HHS Public Access
Author manuscript
Int J Obes (Lond). Author manuscript; available in PMC 2014 June 01.

Published in final edited form as:
Int J Obes (Lond). 2013 December ; 37(12): 1565–1570. doi:10.1038/ijo.2013.39.

Cognitive regulation of food craving: Effects of three cognitive reappraisal strategies on neural response to palatable foods

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Abstract

Objective—Obese versus lean individuals show greater reward region and reduced inhibitory region responsivity to food images, which predict future weight gain. Thinking of the costs of eating palatable foods and craving suppression have been found to modulate this neural responsivity, but these cognitive reappraisal studies have primarily involved lean participants. Herein we evaluated the efficacy of a broader range of reappraisal strategies in modulating neural responsivity to palatable food images among individuals who ranged from lean to obese and tested whether Body Mass Index (BMI) moderates the effects of these strategies.

Materials and method—functional Magnetic Resonance Imaging (fMRI) assessed the effects of three cognitive reappraisal strategies in response to palatable food images versus an imagined intake comparison condition in a sample of adolescents (N = 21; *M* age = 15.2).

Results—Thinking of the long-term costs of eating the food, thinking of the long-term benefits of not eating the food, and attempting to suppress cravings for the food increased activation in inhibitory regions (e.g., superior frontal gyrus, ventrolateral prefrontal cortex) and reduced activation in attention-related regions (e.g., precuneus, and posterior cingulate cortex). The reappraisal strategy focusing on the long-term benefits of not eating the food more effectively increased inhibitory region activity and reduced attention region activity compared to the other two cognitive reappraisal strategies. BMI did not moderate the effects.

Discussion—These novel results imply that cognitive reappraisal strategies, in particular those focusing on the benefits of not eating the food, could potentially increase the ability to inhibit appetitive motivation and reduce unhealthy food intake in overweight individuals.

Keywords

cognitive reappraisal; suppression; obesity; fMRI; inhibition; attention

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The authors declare no conflict of interest.

Introduction

Nearly 70% of US adults are overweight or obese (1). Yet, no treatments produce a return to a healthy weight or lasting weight loss (2), suggesting that overeating or excess adiposity causes emergence of processes that maintain overeating, implying it might be more effective to prevent obesity onset and the emergence of these maintenance processes. However, because obesity prevention programs have not produced clinically meaningful reductions in future weight gain and obesity onset (3), a public health priority is to identify novel and effective programs.

There is evidence that obesity is associated with abberrant neural activity, particularly in reward and inhibitory control regions. Meso-limbic-cortico regions (e.g., striatum, orbitofrontal cortex [OFC]) appear to encode the reward value of food images/cues (4, 5). Obese versus lean children/adolescents (6-8) and adults (4, 9, 10) show greater reward region responsivity to unhealthy food images and cues that signal impending delivery of a high-fat/sugar food. Adults with greater reward activation show poorer response to weight loss treatment (11). Critically, elevated reward activation to palatable food cues (12), high-fat/sugar images (13), and cues signaling impending unhealthy food images (14) predicted future weight gain.

Frontal lobe regions, including superior frontal gyrus (SFG), middle frontal gyrus (MFG), and ventrolateral prefrontal cortex (vlPFC) are mplicated in response inhibition (15, 16). Obese versus lean teens show less activation of these regions when trying to inhibit responses to unhealthy palatable food images (17, 18) and show a preference for immediate food reward over larger delayed reward (19). Obese versus lean adults also show behavioral response inhibition deficits on nonfood go/no-go and stop-signal tasks (20). Inhibitory control deficits in children predicts greater future weight gain (21, 22) and in adults poorer response to weight loss treatment (11). These data suggest that obese versus lean individuals show greater reward region activation and less inhibitory control as they encounter palatable food images/cues and this hyper-responsivity increases risk for weight gain. It is therefore important to investigate strategies that modulate reward and inhibitory region responsivity to food images/cues, which should inform the design of more effective obesity prevention and treatment interventions.

