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Research report

Eye gaze tracking reveals heightened attention to food in adults with binge eating when viewing images of real-world scenes ☆

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ABSTRACT

Individuals with eating disorders often exhibit food-related biases in attention tasks. To assess the engagement and maintenance of attention to food in adults with binge eating, in the present study, eye gaze tracking was used to compare fixations to food among non-clinical adults with versus without binge eating while they viewed images of real-world scenes. Fifty-seven participants' eye fixations were tracked and recorded throughout 8-second presentations of scenes containing high-calorie and/or low-caloriefood items in various settings (restaurants, social gatherings, etc.). Participants with binge eating fixated on both high-calorie and low-calorie food items significantly more than controls, and this was the case when the high- and low-calorie food items were presented in the same image and in different images. Participants with binge eating also fixated on food items significantly earlier in the presentations. A time course analysis that divided each 8-second presentation into 2-second intervals revealed that participants with binge eating attended to food items more than control participants throughout the 8-second presentation. These results have implications for theory regarding the initiation and maintenance of binge eating.

Introduction

Binge-eating disorder (BED), which is characterized by frequent binge eating episodes accompanied by loss of control, is an important contributor to weight gain and obesity. It is estimated that approximately 42% of those with a BED diagnosis are obese, as compared to 16% of people with no history of an eating disorder (Kessler et al., 2013). Given that binge eating involves an overconsumption of calories, weight gain is an expected consequence; however, according to epidemiological research nearly 60% of those with BED are not obese (Kessler et al., 2013). This observation raises questions about what factors may contribute to the development of obesity, or lack thereof, in individuals with BED. In the present study we examined individual differences in attention to food that may underlie eating disorders such as BED, by comparing normal weight individuals with and without binge eating.

Cognitive models of eating disorders propose that attentional biases play a role in initiating and maintaining symptoms in BED, although most of the research investigating the role of attention in eating disorders has examined anorexia and bulimia nervosa (Vitousek & Hollon, 1990; Williamson, Muller, Reas, & Thaw, 1999; Williamson, White, York-Crowe, & Stewart, 2004). Among those with an eating disorder, an attentional bias involves preferential processing of personally salient stimuli, such as food- and body-related stimuli, which may in turn influence cognition and behavior (Shafran, Lee, Cooper, Palmer, & Fairburn, 2007). Attentional biases manifest as either an avoidant response, in which one diverts attention away from salient stimuli more quickly and spends less time attending to these stimuli relative to healthy controls, or as a hypervigilant response, in which one attends more quickly to salient stimuli and for a longer duration than healthy controls (Williamson et al., 1999).

Previous studies have focused primarily on examining the attentional processes of orientation, engagement, and disengagement from food-related stimuli in overweight and obese individuals with a BED diagnosis (e.g., Schmitz, Naumann, Trentowska, & Svaldi, 2014; Svaldi et al., 2014; Svaldi, Tuschen-Caffier, Peyk, & Blechert, 2010). These studies have tended to support findings of hypervigilant attentional responses and preferential engagement with food stimuli in this population. For example, Schmitz et al. (2014) used a word identification task to examine attention to food stimuli in BED. On each trial a food or non-food word was gradually made more visible and the participants' task was to identify the word as quickly as possible. Schmitz et al. found that participants with BED were faster to identify food words than weight-matched controls, which they interpreted as greater attentional vigilance for food stimuli. Schmitz et al. also found that the same participants preferentially

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attended to food stimuli in a spatial cueing task, and that a substantial stimulus engagement effect was present only for the BED group. Other research has shown that BED is associated with impairments disengaging and inhibiting responses to food stimuli relative to weight-matched controls in inhibitory control tasks (Svaldi et al., 2014). The increased attentional engagement with food and the difficulty disengaging from food may reflect the hallmark symptom of BED, namely, loss of control during episodes of overeating. A meta-analysis carried out by Schag, Schönleber, Teufel, Zipfel, and Giel (2013) supports this idea, as it was found that overweight and obese individuals with BED exhibited greater reward sensitivity and impulsive behavior than those without.

Studies of brain activation may also provide insight into attentional biases and the salience of food stimuli for those with BED. Svaldi et al. (2010) found that women with BED had longer latency ERPs than a weight-matched control group when viewing high-calorie food images, but not low-calorie food images (all the participants had BMIs greater than 25 kg/m^2). Svaldi et al. interpreted this result to reflect heightened attention to high-calorie foods and concluded that women with BED found these stimuli more rewarding and were more motivated to attend to them than images of low-calorie foods. Increased orbitofrontal cortex activation in response to food stimuli has been documented in overweight individuals with BED, which also suggests enhanced reward sensitivity (Schienle, Schafer, Hermann, & Vaitl, 2009).

