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Emotional eating and routine restraint scores are associated with activity in brain regions involved in urge and self-control

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HIGHLIGHTS

- Weight-related eating behaviors are associated with prefrontal and insula activation.
- Differential activity is found in response to high-calorie versus low-calorie foods.
- Neural activity suggests a dissociation between two dietary restraint subscales.
- Results support the construct validity of emotional eating and routine restraint.

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ABSTRACT

Researchers have proposed a variety of behavioral traits that may lead to weight gain and obesity; however, little is known about the neurocognitive mechanisms underlying these weight-related eating behaviors. In this study, we measured activation of reward circuitry during a task requiring response and inhibition to food stimuli. We assessed participants' emotional eating, external eating, and two subscales of dietary restraint—routine restraint and compensatory restraint—using the Weight-Related Eating Questionnaire. For routine restraint, we found positive associations with activation in the insula, dorsolateral prefrontal cortex, anterior cingulate cortex, orbitofrontal cortex and ventromedial prefrontal cortex in response to high-calorie versus low-calorie foods. For emotional eating, we found positive associations with insula and dorsolateral prefrontal cortex activation in response to high-calorie versus low-calorie foods. We also found positive associations between emotional eating and dorsolateral prefrontal cortex activation in response to approach versus inhibition towards high-calorie foods. Thus, our results demonstrate an increase in activation across brain regions related to self-control and urges in response to high-calorie food associated with both emotional eating and routine restraint. Overall, these results support the construct validity of both emotional eating and routine restraint and provide preliminary evidence that these subscales have similar neural correlates.

1. Introduction

Obesity rates in the USA have increased dramatically from 12% in 1991 [1] to over one third of adults in 2009–2010 [2]. Environmental factors including culture, technology, and food availability in developed countries have heavily contributed to the rise in obesity rates. However, even within the same environment, some individuals become obese while others do not. Individual characteristics and eating behaviors are critical to determining risk of weight gain. For some individuals, food elicits strong neurocognitive responses related to eating patterns and weight gain.

A growing body of research in neuroimaging supports a triple process framework of reward processing in the brain [3–5], for a broader review of the triple process framework, see [6]. First, the “impulsive” amygdala-striatal circuitry is responsive to external reward cues. These brain regions include the mesolimbic dopamine system, and they respond quickly and automatically to motivational stimuli and are critical to forming habits [7]. Second, neural circuitry involved in impulse control includes primarily prefrontal cortex structures, including

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the anterior cingulate cortex (ACC), orbitofrontal cortex (OFC), ventromedial prefrontal cortex (VMPFC), and dorsolateral prefrontal cortex (DLPFC). This circuitry has been called “reflective” [8] because it responds to hypothetical or remembered emotional triggers. Third, interoceptive circuitry, including the insula, modulates the activity of the other brain regions based on homeostatic signals [9,10]. Specifically, the insula translates internal signals of hunger or satiety into subjective feelings such as the urge to eat.

These brain regions have been implicated in the few studies that have used neuroimaging to examine the neural correlates of theory-based indices of hedonic eating. For example, emotional eating has been associated with activity in the amygdala [11], ACC [12], OFC, and insula [13]. External eating has been associated with activation of the OFC and insula [11] and VMPFC [14] and differential connectivity patterns among the ventral striatum, amygdala, ACC, and premotor cortex [15]. Dietary restraint has been associated with increased activity in prefrontal, inhibitory brain regions [16–19] as well as the dorsal striatum [19], amygdala [20,21], and nucleus accumbens [22].

Problematically, each of these studies used different methodologies and examined different individual weight-related eating behaviors. (An exception is [11], which examined external eating, emotional eating, and restrained eating, but in the specific context of diabetes management.) Additionally, many studies examining the same eating behavior have reported significant associations with different brain regions that serve different functions. These inconsistencies across studies have created challenges in drawing conclusions about the neurobiological similarities and differences across eating behaviors.

Here we address this gap in the literature by testing the neural correlates of different weight-related eating behaviors simultaneously. Our methodology also offers two additional advantages over prior neuroimaging studies on weight-related eating behaviors. First, participants performed an active task designed to engage impulsive food-related behavior. Conversely, in most prior neuroimaging studies of weight-related behaviors, participants have passively viewed images of food items or reported information about an image (e.g., “Is the image a food?” “How much do you like this food?”). In the present study, participants were scanned while performing a food-related go/nogo task. Additional data from this experiment has been reported elsewhere [4]. Using functional magnetic resonance imaging (fMRI), this study measured brain activation in regions of interest across impulsive, reflective, and interoceptive circuitry. The go/nogo task consisted of two trial types: participants needed to inhibit their responses to either high-calorie or low-calorie foods. Thus, the food-related go/nogo paradigm captures impulsive behavior (go trials) and inhibition (nogo trials) related to food stimuli.

