Published in final edited form as:

Obesity (Silver Spring). 2019 October ; 27(10): 1577–1583. doi:10.1002/oby.22572.

The effects of cognitive strategies on neural food cue-reactivity in adults with overweight/obesity

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Abstract

Objective: Functional magnetic resonance imaging (fMRI) studies of obesity have revealed key roles for reward- and inhibitory control-related activity in response to food cues. This study examines how cognitive strategies impact neural food cue-reactivity.

Methods: In a within-subjects block-design fMRI paradigm, 30 participants (24 female, mean BMI=31.8) used four mind-sets while viewing food: DISTRACT (cognitive behavioral therapy-based), ALLOW [acceptance and commitment therapy (ACT)-based], LATER, focusing on long-term negative consequences, and NOW (control), focusing on immediate rewards. Participants rated cravings by noting urges to eat on 4-point Likert Scales after each block.

Results: Self-reported cravings significantly differed among all conditions (pairwise comparison p 's<0.05). Cravings were lowest when considering long-term consequences (LATER, 1.7 ± 0.7), significantly higher while using DISTRACT (1.9 ± 0.7), and ALLOW (2.3 ± 0.9) and highest for NOW (3.2 ± 0.7).

These behavioral differences were accompanied by differences in neural cue-reactivity. LATER (long-term consequences) led to greater inhibitory control activity in dorsolateral prefrontal cortex. CBT-based DISTRACT was associated with greater activity in executive function and reward-processing areas, while ALLOW (ACT) elicited widespread activity in frontal, reward-processing, and default-mode regions.

Conclusions: Since focusing on negative long-term consequences led to the greatest decrease in cravings and increased inhibitory control, this may be a promising treatment strategy for obesity.

Keywords

Brain; Behavior therapy; obesity; overweight

Introduction

Previous studies have identified potentially problematic neural responses to food cues that are associated with obesity and weight gain. Research has shown that, relative to individuals

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Conflict of Interest: The authors declare that they have no conflict of interest.

with healthy BMI, individuals with obesity exhibit greater reward-related brain activity and reduced control-related activity in response to food cues(1). Moreover, enhanced reward-related responses to food cues predict future weight gain(2), while conversely, successful weight loss maintainers exhibit elevated inhibitory control-related activity when viewing food cues(3) and participation in behavioral weight loss treatment and long-term weight loss is associated with relatively less reward-related responsivity(4). Together these findings suggest increased control-related activity and/or reduced reward-related activity may be beneficial, and some evidence suggests using specific cognitive strategies may help alter the brain's response to food cues in this way.

Kober et al. demonstrated cognitive regulation strategies alter brain responses to both smoking and food(5). Smokers were asked to view smoking and food cues while using two distinct mindsets: focusing on the immediate properties of the cues (i.e., how would this make you feel 'NOW'), and considering long-term consequences of the cues (i.e., 'LATER'). Focusing on long-term consequences is a strategy commonly used in smoking cessation treatment(6, 7) in which patients are asked to think about the negative things that will happen if they continue to smoke. Relative to NOW, using the LATER strategy led to decreased reward-related activity in the ventral striatum and increased control-related activity in dorsolateral prefrontal cortex (DLPFC), coupled with significantly decreased craving for both cigarettes and food. Responsivity to food cues was not the focus of Kober's work, however, the food addiction model of obesity suggests similar mechanisms may underlie both substance use and overeating(8), thus regulation strategies used in interventions for substance use may be effective in the treatment of obesity.

Yokum and Stice (2013) employed a similar paradigm specifically targeting food cue-reactivity in adolescents with a wide range of BMIs. They compared neural food cue-reactivity while participants: 1) thought about long-term negative consequences of eating high-calorie foods, 2) considered long-term benefits of avoiding such foods, 3) tried to suppress cravings, and 4) imagined consuming the foods. Relatively greater control-related activity in response to food cues was observed when adolescents considered both long-term costs of eating unhealthy foods and long-term benefits of avoiding unhealthy foods.

