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Research article

Impaired prefrontal cognitive control over interference by food images in binge-eating disorder and bulimia nervosa

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HIGHLIGHTS

- Thirty-nine female adults underwent fMRI scanning during a Stroop match-to-sample task using craving-specific food stimuli.
- Women with BN exhibited impaired prefrontal cognitive top-down control and behavioral performance.
- Women with BED demonstrated activation of the ventral striatum, whereas women with BN exhibited activation of the dorsal striatum.

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ABSTRACT

Binge-eating disorder (BED)characterized by recurrent episodes of binge-eating without inappropriate compensatory behaviors is classified as an official diagnosis in DSM-5. However, the neural bases that differentiate BED from other eating disorders such as bulimia nervosa (BN), are still under debate. Thirty-nine participants (HC, $n = 14$; BN, $n = 13$; BED, $n = 12$) underwent functional MRI while performing a Stroop-Match-to-Sample task. This pilot study investigated how food images interfered with the behavioral performances and blood-oxygenation-level-dependent neuronal activity. Compared to healthy controls, participants with BN showed lower accuracy indicating impaired cognitive control over interference. Compared to healthy controls, participants with BED demonstrated stronger activations in the ventral striatum in response to food images. By contrast, participants with BN exhibited stronger activations in the premotor cortex and dorsal striatum. These aberrant ventral and dorsal frontostriatal activations in response to food images are associated with increased reward sensitivity and habitual binge-eating/purging behaviors in BED and BN.

1. Introduction

Binge-eating disorder (BED) is a diagnosis in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) that has a clinical profile distinct from other eating disorders [1]. It is characterized by recurring episodes of binge-eating to which reward sensitivity and rash-spontaneous impulsiveness contribute [2], but differs from bulimia nervosa (BN) by the lack of inappropriate compensatory behaviors [3]. Despite this difference, it remains unclear whether BED represents a true independent diagnosis rather than a variant of BN [4], as both of these disorders exhibit increased food-related impulsivity [1,5] and encompass comparable levels of dysfunctional cognitive bias [6].

Eating disorders develop and are maintained by dysfunctional attitudes towards food resulting from biased information processing [7]. Individuals with BN show a greater cognitive bias towards eating disorder-related words in the Stroop task [8] and significantly slower reaction times to food-related stimuli than healthy controls (HC) [9,10], indicating that their increased attention requires greater processing capacity and thus prolongs performance times [11]. BED patients also show decreased performance during food-specific task [12]. It was postulated that neurobiological vulnerabilities might drive these cognitive biases towards food stimuli in eating disorder patients [8].

Abbreviations: BAI, Beck anxiety inventory; BDI, Beck depression inventory; BED, binge-eating disorder; BIS, Barratt impulsiveness scale; BMI, body mass index; BES, binge-eating scale; BN, bulimia nervosa; DSM-5, diagnostic and statistical manual of mental disorders fifth edition; BOLD, blood oxygenation level-dependent; EAT-26, eating attitudes test-26; EDE-Q, eating disorder examination questionnaire; fMRI, function magnetic resonance imaging; HC, healthy controls; IQ, intelligence quotient; QEWP-R, revised questionnaire on eating and weight patterns.

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Brain imaging has been used to investigate the neuronal circuits related to behaviors in and the pathophysiology of eating disorders [13–16]. In response to food stimuli, individuals with BN exhibited exaggerated activity in the visual cortex, dorsolateral prefrontal cortex (DLPFC), and ventral striatum (VS) [17,18]. Overall, accumulating evidence indicates that impairments of the frontostriatal circuit supporting self-regulatory control and reward-based learning contribute to the development and maintenance of BN [16,19,20]. Several studies report that BED patients have increased activity in reward-related areas, such as the VS, and a diminished ability to recruit impulse control-related brain regions in response to food stimuli [12,21,22]. However, only a few brain imaging studies focused on the differences between BED and BN. Schienle et al. [23] found increased orbitofrontal cortex(OFC) activity in patients with BED, whereas Weygandt et al. [4] reported that individuals with BN showed stronger responses in the VS and the anterior cingulate cortex. Nevertheless, both BED and BN patients exhibit abnormal activation of the reward system to food-related cues, yet it is supposed that BN patients have more intense top-down control regarding their conflict about "pleasant" but "forbidden" food [23]. The difference between them remains unclear due to the limited understanding of contributing neurobiological factors.

To investigate the differences in prefrontal cognitive control over disease-salient stimuli, we conducted the pilot study testing BN and BED patients using the Stroop match-to-sample task [24] while performing functional magnetic resonance imaging (fMRI). During this task, the subject's attention is controlled by an interaction between bottom-up processing initiated by sensory stimuli and top-down cognitive processing driven mainly by the prefrontal cortex [25,26]. The initiation of the bottom-up signal by food-related stimuli is mediated by reward-related areas, which interfere with the top-down control of attention [27]. We postulate that women with BED and BN experience increased interference toward food images, which impairs their prefrontal cognitive top-down control and behavioral performance. We hypothesize that this increased interference is associated with increased activation in the reward system.