Incentive-sensitization, a theory borrowed from the addictions field that proposes that exposure to salient cues (such as food stimuli) triggers changes in the dopamine reward system, may provide an explanation for increased reward sensitivity (Robinson & Berridge, 1993). Applying the theory to BED, repeated binge-eating episodes, coupled with an activated dopamine reward system, may produce a conditioning process in which the brain interprets food stimuli as a signal for an impending reward, triggering a craving for the stimulus. Alternatively, attentional biases for food-related cues may contribute to cue reactivity (Jansen, 1998). For a person with binge eating, attending to food stimuli, whether through sight, taste, smell, or touch, is hypothesized to trigger subjective cravings through the process of classical conditioning (Jansen, 1998). If these sensory cues are consistently paired with food intake they can become conditioned stimuli for conditioned responses such as cue reactivity, cravings, and, ultimately, increased food consumption. Cue-reactivity theory may therefore explain why individuals with BED exhibit increased attention to food cues.

In contrast to the research with overweight and obese individuals with BED, studies of attention in overweight and obese individuals without BED have reported evidence of an approach-avoidance pattern of visual attention, such that engagement with food stimuli is followed by rapid disengagement. For example, in Werthmann et al.'s (2011) study, although overweight participants directed their initial gaze more often to food in a visual probe task, these fixations were briefer than those of normal weight participants. Similarly, Doolan, McElhinney, Smyth, Breslin, and Gallagher (2012) found that overweight and obese participants shifted attention away from both high- and low-calorie food images soon after fixating them. It has been proposed that this engagement–disengagement inclination may be indicative of lower impulsivity and less rash-spontaneous behavior in obese individuals without BED relative to those with BED (Schag, Schönleber, et al., 2013), as obese individuals without BED are quick to disengage their attention away from food images whereas those with BED are not. BED may represent a phenotype of obesity marked by greater impulsivity, as shown by increased attention and slower disengagement from food images, and increased loss of control over eating behaviors.

A limitation of many previous studies is that they used tasks that use response latencies to infer attentional engagement (e.g., word identification tasks, visual probe tasks, the dot-probe task). Measuring the focus of attention directly using eye gaze tracking is an alternative methodology that allows participants to view stimuli without interruption or the imposition of limited viewing times (as is the case with the dot-probe task, for example). Schag, Teufel, et al. (2013) used eye gaze tracking to measure BED and control participants' attention to food images. They showed pairs of food and non-food images for 3 seconds and tracked participants' eye gaze while they freely viewed the images. They found that overweight and obese participants with BED fixated on food longer than overweight and obese participants without BED and normal-weight participants without BED. Schag, Teufel et al. concluded that the heightened attention to food stimuli observed in those with BED reflects increased food-related reward sensitivity.

Although the literature indicates that there are important differences in attention to food between overweight and obese individuals with and without BED, little is known about the relationship between attention and BED in normal-weight individuals. One possibility is that food-related reward sensitivity and inhibitory control differs between normal-weight individuals with BED and overweight individuals with BED, such that those who are normal-weight are better able to regulate food intake. Weight gain may occur over time with recurrent binge eating, such that normal-weight binge eaters may become overweight or obese if their binge-eating symptoms persist and their regulation of food intake declines. . Interestingly, few studies have examined attention in those with subclinical symptoms of BED. Despite the lowering of minimum frequency and duration criteria for BED in DSM-5 to weekly binge-eating episodes for three months (American Psychiatric Association, 2013), subthreshold binge eating remains prevalent even according to these updated criteria. For example, 3.6% of adolescents had experienced subthreshold BED and 4.4% had experienced subthreshold bulimia nervosa by age 20 in a recent eight-year follow-up study (Stice, Marti, & Rohde, 2013). Research on attention in BED has focused largely on clinical BED populations, and as a consequence relatively little is known of attentional biases in individuals with subthreshold symptoms of BED, one-third of whom may eventually develop clinical BED (Stice et al., 2013). Understanding motivational and cognitive processes underlying disordered eating behaviors such as binge eating contributes to the refinement of theoretical models and to the development of effective prevention and treatment programs.

The present research

The purpose of the present study was to compare adults with and without recent binge eating in their attention to high- and low-calorie foods presented in complex, real-world scenes (see Fig. 1 for an example). Like Schag, Teufel, et al. (2013), we used an eye gaze tracking paradigm to measure participants' attention to food, although there were several important differences between the Schag, Teufel et al. study and our own. First, we compared normal weight individuals with and without binge eating. Second, whereas food and non-food images were presented in pairs in the Schag, Teufel et al. study, we presented single images that had high- and low-calorie food embedded in real-world scenes. Our study complements the Schag, Teufel et al. study by examining attention to food in BED under more naturalistic viewing conditions and over a longer interval (8 seconds vs. 3 seconds). The longer presentation time allowed us to measure changes in attention to food over time. To quantify these changes, we divided the fixation data from each 8-second presentation into 2-second intervals and carried out time course analyses of these data. These analyses allowed us to evaluate group differences in attentional engagement, disengagement, and the maintenance of attention. The depiction of food in real-world settings (e.g., kitchens, parties, restaurants, etc.) enhanced the ecological validity of our study and increased the confidence that our results