Cognitive reappraisals modulate reward and inhibitory region responsivity to palatable food stimuli; thinking of the long-term costs of eating unhealthy food when viewing images of such foods increased inhibitory region activation and decreased reward region activation relative to various contrast conditions, such as imagined intake (23, 24). However, these studies were done in lean individuals. For the improvement of prevention and treatment interventions, it is important to understand how BMI moderates the effects of these strategies. Only one study examined the effects of cognitive reappraisals in a sample varying in weight from lean to obese: Hollman and colleagues (25) found that thinking of the long-term costs of eating unhealthy food increased inhibitory region activation, but did not reduce reward region responsivity. Because overweight/obese versus lean individuals show greater reward region response to palatable food images, the higher weight of participants in this study may have attenuated the effects of reappraisals on reward region response. Further, two studies examined the effects of only one cognitive reappraisal strategy: Hollman et al (25) and Kober et al. (23) tested the effects of thinking of the long-term costs of eating unhealthy food. Siep et al. (24) found that generic craving suppression efforts more effectively reduced reward region response than thinking of the long-term costs of eating the unhealthy foods relative to imaged intake of the foods.

It is possible that different reappraisal strategies elicit differential neural response and that weight status may moderate cognitive reappraisal efficacy. We therefore investigated the effects of several cognitive reappraisal strategies that are intended to increase activation of inhibitory regions and reduce activation of reward regions in response to palatable food images and tested whether BMI moderates the effectiveness of these strategies. Specifically, we examined whether the previously studied reappraisal strategy focusing on the long-term costs of eating the food (i.e., *costs of eating* strategy) as well as a novel reappraisal strategy focusing on the long-term benefits of not eating the food (i.e., *benefits of not eating* strategy) increase inhibitory region activation and reduce reward activation compared to imagined intake of the food. Given the evidence that prevention-oriented health promotion interventions focusing on benefits of a behavior (positive message framing) are more effective than those focusing on consequences (negative message framing) (26), we hypothesized that the *benefits of not eating* strategy would be more effective than the *costs of eating* strategy. We also included a simple suppression strategy (i.e., *suppress craving*) to contrast the effectiveness of the two cognitive reappraisal strategies with a strategy that most people likely utilize when confronted with tempting palatable foods. We hypothesized that the *costs of eating* and *benefits of not eating* strategies would be more effective than the *suppress craving* strategy. We further hypothesized that overweight/obese individuals would be less effective in utilizing all three strategies.

Materials and Methods

Participants

were 21 adolescents (*M* age = 15.2, *SD* = 1.18; *M* BMI = 27.9 ± 5.16 13 females). We selected this sample size because it was the size of the largest past reappraisal study (23) and was larger than the sample size used in the other reappraisal studies (24, 25). Because we used a within subjects design, which has greater power than between subjects designs, we expected to be able to find medium to large main effect sizes, such as were found in previous studies (*M* r = 0.78). Adolescents and parents provided written informed consent for this IRB-approved project. Exclusion criteria were current regular use of psychotropic medications or illicit drugs, pregnancy, head injury, significant cognitive impairment, or Axis I psychiatric disorder in the past year. A phone screen interview with items from the Schedule for Affective Disorders and Schizophrenia for School Age Children – Epidemiologic Version (K-SADS-E; (27)) identified probable Axis I psychiatric disorders and other exclusion criteria; this interview has shown high test-retest and inter-rater reliability (28).

BMI

BMI (kg/m^2) was used to reflect adiposity. Height was measured to the nearest millimeter using a stadiometer and weight was assessed to the nearest 0.1 kg using a digital scale (after removal of shoes and coats). Two measures were obtained and averaged. BMI correlates with direct measures of total body fat such as dual energy x-ray absorptiometry (r = .80 to .90) and with various health measures in adolescent samples (29).

