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Research report

Allured or alarmed: Counteractive control responses to food temptations in the brain

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HIGHLIGHTS

- We measured brain responses to food temptations in successful dieters.
- Food temptations activate not only reward but also self-control areas in dieters.
- Diet importance predicts food-induced brain activation in self-regulation areas.
- Our neuroimaging findings support counteractive control theory.

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ABSTRACT

Typically, it is believed that palatable, high caloric foods signal reward and trigger indulgent responses. However, Counteractive Control Theory suggests that, to the extent that people are concerned about their weight, a confrontation with palatable foods should also trigger 'alarm bell responses' which promote successful self-control. Our study is the first to investigate such counteractive control processes in the brain employing functional magnetic resonance imaging (fMRI) in a sample of successful self-regulators. Indeed, besides the traditional finding that foods elicit heightened attention as witnessed by greater activation of primary visual cortex, we found that viewing palatable foods elicited brain activation in areas associated with self-regulation. Crucially, brain activation in self-regulation areas was related to diet importance. Thus, our results are the first to show that food cues not only evoke hedonic brain responses; in successful self-regulators they also trigger alarm bell responses, which may reflect the neural processes underlying successful self-control.

1. Introduction

Whereas our ancestors in times of hunters and gatherers faced up to eating as much food as they could possibly find, people in the modern Western food environment face quite a different challenge. The ubiquitous availability of cheap, calorie-dense fast foods is often held responsible for the rapidly rising numbers of people who are overweight or obese [1]. Consequently, many people report to have the intention to watch their weight and limit their food intake in order to prevent weight gain. The conflict between the appeal of highly palatable 'unhealthy' foods and weight watching goals represents a typical self-regulation dilemma in which immediate gratification can have negative consequences on the long term.

Since food is a primary reward, it is presumably common sense that people are impulsively drawn toward food cues, especially those that are associated with high energy content, and in particular when people are hungry (e.g., [2]). Counteractive Control Theory, however, suggests that (food) temptations, which trigger indulgence, simultaneously trigger the self-control response that overrides the tendency to indulge [3]. That is, in weight-conscious people unhealthy foods may automatically activate defensive self-regulation mechanisms that serve to protect the weight watching goal and inhibit indulgence [3]. Indeed, empirical evidence for this intriguing notion is accumulating and has been found on cognitive as well as behavioral outcome measures. For example, it was shown that exposure to food temptations increases the mental accessibility of weight watching goals [4], and that participants who were exposed to food temptations subsequently made healthier food choices compared to those in neutral control

Abbreviations: fMRI, functional magnetic resonance imaging; ROI, region of interest; SVC, small volume correction.

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conditions [4,5]. Hence, besides instinctive, reward-driven, approach responses, food cues can also trigger 'alarm bell' responses so as to protect weight watching goals.

Although people's responses toward food cues have gained considerable attention in neuro-imaging studies as well, most research in this area has focused on reward-driven responses toward food. For example, in a recent fMRI study in obese individuals it was found that greater food-cue induced activation in brain regions mediating reward and attentional salience of food cues was associated with less success in a weight-loss program and poorer weight control over a 9-month follow-up period [6].

Conversely, the 'alarm bell'-response has not received particular attention so far. To illustrate, a recent meta-analysis [7] investigated the moderation of brain responses to visual food cues by energy content and hunger, both of which modulate the reward value of food (i.e., food is more rewarding when hunger and/or energy content are high). Whereas the authors argued that dietary restraint (i.e., having adopted a weight watching goal), which in our reasoning would be related to the 'alarm bell' responses in the brain, may indeed serve as a moderator as well, they noted that the number of studies addressing this factor was very small.

The current study aims to address this gap in the literature by specifically focusing on brain activation related to self-regulation in response to tempting (palatable high-caloric) food cues employing fMRI techniques. Although, recently, increasing attention has been devoted to self-regulation in neuro-imaging studies [8,9], no studies have yet reported on counteractive control processes in the brain in response to temptations (but see McCaffery et al. (2009), for a study comparing people who lost weight to lean and obese controls [10]). We hypothesize that in participants with a weight watching goal exposure to food temptations will trigger brain activation in areas related to self-regulation, besides brain areas involved in visual attention and reward processing. We expect these protective self-regulation responses to emerge only to the extent that people have a personally valued weight watching goal. Therefore, we specifically predict that the activation of self-regulation areas in response to food cues will be moderated by the importance attached to the weight watching goal. Our a priori specified regions of interest were based on recent studies of self-regulation in the brain, and include the lateral prefrontal cortex/inferior frontal gyrus and the anterior cingulate cortex, which have been consistently implicated in the exertion of self-control (e.g., [8,9,11]).

2. Materials and methods

2.1. Participants

Participants were thirty healthy, normal-weight, right-handed women with a mean age of 22.1 years (SD = 2.0) and a mean body mass index [BMI] of 20.7 kg/m^2, (SD = 2.0). To promote homogeneity, our sample was restricted to females between 18 and 30 years of age, as this is a group known to be concerned about their weight (e.g., [12]). As we were specifically interested in people who successfully deal with food temptations, only participants who had a normal weight (i.e., BMI 18–25 kg/m^2) were included. Also, we only included participants who were not high on restraint eating as they are known to have troubled relations with food (e.g., Fedoroff, Polivy, & Herman, 2003). In addition, we employed common fMRI exclusion criteria (e.g., metal implants in the body, claustrophobia, and pregnancy) and exclusion criteria indicating an altered response to food cues (e.g., metabolic or endocrine disease, gastrointestinal disorders or eating disorders). On average, participants reported to attach moderate importance to dieting (M = 2.7 on a 5 point scale, SD = 0.8). Participants' appetite was moderate before the scan (M = 3.3, SD = 0.9), but significantly higher after the scan (M = 4.1, SD = 0.7; t (29) = −5.49, P < .01).