Fig. 1. Example eye tracking data for an image containing both low-calorie and high-calorie foods (low-calorie apples and high-calorie tarts and cheese). The small white circles denote individual fixations; numbers adjacent to fixations indicate the duration of the fixation (in milliseconds). The large circles and rectangles denote regions that were defined for each image to demarcate the low-calorie and high-calorie foods items; fixations located within these regions were categorized as fixations to low-calorie or high-calorie food. These markings are superimposed on the image for illustration purposes and were not visible to participants. The image is shown in gray scale to increase the contrast of the markings; the images were shown in color to participants.

reflected genuine differences in the way that binge-eating and control participants attend to food in their environment. If participants with binge-eating experience greater food-related reward sensitivity then one would predict that they would attend to food stimuli in these scenes significantly more than control participants, and possibly earlier in the presentation as well. The time course analyses allowed us to test the prediction that participants with binge-eating would be slower or less likely to disengage from food stimuli than control participants.

Method

This study received approval from an institutional research ethics board and all participants provided informed consent.

Participants

Participants consisted of community members and undergraduate students. Both women and men were recruited. Participants were recruited through an online research participation system (students only) and advertisements placed on campus and in the community (e.g., health care centers in Calgary). In exchange for taking part in the study, participants received either bonus credit in a psychology course or a $25 gift card. Participants were classified into binge-eating or non-binge-eating (control) groups according to criteria described below.

Measures

Potential participants were invited to complete the Eating Attitudes Test (EAT-26; Garner, Olmsted, Bohr, & Garfinkel, 1982) and a web-based demographics questionnaire created using Qualtrics software (www.qualtrics.com). The EAT-26 includes a yes/no question assessing binge eating. Individuals who reported binge eating, and a comparable group of individuals who reported no binge eating, were invited for a laboratory visit to participate in the eye tracking task.

During their lab visit, participants completed the Questionnaire on Eating and Weight Patterns Revised (QEWP-R; Spitzer et al., 1993), a more detailed measure of binge eating. The QEWP-R includes 23 questions about weight and eating behaviors, including compensatory behaviors such as fasting, vomiting, and exercise, and details regarding past binge eating episodes over the past 3 to 6 months. It has been shown to have a specificity of 74% and to identify 95.3% of individuals with two or more binge eating episodes per week (Celio, Wilfley, Crow, Mitchell, & Walsh, 2004). Binge-eating ($n = 27$; 22 women and 5 men) and control ($n = 30$; 21 women and 9 men) groups were created based upon presence versus absence of self-reported binge eating using the QEWP-R. Binge-eating participants endorsed having eaten within a 2-hour period what most people would regard as an unusually large amount of food, during which they felt a lack of control regarding what or how much they were eating, at least once over the past 6 months.

Participants provided demographic information, including their weight and height, from which body mass index (BMI) was calculated.

Stimuli

Stimuli consisted of 125 images of real-world scenes, 75 of which contained food items (60%). The large number of images presented allowed us to be confident that our results were not due to any peculiarities of a small set of images. Images with food showed food in various contexts (e.g., kitchens, grocery stores, parties, offices). Food was only part of these images and encompassed no more than 40% of the image area (ranging from 5% to 40%). Thus, each image contained many other stimuli for participants to attend to, similar to real-world environments. The remaining 50 images did not contain food and were included to make the purpose of the study less obvious, more ecologically valid, and to create variety in the sequence of images. Figure 1 shows an example image (with fixation data superimposed on the image).

There were three categories of food images: images with high-calorie food ($N = 25$), images with low-calorie food ($N = 25$), and images with both high- and low-calorie food ($N = 25$). Categorization of foods as high-calorie was based on a study that listed the most common binge foods in a community sample (Allison & Timmerman, 2007). High-calorie foods included items such as high fat meats, sweet foods, and snacks high in sodium. Low-calorie foods included items such as salad, fruits, and vegetables. We presented separate images with high- and low-calorie food and images including both types of food to increase the generalizability of our findings. In addition, presenting images with both high- and low-calorie food allowed us to determine how these foods would be attended to when they competed for attention within the same image.

Apparatus

Eye movements were recorded using an EyeLink 1000 eye tracking system (SR Research Ltd., Ottawa, Ontario), which uses infrared video-based tracking technology. The system has a 1000 Hz sampling rate, a temporal resolution of 2 ms, and an average gaze error of less than 0.5 degrees of visual angle. Stimuli were shown on a 21-inch ViewSonic G22f monitor positioned approximately 60 cm away from the participant. Participants used a chin rest to minimize head movements while they viewed the images in order to increase tracking accuracy.

