. EG=experimental group; CG=control group; BMI=body mass index; ET=eye tracking; BED=binge-eating disorder; NES=night eating syndrome; n.r.=not reported.

Table S2

Reaction Times (RTs) in the Visual Search Task as a function of group and time.

	EG		CG		Group×Time		
	T0	T1	T0	T1			
	M (SD)		*M (SD)*		$F(1, 59)$	p	η^2
Visual Search Task							
RTs food target (ms)							
All food	932.9 (197.4)	864.0 (157.2)	866.5 (161.2)	847.6 (156.3)	3.327	.073	.05
Attractive food	939.1 (204.1)	858.5 (152.9)	858.7 (158.3)	855.8 (162.5)	6.879	.011	.10
Unattractive food	926.3 (195.3)	871.7 (166.9)	870.0 (170.3)	839.7 (156.4)	0.619	.435	.01
RTs non-food target (ms)							
All food	925.9 (195.8)	860.5 (149.5)	858.3 (151.8)	843.3 (152.5)	2.894	.094	.05
Attractive food	922.4 (186.9)	846.8 (143.1)	857.5 (168.7)	838.4 (149.6)	3.546	.065	.06
Unattractive food	931.1 (209.6)	873.5 (166.4)	858.3 (139.2)	850.2 (161.2)	2.102	.152	.03

Notes. EG=experimental group; CG=control group; T0=baseline, for EG: assessed prior to obesity surgery; T1=1-year follow-up, for EG: assessed 1-year post-surgery.

Table S3

Associations between attentional processing data and clinical variables in the experimental group (EG).

	Time Point	EG					
		BE	EDE-Q	BIS-15	DDT	CLT	BMI
Free Exploration Paradigm							
Direction bias	T0	-.14	.05	-.05	-.08	.07	**.43**
	T1	-.18	.00	-.04	-.03	-.01	-.21
Duration bias	T0	-.23	.05	.04	-.23	-.03	.28
	T1	.17	.17	-.10	-.19	-.11	-.05
Visual Search Task							
Detection bias	T0	.02	-.30	-.11	-.00	-.21	.20
	T1	.05	-.04	-.22	.02	-.20	-.13

Notes. Bivariate correlations are displayed as Pearson's *r*. Correlations with p<.05 are in boldface. T0=assessed prior to obesity surgery; T1=assessed 1-year post-surgery; BE=binge-eating episodes; EDE-Q=Eating Disorder Examination-Questionnaire (0-6*, less favorable scores are asterisked); BIS-15=Barratt Impulsiveness Scale (15-60*); DDT=Delay Discounting Task (0*-1); CLT=Cards and Lottery Task (0*-36); BMI=body mass index.

Table S4

Prediction of clinical outcomes by changes in attentional bias scores in the experimental group (EG).

	B	*SE*	β	*p*	Statistics	*p*	Total R^2
Dependent variable: %TBWL T1					$F(3, 24)=0.115$	.951	.01
direction bias T1-T0	0.033	0.100	0.069	.743			
duration bias T1-T0	0.002	0.005	0.087	.677			
detection bias T1-T0	-0.002	0.017	-0.023	.912			
Dependent variable: EDE-Q T1					$F(4, 19)=0.999$	.433	.17
EDE-Q T0	0.382	0.259	0.358	.158			
direction bias T1-T0	0.005	0.015	0.073	.742			
duration bias T1-T0	0.000	0.001	-0.002	.993			
detection bias T1-T0	.001	0.003	0.107	.663			
Dependent variable: BE T1					$F(4, 23)=0.912$	.474	.14
BE T0	-0.017	0.052	-0.064	.750			
direction bias T1-T0	−0.007	0.009	-0.164	.425			
duration bias T1-T0	0.001	0.000	0.309	.131			

Visual attention towards food cues after OS

	B	*SE*	β	*p*	Statistics	*p*	Total R^2
detection bias T1-T0	0.001	0.001	0.170	0.395			

Notes. T0=assessed prior to obesity surgery; T1=assessed 1-year post-surgery; %TBWL=percentage of total body weight loss; EDE-Q=Eating Disorder Examination-Questionnaire; BE=binge-eating episodes.