fMRI paradigm

Participants were asked to consume their regular meals, but to refrain from eating or drinking caffeinated beverages for 5 hours preceding their scan for standardization. Within two days of the scan, participants rated how appetizing they found foods shown in 128 pictures using a visual analog scale (VAS: range: *least appetizing* = − 395 to *most appetizing* = 395). The task also included a “YUCK” button. Participants were instructed to only use this button if they would have a strong aversion to the food or if the food would make them sick. Food images rated as “YUCK” were excluded from the MRI and analyses. Food images (30) included fruits (e.g., blueberries, cherries), discretionary foods (e.g., brownies, French fries), grains (breads, pastas), dairy (e.g., different types of cheeses), fats and oils (i.e., butter), vegetables (e.g., broccoli, peas), mixed dishes (e.g., a plate with eggs and hash browns), and protein (e.g., steak, seafood) (31). The United States Department of Agriculture Food Database was used to calculate energy density of the foods (kcal/food (g)). For the scanning session, we selected 20 most appetizing and 20 least appetizing food images based on the individual’s food preferences to maximize the saliency value of the food cue as a reinforcer for the participants. On each trial, participants were instructed to think about the food in the pictures in one of four ways: 1) *imagine eating* (24 events), 2) *costs of eating* (8 events), 3) *benefits of not eating* (8 events), and 4) *suppress craving* (8 events). In total, there were 48 events (32 appetizing food events, 16 unappetizing food events). The instructions *costs of eating*, *benefits of not eating*, and *suppress craving* were given only during appetizing food trials. The instruction *imagine eating* was giving during both appetizing (8 events) and unappetizing food trials (16 events). To avoid potential habituation effects to repetition of the same pictures in the appetizing food trials on blood oxygenation level-dependent (BOLD) activation, individuals were exposed to more appetizing food events than unappetizing food events. Training of the participant prior to the scan included initial instructions, followed by a 10 minute practice as the investigator observed and shaped the participant’s technique.

Each trial (Fig 1) started with a 2 second instruction cue to inform the participant which strategy to use. The cue was followed by a 5 second presentation of the stimulus and a 1-4 second jitter during which the screen was blank. On 50% of the trials, the jitter was followed by a 3 second vertical 100 mm VAS, assessing wanting of the food presented (ranging from 1, *not at all*, to 5, *very much*). The trial ended with a second 1-4 second jitter. Exposure to the stimuli and the order of the instructional cues was randomized across participants. The scan lasted 12 minutes. Participants rated their hunger levels before the scan using a VAS. We collected data on menstrual phase in female participants because reward-related neural function in women is heightened during mid-follicular phase (32). In addition to hunger and menstrual cycle, we controlled for sex because previous studies found sex differences in brain responses to food stimuli (33, 34) and in brain metabolic responses during cognitive down-regulation of food craving (35).

fMRI data acquisition

Scanning was performed by a Siemens Allegra 3 Tesla head-only MRI scanner. Functional scans used a T2* weighted gradient single-shot echo planar imaging (EPI) sequence (TE = 30ms, TR = 2000ms, flip angle=80°) with an in plane resolution of 3.0 × 3.0 mm^2 (64 × 64 matrix; 192 × 192 mm^2 field of view). To cover the whole brain, 32 interleaved, no skip, 4mm slices were acquired along the AC-PC transverse oblique plane, as determined by the midsagittal section. Prospective acquisition correction (PACE) was used to adjust slice position and orientation and to re-grid residual volume-to-volume motion in real-time during data acquisition for the purpose of reducing motion-induced effects (36). All participants met the movement inclusion criteria (within-run movement before correction < 2 mm in translational movement and $< 2^0$ in rotational movement). Anatomical scans were acquired using a high-resolution inversion recovery T1 weighted sequence (MP-RAGE; FOV = 256 × 256 mm^2, 256 × 256 matrix, thickness = 1.0 mm, slice number ≈ 160).

fMRI data processing

Images were skull stripped using the BET function in FSL (37). Data were pre-processed and analyzed using SPM8 (Functional Imaging Laboratory, Wellcome Department of Imaging Neuroscience, Institute of Neurology, University College of London) in MATLAB 7.5 (The Mathworks, Inc., Natick, MA, USA). Functional images were realigned to the mean and both the anatomical and functional images were normalized to the standard Montreal Neurological Institute (MNI) T1 template brain (ICBM152). Normalization resulted in a voxel size of 3 mm^3 for functional images and a voxel size of 1 mm^3 for high-resolution anatomical images. Functional images were smoothed with a 6 mm FWHM isotropic Gaussian kernel. Anatomical images were segmented into gray and white matter using DARTEL (38). A mean of the resulting gray matter was used as a base for an inclusive gray matter mask.