2.2. Study procedures

Before inclusion in the study, potential participants completed a questionnaire with items on demographic variables (age, length, weight), general health, use of medication, eating disorders [13], restraint eating [14], smoking, alcohol consumption, and contra-indications for fMRI. Eligible participants were requested to refrain from eating and drinking (except water) for at least 3 h prior to the scanning session.

Upon their arrival, participants indicated the date of their last menstrual period. This was used to assess the current phase of their menstrual cycle, as this affects brain reward responses in general [15] and responses to food images in particular [16,17]. In addition, prior to and after the scan appetite was assessed with 3 items (i.e., "To what extent are you hungry/feeling like a bite/experiencing appetite?" (Cronbach's α = .91 and .84, respectively) that could be answered on a scale from 1 (*not at all*) to 5 (*very much*).

Participants were then scanned by use of functional magnetic resonance imaging (fMRI) while viewing images of palatable foods and non-foods (office utensils). After the scan, participants filled out another set of questions including assessments of appetite, and diet goal importance. Diet goal importance was assessed with 2 items (i.e., "To what extent are you concerned about your weight/being slim"; Pearson's r = .71; cf. [4]) that could be answered on a scale from 1 (*not at all*) to 5 (*very much*).

Written informed consent was obtained from all subjects according to the Declaration of Helsinki (amendment of Seoul, 2008), and the study protocol was approved by the Medical Ethical Committee of the University Medical Center Utrecht, The Netherlands.

2.3. Task design

During scanning, subjects alternately viewed 24 s blocks of palatable food images (8 blocks) and non-food images (i.e., office utensils; 8 blocks), interspersed with 8–16 s rest blocks showing a crosshair (12 s on average). Halfway the task there was a 10 s break. In the image blocks, 8 images were presented for 2.5 s each with a 0.5 s inter-stimulus interval. All pictures were of equal size and displayed the (food) object on a white background. Food pictures were selected to represent foods that are both attractive and 'forbidden' (i.e., fattening), congruent with our definition of temptations [18]. Examples are shown in Supplementary Fig. S.1. A pilot test among 31 female students showed that on average the food pictures were rated as fattening (M = 5.5, SD = 1.2), as assessed on a scale ranging from 1 (*not at all fattening*) to 7 (*very fattening*) and as rather attractive (M = 5.1, SD = .9), as assessed on a scale from 1(*not at all attractive*) to 7 (*very attractive*). Food pictures were significantly more attractive than office utensil pictures, which were rated as neutral (M = 3.4, SD = 1.2; P < .01). The tempting nature of the food pictures was confirmed by ratings of random subsamples of these pictures that were obtained from participants in the main study after the scan (M = 4.4, SD = .8; on a scale from 1 (*not at all tempting*) to 7 (*very tempting*)).

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.bbr.2013.03.041.

2.4. Data acquisition

The functional scan was a T_2^*-weighted gradient echo 2D-echo planar imaging sequence (64 × 64 matrix, repetition time = 1600 ms, echo time = 23 ms, flip angle = 72.5°, FOV = 208 × 119 × 256 mm, SENSE factor AP = 2.4, 30 axial 3.6 mm slices with 0.4 mm gap, reconstructed voxel size = 4 mm × 4 mm × 4 mm). In one functional run 370 scans were made (∼10 min). In addition to the functional scan, a high resolution T_1-weighted anatomical MRI scan was made (3D gradient echo sequence, repetition time = 8.4 ms, echo time = 3.8 ms, flip angle = 8°, FOV = 288 mm × 288 mm × 175 mm, 175 sagittal slices, voxel size = 1 mm × 1 mm × 1 mm). During the functional run, stimuli were presented on a screen with the use of the E-Prime software package.

2.5. Data processing and analysis

FMRI data were preprocessed and analyzed with the SPM8 software package (Wellcome Department of Imaging Neuroscience, London, United Kingdom, (http://www.fil.ion.ucl.ac.uk/spm/software/spm8/) in conjunction with the MarsBar toolbox (http://marsbar.sourceforge.net/) run with MATLAB 7.9 (The Mathworks Inc, Natick, MA). The functional volumes of every subject were realigned to the first volume of the first run, globally normalized to Montreal Neurological Institute space (MNI space) retaining 4 mm × 4 mm × 4 mm voxels, and spatially smoothed with a gaussian kernel of 8 mm full width at half maximum. A statistical parametric map was generated for every subject by fitting a boxcar function to each time series, convolved with the canonical hemodynamic response function. Data were high-pass filtered with a cutoff of 128 s. Three conditions were modeled: viewing foods, viewing non-foods and the half-way break. For every subject, parameters were estimated for three comparisons (referred to as contrasts); contrast images were calculated for viewing foods (F), viewing non-foods (NF) and for foods > non-foods (F > NF).

First, brain activation by food versus non-food images was assessed using a t-test with phase of the menstrual cycle and hunger added as control variables.[2]

[2] As an additional research question we examined differences between food images presented in color and grayscale versions. Therefore, half of the participants viewed all images in color, whereas the other half viewed grayscale versions of the same images. Post-scan ratings of the images revealed that color and grayscale versions were considered equally attractive. Furthermore, no group differences were found between brain responses to color and grayscale images: there was no