Procedure

As noted, for the eye tracking phase of the study, each participant viewed 125 images (25 images containing low-calorie food, 25 images containing high-calorie food, 25 images containing both low-calorie and high-calorie food, and 50 images containing no food). Each image was presented for 8 seconds and filled the entire computer display (i.e., a single image was displayed per trial). The order in which the 125 images were presented was randomized separately for each participant. The eye tracking system was calibrated for each participant prior to the collection of data, a procedure that required approximately 5 minutes. At the start of each trial, the participant fixated on a small solid white circle in the center of the display in order to ensure proper gaze measurement before the image appeared. Each image was presented in the center of the display, and so for all participants the first fixations were typically near the center of the image. Participants were instructed to look freely at the image throughout the 8-second presentation, as if they were watching a slide show. Eye fixations (from the right eye only) were recorded continuously throughout each 8-second presentation. Viewing all 125 images required approximately 15 minutes. Participants then completed the QEWP-R and a demographics questionnaire, after which they were debriefed and provided with information on eating disorders and body image issues and contact information for local agencies offering counseling services.

Results

There were 27 participants in the binge-eating group (22 females and 5 males) and 30 participants in the control group (21 females and 9 males). Table 1 lists descriptive statistics for each group. Participants in the control group reported no binge eating or purging behavior in the past six months. Because it can be argued that excessive exercise and fasting may occur in non-eating disordered samples, we retained as controls three individuals who reported these behaviors in the absence of binge eating.[1] The binge-eating and control groups did not differ in their gender distribution, χ^2 (1, $N = 57$) = 1.01, $p = .36$, or age, $t(53) = 0.22$, $p = .82$. As expected, the binge-eating group had higher EAT-26 scores than the control group, $t(51) = 7.14$, $p < .001$. As can be seen in Table 1, the mean BMI of the binge-eating group was slightly higher than the mean BMI of the control group, $t(54) = 2.11$, $p = .03$.[2] Participants in the binge-eating group had a mean age of 21.6 years, which is comparable to the estimated onset period of BED (15.5–27.2 years of age; Kessler et al., 2013).

Table 1
Participant demographics and eating disorder psychopathology.

	Binge-eating group ($N = 27$)	Control group ($N = 30$)
Female (%)	81.5%$_a$	70.0%$_a$
Age (mean, SD)	21.6 (3.4)$_a$	21.8 (2.2)$_a$
Body mass index (kg/m^2; mean, SD)	24.4 (4.9)$_a$	22.0 (3.4)$_b$
White/Caucasian (%)	51.9%$_a$	50.0%$_a$
Eating Attitudes Test (mean, SD)	24.0 (12.5)$_a$	6.1 (5.1)$_b$
Questionnaire on Eating and Weight Patterns – Revised (percentages)		
Frequency of binge eating in past 6 months:		
<1 day/week	22.2%	0%
1 day/week	33.3%	0%
2–3 days/week	37.0%	0%
4–5 days/week	3.7%	0%
Nearly every day	3.7%	0%
Compensatory behaviors to avoid weight gain in past 3 months:		
Self-induced vomiting	26.6%	0%
Laxative abuse	3.3%	0%
Diuretic abuse	6.7%	0%
Diet pill abuse	0%	0%
Exercise >1 hour	50%	10%
Fasting for >24 hours	26.6%	3.3%

Note: Standard deviations in parentheses. Means having the same subscript were not significantly different ($p > .05$).

The fixation data were processed using the EyeLink Data Viewer software (SR Research) to filter for blinks and other recording artifacts. To be included in the analyses, a fixation had to be at least 100 ms in duration; adjacent, sequential fixations less than 100 ms were merged into one fixation. The eye tracking system measured the fixations and fixation times to the food items and all other items in each image. The dependent variable was the percentage of fixation time to the food items in each image (i.e., the sum of the fixation times to the food items divided by the sum of all fixation times, to food and non-food items). To examine changes in attention over time (time course analyses), the percentage of fixation time to the food items was calculated for each 2-second interval (see Fig. 2 and 3). For example, a fixation percentage of 25% indicates that food items were fixated for 25% of the total fixation time within a 2-second interval; higher percentages therefore reflect greater attention to food items during the interval.

Attention to images containing either low-calorie or high-calorie food items

These images contained either low-calorie food items ($N = 25$ images) or high-calorie food items ($N = 25$ images). The fixation data were averaged over the 25 images in each set. The data were then analyzed using a 2 (Group: binge-eating, control) × 2 (Food Type:

[1] Excluding these three participants from the control group did not produce any changes in the pattern of statistically significant effects.

[2] Controlling for BMI in the analyses using analysis of covariance (ANCOVA) did not produce any changes in the pattern of statistically significant effects.