fMRI analysis

To identify the effects of *costs of eating*, *benefits of not eating*, and *suppress craving*, we contrasted BOLD response when viewing the appetizing food pictures after each of these instructions versus when viewing the appetizing food pictures after the *imagine eating* instruction (e.g., *suppress craving* > *imagine eating*). To compare the effects of the cognitive reappraisal strategies with each other, we contrasted BOLD response when viewing the food pictures after each of the three instructions (e.g., *benefits of not eating* > *suppress craving*). Condition-specific effects at each voxel were estimated using general linear models. Vectors of the onsets for each event of interest were compiled and entered into the design matrix so that event related responses could be modeled by the canonical hemodynamic response function. A 128 sec high-pass filter was used to remove low-frequency noise and slow drifts in the signal.

Individual maps were constructed to compare activations within each participant for all contrasts. Consistent effects across subjects were then tested using the contrast images in one-sample random effects t-tests. An overall significance level of $p < 0.05$ corrected for multiple comparisons across the whole brain was calculated. This was accomplished by first estimating the inherent smoothness of the masked functional data with the 3dFWHMx module in AFNI (39). This smoothness was then used in 10,000 Monte Carlo simulations of random noise at $3mm^3$ through the gray matter masked data using the 3DClustSim module of AFNI (39, 40). Results indicated that activity surviving a threshold of $p < 0.001$ and a cluster (k) ≥ 19 was significant corrected for multiple comparisons. Effect sizes (r) were derived from the Z-values (Z/√N). To test whether BMI moderated effects, parameter estimates in voxels showing a significant main effect across the sample were extracted at the individual level using MarsBar (http://marsbar.sourceforge.net) to compute the correlations between neural activation in response to the various contrasts and BMI in SPSS (SPSS for Windows, version 19.0, IBM-SPSS, Chicago, IL).

Results

Participants rated appetizing (M = 323.48, SD = 77.02) versus unappetizing food pictures (M = −211.66, SD = 131.76) as significantly more appetizing; t (20) = 17.28, p<.0.001. The 20 food images rated as most appetizing (e.g., discretionary foods and fruits) were significantly of lower energy density (M = 1.34, SD = 1.27) than the 20 food images rated as most unappetizing (e.g., fats and oils, vegetables) (M = 2.65, SD = 1.50; t (38) = 2.97, p = 0.005). Pre-scan hunger ratings suggest that participants were on average in a neutral hunger state (M = −0.12, SD = 5.19). In total, 7 participants were obese (M BMI = 32.6, SD = 3.44), 9 were overweight (M BMI = 25.3, SD = 1.33), and 5 were lean (M = 21.8, SD = 0.58) based on the Centers for Disease Control BMI-for-age growth chart (Table 1). BMI did not correlate with energy density of chosen foods. There were no sex differences observed for hunger and BMI.

Behavioral ratings

The VAS ratings during the scan were averaged over participants, for each strategy separately. Compared to food wanting ratings in the *imagine eating* condition (M = 3.46, SD = 0.84), wanting ratings were non-significantly lower in the *costs of eating* condition (M = 3.39, SD = 0.73, r = 0.02), *benefits of not eating* condition (M = 3.21, SD = 1.03, r = 0.11), and *suppress craving* condition (M = 3.20, SD = 1.14, r = 0.13) (all p's > .10).

Neural Activation Differences between Cognitive Reappraisal Strategies versus Imagine Eating Instruction

Participants showed greater activation in the left medial SFG (r > 0.90), left vlPFC (r > 0.90; Fig 2A), and right posterior cerebellar lobe (r > 0.90), and less activation in the left supramarginal gyrus (SMG; r > −0.90) in response to the *costs of eating* > *imagine eating* contrast (Table 2).

Participants exhibited greater activation in the left medial SFG (r > 0.90), right posterior cerebellar lobe (r > 0.90), left vlPFC (r > 0.90, Fig 2B and r = 0.89), left MFG (r = 0.89) and less activation in the right precentral gyrus (r > −0.90), left precuneus (r > 0.90) and right posterior cingulate gyrus (PCC; $r = -0.86$) in response to the *benefits of not eating* > *imagine eating* contrast (Table 2).