2. Methods

2.1. Participants

The participants in this study were 39 right-handed, female adults (HC, $n = 14$; BN, $n = 13$; BED, $n = 12$) between 20 and 30 years of age that were recruited through an internet advertisement. All participants reported their height and weight and completed the Korean version of the Eating attitudes test-26 (EAT-26) [28] for screening of eating disorders. Participants who scored below 21 points on the EAT-26 and had no history of axis I disorders were classified as the control group (HC). Formal diagnoses of eating disorders were established according to the DSM-5 through clinical interviews conducted by a psychiatrist. The presence of comorbid psychiatric disorders was assessed using a structural clinical interview for DSM disorders [29]. Participants with a BMI lower than 17.5 kg/m^2, had current or past psychiatric disorders, had current or past use of psychiatric or herbal medications, had traumatic brain injury, neurological illness, relevant visual defects, or any radiological contraindications for MRI were excluded. All participants answered a set of questionnaires after the screening for eating disorders, including the Korean version of the Eating disorder examination questionnaire (EDE-Q) [30], the Binge-eating scale (BES) [31], Beck depression inventory (BDI) [32], Beck anxiety inventory (BAI) [33], Barratt impulsiveness scale (BIS) [34], and the revised Questionnaire on eating and weight patterns (QEWP-R) [35]. Eating disorder symptoms were evaluated using the EDE-Q, BES, and QEWP-R, and impulsiveness was assessed with the BIS. Verbal intelligence quotient (IQ) scores were determined using the Wechsler adult intelligence scale-IV [36]. This study was carried out under the guidelines for the use of human participants established by the institutional review board at Yonsei University. Written informed consent was obtained from all participants after they were provided with a complete description of the scope of the study.

2.2. Procedure and stimuli

Participants were asked to abstain from eating for at least 6 h before an fMRI session, which was performed between 6 p.m. and 8 p.m. Before the fMRI experiment, each participant rated their feeling of hunger on a 7-point Likert scale ("not hungry" to "very hungry") and underwent a blood glucose test to confirm the fasting status.

2.2.1. Stroop match-to-sample task using craving-specific food stimuli

To test the interference from food stimuli on cognitive control, we modified the Stroop match-to-sample task [24] using two different conditions, food and neutral (Fig. 1, top panel). We chose food pictures for the interference stimuli as this is a symptom-specific stimulus with a high possibility of stimulating the targeted neural circuits [37]. As craving-specific changes in fMRI signals have been reported [38] and there are individual preferences for types of food that may affect craving, we applied an individualized Stroop task. All the participants were shown 60 pictures (54 food pictures and 6 neutral pictures) and instructed to rate their level of craving after seeing each image. Food stimuli included Korean-specific food as well as Western food for considering a culture-bound effect. The six food pictures with the highest craving scores were selected as the interference stimuli. In the food stimuli condition, these six food pictures were presented between the cue and the target word for each individual, whereas six neutral pictures selected from the International affective picture system [39] were presented in the neutral condition. Stimuli were created using E-prime software (Psychology Software Tools, Inc.) and presented through nonmagnetic goggles. Subjects matched the color of a cue ("XXX") displayed for 500 ms in the center of the screen to the color of a Stroop word target, which appeared for 1000 ms after an interference stimuli interval of 2700 ms. The intertrial fixation interval was 2400 ms. The total duration of each trial was 6.6 s.

For these experiments, there were 2 runs, run 1 and run 2 (Fig. 1), for which the order was randomized to minimize the learning effect. Run 1 was a match-to-color task and run 2 was a match-to-letter task. In run 1, the participants were instructed to match the color of the cue to the written color of a Stroop word (e.g., the word "YELLOW" written in red font is regarded as red). In run 2, the participants were instructed to match the color of the cue to the color that the Stroop word means (e.g., the word "YELLOW" written in red font is regarded as yellow). The colors of the cue and target words were red, yellow, or blue. Subjects were instructed to press a red key when the cue and target matched and a green key for nonmatches using their right hand, yielding accuracy and reaction time measures. Each run had eight blocks (four with food stimuli and four with neutral stimuli) comprising six trials. The total duration of each run was 323.4 s. The subjects performed a practice session before entering the scanner.

2.3. Image acquisition

MRI was conducted on a 3T Siemens Magnetom MRI scanner (Siemens AG, Erlangen, Germany) equipped with an eight-channel head coil. Whole-brain fMRI data were acquired during the Stroop