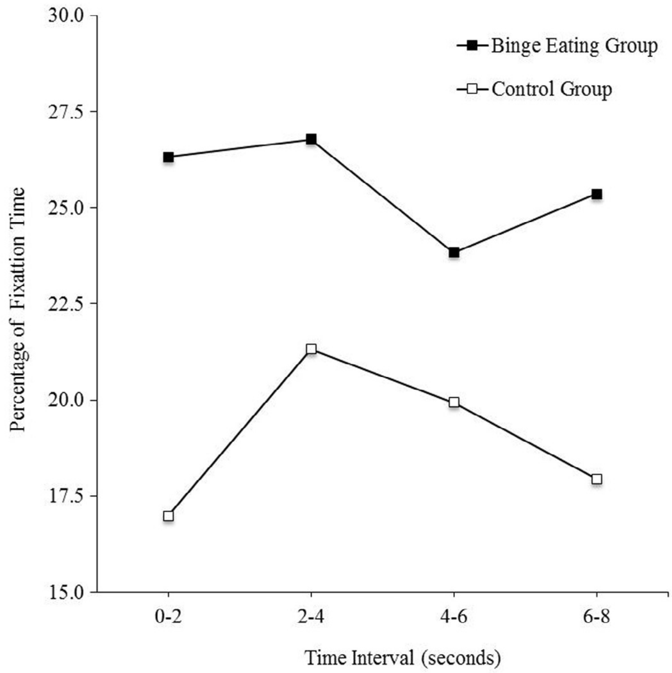

Fig. 2. Percentage of fixation time for food items (averaged over high-calorie and low-calorie foods) during each 2-second interval of the 8-second presentation, for control and binge-eating groups (low-calorie and high-calorie food items presented in different images).

low-calorie food items, high-calorie food items) × 4 (Time Interval: 0–2 seconds, 2–4 seconds, 4–6 seconds, 6–8 seconds) mixed-model analysis of variance (ANOVA).

There was a significant main effect of Food Type, $F(1, 55) = 163.62$, $p < .001$, partial $\eta^2 = .75$. Overall, low-calorie food items were attended to more than high-calorie food items ($M = 25.9\%$ vs. 18.7%). There was also a main effect of Time Interval, $F(3, 165) = 4.18$, $p = .007$, partial $\eta^2 = .07$, as the percentage of time spent fixating on food items varied across the 0–2, 2–4, 4–6, and 6–8 second intervals ($M = 21.6\%$, 24.0%, 21.9%, and 21.7%, respectively). More important was the main effect of Group, $F(1, 55) = 8.54$, $p = .005$, partial $\eta^2 = .13$. Overall, the binge-eating group attended to food items significantly more than the control group ($M = 25.6\%$ vs. $M = 19.0\%$). The interaction between Group and Food Type was not significant, $F(1, 55) = 2.79$, $p = .10$, partial $\eta^2 = .04$, as the binge-eating group attended to both low-calorie and high-calorie food items more than the control group ($M = 28.7\%$ vs. 23.1% for low-calorie food and $M = 22.5\%$ vs. 15.0% for high-calorie food).

The only significant interaction was between Group and Time Interval, $F(3, 165) = 4.27$, $p = .006$, partial $\eta^2 = .07$. This interaction is shown in Fig. 2, which shows the data averaged over low-calorie and high-calorie food items. Follow up t-tests revealed that for three of the four 2-second intervals participants in the binge-eating group fixated on food items significantly more than those in the control group: for the 0–2 second interval (26.3% vs. 16.9%), $t(55) = 3.69$, $p < .001$, the 2–4 second interval (26.7% vs. 21.3%), $t(55) = 2.21$, $p = .03$, and the 6–8 second interval (25.3% vs. 17.9%), $t(55) = 2.97$, $p = .004$. This was also true for the 4–6 second interval (22.2% vs. 18.8%), but the difference between the groups was not statistically significant, $t(55) = 1.71$, $p = .09$.

An alternative way of interpreting the Group × Time Interval interaction is to examine the time course of attention over the 8-second presentation for each group separately. These analyses revealed that the binge-eating and control groups differed in how their attention to the food items changed over time. More specifically, an analysis of the control group's data revealed that the percentage of time spent attending to food items varied significantly over the 8-second presentation, $F(3, 87) = 7.81$, $p < .001$, partial $\eta^2 = .21$. A trend analysis revealed significant quadratic, $F(1, 29) = 28.86$, $p < .001$, partial $\eta^2 = .49$, and cubic trends, $F(1, 29) = 4.02$, $p = .05$, partial $\eta^2 = .12$. As can be seen in Fig. 2, control participants' attention to food items increased between the 0–2 second and 2–4 second intervals and then decreased thereafter. In contrast, the analysis of the binge-eating group's data revealed an entirely different pattern of attending to food – for these participants the percentage of time spent attending to food items did not vary significantly over the 8-second presentation, $F(3, 78) = 2.00$, $p = .12$, partial $\eta^2 = .07$. This result indicates that for participants with binge eating, attention to food items was unchanged throughout the presentation. Taken together, these analyses indicate that participants with binge eating attended to high- and low-calorie food items significantly more than control participants throughout most of the 8-second presentation time, and that participants with binge eating did not reduce their attention to food items over time as control participants did.