Participants exhibited greater activation in the left frontal operculum ($r > 0.88$) and less activation in the left inferior parietal lobule (IPL; $r = -0.83$) in response to the *suppress craving* > *imagine eating* contrast (Table 2).

Neural Activation Differences between the Cognitive Reappraisal Strategies

Participants showed greater activation in the left SFG ($r = 0.89$) in response to the *costs of eating* > *suppress craving* contrast (Table 2). Participants showed greater activation in the left medial SFG ($r > 0.90$) and less activation in the right IPL ($r > -0.90$) and right precuneus ($r = -0.89$) in response to the *benefits of not eating* > *suppress craving* contrast (Table 2). There were no significant differences in BOLD signal between the *benefits of not eating* versus the *costs of eating* contrasts[1].

Relations of BMI to Neural Activation in Response to the Instructional Set

BMI did not significantly moderate the relations between the instructional set and neural response to palatable food images. We also examined group differences in neural response by conducting a 3 (group: obese, overweight, lean) by 2 (instruction type: e.g., benefits of not eating > imagine eating) analysis of variance (ANOVA). No significant weight status differences occurred.

Discussion

The first aim was to examine the effects of three cognitive reappraisal strategies versus imagined intake on neural responses to palatable food images. The *costs of eating* reappraisal strategy versus imagined intake of food resulted in greater activation in the medial SFG, vlPFC, and posterior cerebellar lobe and less activation in the SMG. The medial SFG and vlPFC are consistently implicated in response inhibition and cognitive control of memory (41, 42) and the posterior cerebellar lobe has been linked to several cognitive processes, such as motor planning (43). The SMG has been associated with spatial attention (44). The *suppress cravings* strategy resulted in greater activation in the frontal operculum and less activation in the IPL. The frontal operculum is typically activated in tasks requiring executive control (45). The IPL is thought to mediate attentional processes (46). The increased activation in the vlPFC, frontal operculum and decreased activation in the SMG and IPL found for the *costs of eating* and *suppress craving* strategies converges with findings of previous studies (23-25) and suggest that these strategies modulate inhibitory and attention-related region activation in response to palatable food images.

The *benefits of not eating* strategy resulted in greater activation in the medial SFG, posterior cerebellar lobe, vlPFC, and MFG and less activation in the precentral gyrus, precuneus, and PCC. The precentral gyrus is involved in motor processing and has found to be activated

[1]We tested for sex differences in the efficacy of all three cognitive reappraisal strategies. Males ($M = 0.63$, $SD = 0.22$) compared to females ($M = 0.19$, $SD = 0.31$) showed greater activation in the frontal operculum in response to the suppress craving > imagine eating contrast, $t(19) = 3.48$, $p = 0.002$.

during fasting (47). The precuneus and PCC have been associated with spatial attention (44, 48), motivation and reward (49), and visual imagery (50). In addition, greater activation in the PCC was found in response to food cues during a fasted versus sated state (51).

When comparing the three cognitive reappraisal strategies with each other, results suggested that the *costs of eating* and *benefits of not eating* strategies are more successful in increasing inhibitory region activation (i.e., SFG) than the *suppress craving* strategy. The *benefits of not eating* strategy versus the *suppress craving* strategy also resulted in less activation in regions involved in attention (i.e., IPL, PCC). Although no significant differences in response were observed between the *benefits of not eating* and *costs of eating* strategies, the number of significant peaks and voxel sizes found for the *benefits of not eating* strategy imply that this strategy is slightly more effective than the *costs of eating* strategy, which is the only one previously evaluated (23-25). Overall, results suggest that all three reappraisal strategies, but in particular the *benefits of not eating* strategy, were successful in modulating neural activation in response to palatable food images. The fact that thinking of the long-term benefits of not eating was more effective than thinking of the long-term costs of eating aligns with evidence that prevention-oriented health promotion interventions focusing on benefits of a behavior are more effective than those focusing on consequences (26).