Second, unlike the previous neuroimaging studies of weight-related eating behaviors, the present study used the Weight-Related Eating Questionnaire (WREQ). The WREQ has strong convergent validity with similar scales such as the Dutch Eating Behavior Questionnaire [23]. It is unique, however, from other similar measures in that the WREQ subscale of dietary restraint is separated into compensatory and routine restraint, reflecting more flexible and rigid aspects of dietary restraint, respectively. Therefore, the WREQ is able to highlight underlying differences between these two styles of restricted dietary intake.

The primary goal of this study was to determine the neural correlates of each eating behavior assessed by the WREQ: emotional eating, external eating, compensatory restraint, and routine restraint. By analyzing the relationship between brain activity and all of the eating behaviors in a single neuroimaging task, we were able to compare across eating behaviors for commonalities and differences. This approach allowed us to examine whether patterns of activation were overlapping or entirely distinct across eating behaviors. Moreover, this approach directly contrasts with past studies examining the association between specific eating behaviors and subsets of the brain's reward circuitry (e.g., the association between emotional eating and amygdala-striatal regions or the association between restraint and the prefrontal cortex).

2. Methods

2.1. Participants

Twenty healthy, right-handed adults participated in this study (12 female, mean age = 19.8 years, SD = 1.0, range = 18–22).[1] Their mean BMI was 22.6 kg/m^2 (SD = 3.0, range = 18.5–31.3; 85% with BMI < 25 kg/m^2). All participants had normal or corrected-to-normal vision and had no history of neurological or psychiatric disorders. All participants provided written, informed consent, and all study procedures were approved by the University of Southern California Institutional Review Board.

2.2. Measures

2.2.1. Questionnaire

The WREQ was used to assess theory-based eating behaviors [24,25]. The WREQ consists of 16 items reflecting indices of hedonic eating: emotional eating (5 questions), external eating (5 questions), and two subscales of dietary restraint (compensatory restraint: 3 questions; and routine restraint: 3 questions). The WREQ was developed and validated for use in a diverse range of populations including young adults and has demonstrated good internal consistency and test-retest reliability among the subscales [24]. Subscales of the WREQ have demonstrated strong convergent validity with the Three Factor Eating Questionnaire R-18 [26] and the Dutch Eating Behavior Questionnaire [23], but the WREQ is unique in that it assesses two subscales of dietary restraint [25]. The WREQ subscales are associated with body weight status, weight control practices, and consumption of fruits/vegetables and dietary fat [24,25]. Notably, the compensatory restraint subscale has been associated with lower BMI and less adult weight gain over time [24, 25], whereas the routine restraint subscale has been associated with higher BMI [25].

2.2.2. fMRI task

During scanning, participants were asked to perform two food-related go/nogo tasks: 1) a high-calorie food go and low-calorie food nogo task (HGo/LNogo task), and 2) a low-calorie food go and high-calorie food nogo task (LGo/HNogo task). In the HGo/LNogo condition, participants were instructed to press a button as quickly as possible when shown a picture of a snack food (“HGo”) and inhibit responding when shown a picture of a vegetable (“LNogo”). In the LGo/HNogo condition, the participants were instructed to respond to vegetable pictures (“LGo”) and inhibit their response to snack pictures (“HNogo”). Thus, our task provided an estimate of brain activity across four states: 1) responding to high-calorie foods, HGo; 2) responding to low-calorie foods, LGo; 3) inhibiting response to high-calorie foods, HNogo; and 4) inhibiting response to low-calorie foods, LNogo.

The food pictures that were used in the task are shown in Fig. 1. The foods were chosen to accord with focus group data on snacks and vegetables that adolescents consume most frequently. The photographs of the foods were taken by a professional photographer to minimize differences in the lighting, background, and quality of the pictures. Images of each food were ranked internally from least appealing to most appealing by a dozen project staff. The most appealing version of each food was then used for the task. Each participant saw 11 low-calorie foods

[1] There were 30 participants in the fMRI portion of the experiment. The WREQ was added to expand the behavioral measures of the parent study. Study participants who were not given the option of completing the questionnaire at the time of their fMRI scan were contacted to voluntarily respond to the WREQ by online survey. We obtained WREQ data from 20 participants.