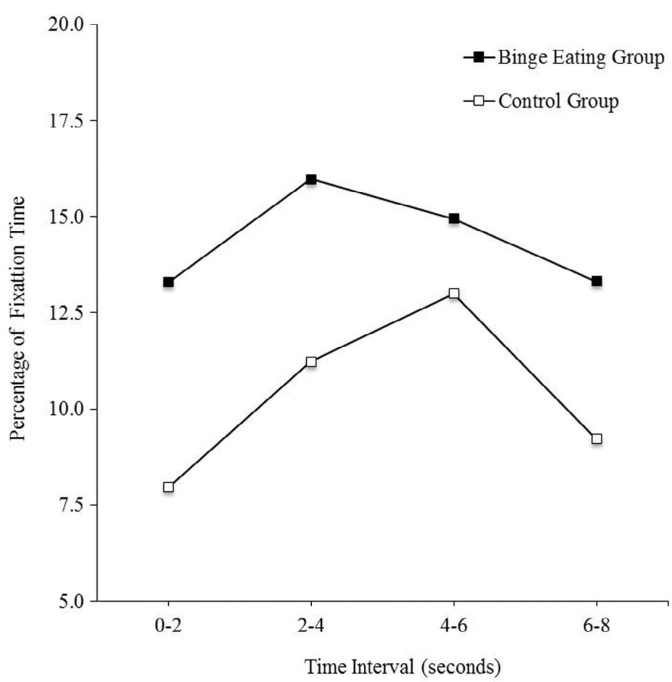

Fig. 3. Percentage of fixation time for food items (averaged over high-calorie and low-calorie foods) during each 2-second interval of the 8-second presentation, for control and binge-eating groups (low-calorie and high-calorie food items presented in the same images).

Attention to images containing both low-calorie and high-calorie food items

This set of images contained both low-calorie and high-calorie food items within the same image ($N = 25$ images). Because both types of food items were present within the same image they could compete for participants' attention during the 8-second presentation, which likely allows for a more sensitive test for differences in attention to high- and low-calorie food relative to when they are presented in separate images. The fixation data were averaged over the 25 images shown to each participant. The data were analyzed using a 2 (Group: binge-eating, control) × 2 (Food Type: low-calorie food items, high-calorie food items) × 4 (Time Interval: 0–2 seconds, 2–4 seconds, 4–6 seconds, 6–8 seconds) mixed-model ANOVA. The fixation data for this set of images (averaged over high-calorie and low-calorie foods)are shown in Fig. 3.

There was a significant main effect of Food Type, $F(1, 55) = 32.38$, $p < .001$, partial $\eta^2 = .37$. Averaged over the control and binge-eating groups, participants spent a greater percentage of time attending to high-calorie food items ($M = 13.5\%$) than low-calorie food items ($M = 11.2\%$). Note that this result is just the opposite of that observed when the low- and high-calorie foods were presented in separate images (described previously). This outcome indicates that when low- and high-calorie foods competedfor attention within the same image the high-calorie food received more attention, whereas when these foods were presented separately the opposite was true.

There was also a significant main effect of Group, $F(1, 55) = 11.99$, $p < .001$, partial $\eta^2 = .18$. Overall, participants in the binge-eating group attended to food items a greater percentage of time than participants in the control group ($M = 14.4\%$ vs. 10.4%), which replicated the group difference observed when low-calorie and high-calorie foods were presented in separate images (described previously). The fact that participants with binge eating attended to food items more than control participants when low-calorie and high-calorie food was presented in separate images and within the same image demonstrates the generalizability of this attentional bias.

The interaction between Group and Food Type was not significant ($F < 1$). Recall that this was also the case when low-calorie and high-calorie foods were presented in separate images. Thus, the binge-eating group attended to both low-calorie and high-calorie food items more than the control group and the difference was not larger for one type of food over the other.

There was a significant main effect of Time Interval, $F(3, 165) = 16.30$, $p < .001$, partial $\eta^2 = .23$. Follow-up tests showed that participants spent more time fixating on the food items during the 2–4 second interval ($M = 13.6\%$) and the 4–6 second interval ($M = 14.0\%$) than the 0–2 second interval ($M = 10.6\%$) and the 6–8 second interval ($M = 11.3\%$). There was also a Food Type × Time Interval interaction, $F(3, 165) = 10.18$, $p < .001$, partial $\eta^2 = .15$. Averaged over the two groups, there was a greater difference between low-calorie and high-calorie food items during the 2–4 second interval ($M = 15.6\%$ vs. $M = 11.6\%$) and the 4–6 second interval ($M = 16.1\%$ vs. $M = 11.8\%$) relative to the 0–2 second interval ($M = 10.7\%$ vs. M = 10.5%) and the 6–8 second interval ($M = 11.7\%$ vs. $M = 10.8\%$). The most straightforward interpretation of this interaction is that high-calorie food items were attended to more than low-calorie food items only during the middle of the 8-second presentation (from 2 to 6 seconds).