The second aim was to test whether BMI moderates the effectiveness of the reappraisal strategies. In contrast to our hypotheses, BMI did not moderate any of the main effects. It is possible that overweight and obese individuals were as successful as lean individuals in recruiting inhibitory region activation and reducing attention-related activation when applying the cognitive reappraisal strategies. However, it is also possible that there was not enough variability in weight status in our small sample to detect moderating effects of BMI.

Although results indicate that all three strategies were successful in increasing inhibitory regions and decreasing activation in attention-related regions, they had limited effects on reward-related regions. Further, the behavioral VAS data did not show significant reductions in food wanting in response to the reappraisal strategies versus the *imagined intake* strategy. These findings are in contrast with two studies in lean individuals (23, 24) but comparable with the null findings in another study that included individuals varying in weight from lean to obese (25). An explanation is that the relatively low energy density of appetizing foods may have confounded our results; it may be possible that these foods do not activate reward regions as strongly. However, despite using high energy dense, appetizing food images, Hollman et al. also did not find significant reductions in reward regions. Therefore, an alternative explanation is that because obese versus lean individuals show greater reward region response to palatable food images/cues (4, 7, 10), the former may need more intensive training to effectively inhibit reward region activation in response to palatable food images/cues. Future studies should test whether a more extensive training in cognitive reappraisal strategies reduces reward region activation in response to food images/cues in a larger sample containing overweight/obese individuals.

It is important to consider the limitations of the present study when interpreting the findings. First, events per condition occurred only 8 times, limiting statistical power. However, the fact that we did find strong effects for inhibitory region and attention areas, suggest that we had adequate sensitivity. Second, although the sample size is comparable with previous reappraisal studies (23-25), it is relatively small and this may have limited power to detect the moderated effects of BMI. Results should therefore be considered provisional until replicated in a larger sample. Third, given that not all people find the same foods appetizing, we thought it would be best to select food images based on individuals' food preferences. Yet, the overall energy density of the appetizing food images was significantly lower than that of unappetizing food images. Although these results dovetail with findings from a previous study (30), it is possible that the relatively low energy density of appetizing foods may have confounded our results; it may be easier to activate inhibitory control regions in response to low energy dense appetizing food. Fourth, our sample is limited to adolescents and thus results may not be generalizable to other demographic groups. This is important given the evidence of developmental differences in neural activation in response to reward, inhibition, and cognitive reappraisals (52-54). However, the fact that our results are comparable to those from studies with adults (23-25), suggest that developmental differences had a limited impact. Fifth, although we found some evidence of sex differences in the effects of the cognitive reappraisal strategies, our sample size was rather small. Future research should address sex-related differences in cognitive regulation of food craving. Finally, the current study is cross-sectional and provided only limited training in the cognitive strategies.

Overall, findings suggest that it might be useful to incorporate cognitive reappraisals in obesity prevention and treatment interventions. As previous studies found evidence for a possible comorbidity between Attention Deficit and Hyperactivity Disorder (ADHD) and obesity (55, 56) and that cognitive reappraisals are effective at reducing craving across various psychiatric disorders characterized by inhibitory deficits (57), the present results may provide additional insight into neurological mechanisms underlying inhibitory control and obesity. Future neuroimaging research should examine the long-term effects of these strategies on future inhibitory deficits, dietary intake, and weight gain.

Acknowledgements

This project was supported by National Institute of Diabetes and Digestive and Kidney Diseases grant (R01 DK80760, 8/09-7/14). The authors would like thank the Lewis Center for Neuroimaging at the University of Oregon for their assistance in data collection for these projects.

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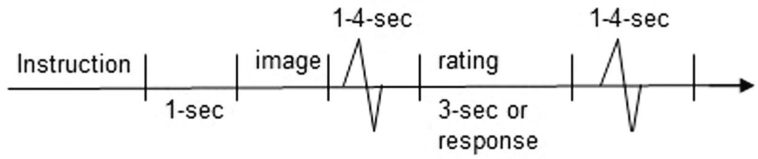

Figure 1.

Example of timing and ordering of presentation of instructions, images, and ratings of the suppression and cognitive reappraisal strategies paradigm.