The more important interaction was between Group and Time Interval, $F(3, 165) = 3.21$, $p = .02$, partial $\eta^2 = .06$. Recall that this interaction was also present when the low-calorie and high-calorie food items were presented in separate images, although the nature of the interaction was somewhat different. As can been seen in Fig. 3, for both groups attention to food items changed over the course of the 8-second presentation, as confirmed by separate analyses of the control and binge-eating groups' data, $F(3, 87) = 13.88$, $p < .001$, partial $\eta^2 = .32$, and $F(3, 78) = 5.40$, $p = .002$, partial $\eta^2 = .17$, respectively. A trend analysis revealed a significant quadratic trend in the time course of attention for the binge-eating group, $F(1, 26) = 9.63$, $p < .005$, partial $\eta^2 = .27$, and for the control group, $F(1, 29) = 34.04$, $p < .001$, partial $\eta^2 = .54$. Thus, unlike the case when the low- and high-calorie foods were presented in separate images, when they were presented in the same image attention to the food items changed over time for both groups of participants.

Comparing the two groups at each of the four time intervals revealed that participants in the binge-eating group fixated on food items significantly more than those in the control group during the 0–2 second interval (13.3% vs. 7.9%), $t(55) = 3.62$, $p < .001$, the 2–4 second interval (15.9% vs. 11.2%), $t(55) = 3.31$, $p = .002$, and the 6–8 second interval (13.3% vs. 9.2%), $t(55) = 3.29$, $p = .002$. The exception was the 4–6 second interval; for this interval the binge-eating group fixated on food items more than those in the control group, but the difference was not statistically significant (14.9% vs. 13.0%), $t(55) = 1.49$, $p = .14$. These results are consistent with those from the analyses of the separate high- and low-calorie food images and indicate that participants with binge eating attended to high- and low-calorie food items significantly more than control participants throughout most of the 8-second presentation.

Time of first fixation for food items

A final set of analyses examined how early in the 8-second presentation participants attended to food items. If participants with binge eating were hypervigilant to food stimuli, then one would expect that they would attend to high- and low-calorie food items earlier in the 8-second presentation than control participants. For these analyses we used the fixation data to determine at what point in each trial a food item was first fixated (for more than 100 ms, to be consistent with the definition used in the other analyses). Average first fixation times were then calculated for the images with low-calorie food items ($N = 25$ images), the images with high-calorie food items ($N = 25$ images), and the images with both low- and high-calorie food items ($N = 25$).

For the images with low-calorie food items, participants in the binge-eating group attended to the food items significantly earlier in the 8-second trial than those in the control group (1670 ms vs. 1929 ms), $t(55) = 4.21$, $p < .001$. For the images with high-calorie food items the same group difference was observed, with participants in the binge-eating group attending to the food items significantly earlier (2118 ms vs. 2650 ms), $t(55) = 2.45$, $p = .017$. Similarly, for the images with both high- and low-calorie food items, participants in the binge-eating group attended to the high-calorie food items significantly earlier in the trial than those in the control group (2190 ms vs. 2541 ms), $t(55) = 2.05$, $p = .046$. This was also the case for the low-calorie food items (2392 ms vs. 2589 ms), but the difference was not statistically significant, $t(55) = 1.09$, $p = .27$. Taken together, these results show that participants with binge eating attended to high- and low-calorie foods earlier in the image presentations than control participants, a result that indicates that for these participants binge eating was associated with hypervigilance to food.

Discussion

In this study, participants' eye fixations were tracked and recorded while they viewed real-world scenes containing low-calorie and/or high-calorie food items in various settings. The eye tracking data provided a direct and continuous measure of attention to food items (as opposed to the single "snapshot" of attention captured in tasks using probes), and our analyses compared non-clinical adults who self-reported the presence of recent binge eating with a comparable group of control individuals who reported no recent binge eating. This is one of the first studies to use eye-gaze tracking to evaluate attention to food in individuals with possible BED.

Our results showed that participants with binge eating attended to food items in the images significantly more than control participants, and that they attended to food items significantly earlier in the 8-second presentation. This was true for both high- and low-calorie food and when these foods were presented together in the same image or in different images, which indicates that the binge-eating participants' heightened attention to food was not confined to a certain type of food or a particular type of viewing situation. We also found that the binge-eating participants, unlike the control participants, did not reduce their attention to food items over the course of the 8-second presentation when the high- and low-calorie food items were presented in separate images. This outcome suggests that under some circumstances individuals with recurrent binge eating have difficulty disengaging their attention from food stimuli.

With respect to the distinction between high- and low-calorie foods, our results are not definitive. When high-calorie and low-calorie foods were presented in separate images both binge-eating and control group participants paid more attention to low- than high-calorie foods; when high- and low-calorie foods were presented together within the same image we observed the opposite result – participants attended more to high-calorie food items, especially during the middle 4 seconds of the 8-second presentation. These findings are in contrast to previous research with the dot-probe task, which showed speeded detection of high-calorie food images and slower detection of low-calorie food images among eating disorder patients relative to healthy controls (e.g., Shafran et al., 2007, Shafran, Lee, Cooper, Palmer, & Fairburn, 2008). It is likely that our mixed findings for food type (high- vs. low-calorie) is related to our use of complex, naturalistic scenes involving food and non-food items as well as people. Previous studies that have examined differences in attention to different food types have used images that did not include competing objects or people (Giel et al., 2011). Our use of real-world scenes was designed to mimic cues participants would encounter in their own environments, but may have made it more challenging for participants to quickly discern whether the food items were high- or low-calorie, as the items were competing for attention with non-food items within the images (and with each other when both food types were presented in the same image). Thus, our decision to use ecologically-valid images benefited the study by increasing its external validity but may have compromised our ability to measure differences in attention to high- and low-calorie foods. Presenting the images for a longer duration (e.g., 15–20 seconds) would have provided participants more time to distinguish between high- and low-calorie food items and would have created a better opportunity to assess for differences in attention to high- and low-calorie foods.

The fact that the binge-eating group exhibited attentional hypervigilance to food items regardless of whether they were high- or low-calorie foods and throughout the 8-second presentation is inconsistent with the theory that individuals with binge eating exhibit a motivational ambivalent response to food stimuli. Instead, the heightened and sustained attention to food stimuli relative to control individuals is consistent with cue reactivity and incentive-sensitization theory (Jansen, 1998; Robinson & Berridge, 1993). The sustained attention could be interpreted as evidence of the activation of a motivational approach system, as theorized by Schmitz et al. (2014). A more comprehensive test of incentive-sensitization theory would involve the assessment of psychophysiological arousal, cravings, and patterns of brain activation following exposure to food cues.

Limitations and considerations for future research

Our conclusions need to be moderated in light of the following limitations of this study. First, binge eating was identified through self-report. As previous research has indicated that higher rates of binge eating are identified through self-report than interview (Black & Wilson, 1996), our binge-eating group may have been overly inclusive. Second, participants were not probed for their impressions of the purpose of the study, and so it is not known what impact expectancy effects might have had and whether they differed for binge-eating and control participants. Third, although the binge-eating group was intended to include individuals with subthreshold eating disorders, the range of binge-eating severity included may have diminished the magnitude of some effects. Fourth, we included those with and without compensatory behaviors in the binge-eating group (consistent with a transdiagnostic approach to eating disorder diagnosis; Fairburn, Cooper, & Shafran, 2003), and this may have obscured differences in attention between these eating disorder types; the small sample size made it impractical to perform the appropriate post-hoc analyses necessary to examine this possibility. Fifth, our recruitment strategy targeted community members and undergraduates with binge eating, who were not seeking treatment for an eating disorder, and the participants in our binge-eating group were fairly young ($M = 21.6$ years), and thus our findings may be most relevant to the early stages of BED symptoms. Finally, recall that the binge-eating group had a significantly higher BMI than the control group (24.4 vs. 22.0 kg/m^2), although their mean BMI did not exceed the cutoff necessary to be classified as overweight (25.0 kg/m^2). As previously noted (Footnote 2), there was no change in the pattern of statistically significant effects in our analyses when we controlled for BMI using ANCOVA, and so there is no reason to believe that the binge-eating participants' heightened attention to food was a consequence of their higher BMI scores. Nevertheless, given the restriction in the range of BMI scores in both of our groups, we cannot rule out the possibility that higher BMI scores would be associated with greater attention to food in a similar eye tracking study. Ideally, future studies would include a weight-matched control group in order to evaluate the influence of BMI on attentional biases in those with binge eating.

Conclusions

This study identified differences in the level and pattern of attention to food between a non-clinical sample of individuals of normal weight with and without recent binge eating. When viewing real-world scenes containing food items in various settings, participants with binge eating attended to high- and low-calorie food earlier than control participants and exhibited heightened attention to food throughout the 8-second presentation. We conclude that heightened attention to food may help maintain binge-eating behaviors; alternatively, or in addition, it may reflect an existing bias toward food exhibited by people who binge eat. These results have implications for theory regarding the development and maintenance of binge eating, and may therefore contribute to the design of effective programs for the prevention and treatment of binge eating disorder.

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