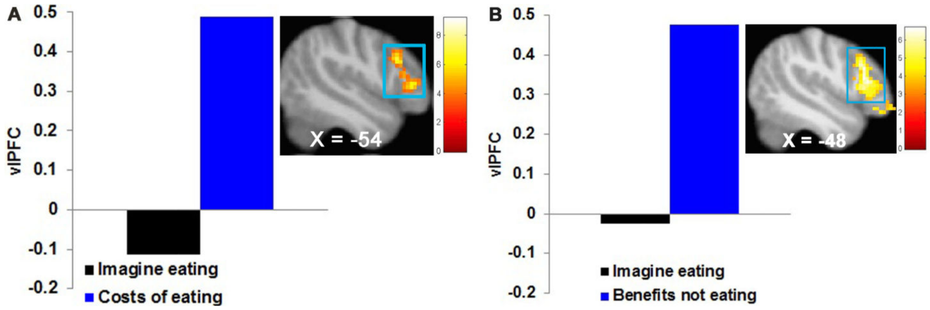

Figure 2.

Greater activation in **A**) the left vlPFC (−54, 29, 7, Z = 5.04, *k* = 88) when viewing palatable food images after the instruction to think of the long-term costs of eating the pictured food versus the instruction to imagine eating the pictured food and in **B**) the left ventrolateral prefrontal cortex (vlPFC; −48, 17, 28, Z = 4.56, *k* = 161) when viewing palatable food images after the instruction to think of the long-term benefits of not eating the pictured food versus the instruction to imagine eating the pictured food.

Table 1

Descriptive statistics for each weight group.

	Obese	Overweight	Lean	F (2,18)	*p*
N	9	7	5		
BMI range	27.6-37.9	23.2-26.4	21.5-22.7	36.5	0.0
Age	15.8	14.7	14.5	2.8	0.1
Males/Females	2/7	4/3	2/3	0.9	0.4

Table 2

Main Differences in Brain Activation in Response to Suppression and Cognitive Reappraisal Strategies

Contrast and region	BA	*k*	Z-value	MNI coordinates	*r*
Costs of eating > imagine eating					
Medial superior frontal gyrus		85	5.37	−6, 14, 58	>0.9
Ventrolateral prefrontal cortex		88	5.04	−54, 29, 7	>0.9
Posterior cerebellar lobe (Pyramis)		104	4.67	12, −82, −38	>0.9
Imagine eating > costs of eating					
Supramarginal gyrus	40	28	4.54	−63, −22, 19	>0.9
Benefits of not eating > imagine eating					
Medial superior frontal gyrus		113	4.97	−3, 20, 49	>0.9
Posterior cerebellar lobe (Pyramis)		39	4.74	9, −82, −41	>0.9
Ventrolateral prefrontal cortex	46	161	4.56	−48, 17, 28	>0.9
Ventrolateral prefrontal cortex	47	32	4.06	−45, 29, −15	0.89
Middle frontal gyrus	8	21	4.06	−30, 17, 55	0.89
Imagine eating > benefits of not eating					
Precentral gyrus		23	4.18	42, 5, 34	>0.9
Precuneus		40	4.12	−3, −49, 49	0.90
Posterior cingulate gyrus	31	20	3.92	6, −34, 43	0.88
Suppress craving > imagine eating					
Frontal operculum	45	32	4.54	−45, 20, 4	0.88
Imagine eating > suppress craving					
Inferior parietal lobule		56	3.80	−45, −31, 37	0.83
Costs of eating > suppress craving					
Superior frontal gyrus		32	4.19	−6, 11, 55	0.89
Future benefits of not eating > suppress craving					
Medial superior frontal gyrus		37	4.07	−6, 14, 52	>0.9
Suppress craving > benefits of not eating					
Inferior parietal lobule		70	4.34	54, −46, 25	>0.9
Precuneus	7	35	4.01	3, −49, 49	0.89

For all contrasts, activated regions, Brodmann areas (BA), number of contiguous voxels (*k*), Z-values, and peak coordinates within the MNI coordinate system are displayed. Peaks within the regions were considered significant at $k \geq 19$, $p < 0.05$, corrected for multiple comparisons across the entire brain.