Thus cognitive strategies can influence the brain's response to appetitive cues, and simply focusing on long-term negative health consequences may be an effective strategy to reduce cravings. Although focusing on negative long-term consequences is a commonly used technique for smoking cessation, it is not typically used in weight control treatment, but deserves further study. The most widely employed approach for behavioral weight loss treatment is Cognitive Behavioral Therapy (CBT), which incorporates strategies to control and change cognitions (e.g., avoid desire to eat tempting foods by focusing on something other than food). In CBT, participants are taught to recognize a maladaptive thought, stop it, and replace it with a positive thought. Alternatively, emerging evidence suggests Acceptance and Commitment Therapy (ACT), which teaches participants to recognize and allow or accept their cravings as feelings that need not be acted upon, may also be effective in treating obesity(9). ACT incorporates mindfulness techniques to enhance tolerance of unpleasant states, and the extent to which people accept these negative states versus try to avoid such experiences has been associated with decreases in binge eating,(10) alcohol

abuse,(11) and smoking.(12) In a study comparing acceptance-based cognitive strategies to strategies based on CBT for weight loss (i.e., control-based), use of acceptance-based strategies led to reduced cravings and less consumption of chocolates among individuals who reported being highly influenced by food/food cues in the environment. Taken together, these three unique cognitive strategies may each be effective, but, to date, no studies have compared these strategies in terms of their ability to reduce urges to eat and their impact on the brain's response to food cues.

In this study, participants with overweight/obesity were briefly trained to use each of these three different treatment-based cognitive strategies (i.e., CBT-based 'CHANGE/DISTRACT', ACT-based 'ACCEPT/ALLOW', and the 'LATER' mindset adapted from smoking cessation treatment). Ratings of participants' urge to eat and neural responses to tempting food cues were assessed while they used each cognitive mindset as well as during a control condition in which they focused on immediate rewarding qualities of the presented foods ('NOW'). Given their use in weight loss treatment programs, it was hypothesized that both DISTRACT and ALLOW would lead to reduced desire to eat relative to NOW, and based on previous research in smokers it was hypothesized that the LATER mindset would also produce some reductions in desire to eat. Although participants viewed the same food images across all conditions, given the uniqueness of each mindset and the potentially different mechanisms through which they may alter cravings, it was hypothesized that the patterns of brain activity in response to these food cues would differ. It was specifically hypothesized that DISTRACT and LATER would be associated with greater inhibitory-control and potentially reduced reward-related activity relative to NOW.

METHODS

Participants

A total of 34 individuals (27 female) between the ages of 25-55 years with BMIs between 25-40 kg/m² participated in this study. Eligible participants were weight stable (within +/-5 lbs. for two months), not taking weight loss medications, and deemed MRI compatible (i.e., no ferrous metallic implants or claustrophobia). Other standard fMRI exclusion criteria included left-handedness, use of psychiatric medications, or current use of medications affecting blood flow. One individual did not successfully complete mindsets training and therefore was removed from the study prior to scanning. One participant's BMI was found to be below the specified BMI eligibility criteria, and fMRI data from 2 participants were excluded due to movement artifact. Thus the final sample included 30 participants (24 female, mean age=42.3±9.9 years, BMI=31.8±3.5). Behavioral data from 3 of these participants was not collected due to equipment malfunction, therefore craving ratings from 27 of the 30 participants are reported. The protocol was approved by the Miriam Hospital and Brown University Institutional Review Boards. All individuals provided written consent before participating and were compensated \$50 for their time.

Procedures

Weight was assessed with Tanita digital scales (TANITA Corporation of America, Inc, Arlington Heights, IL) (participant in street clothes, without shoes) and height was measured

with a wall-mounted stadiometer. Participants completed demographic questionnaires prior to Mindset Training.

The Mindsets: The four cognitive strategies are described below with excerpts of instruction language:

(1) **‘NOW’**. This mindset was used as the control condition. It is designed to elicit typical immediate responses to appetizing foods.

‘As you see the foods come up on the screen, imagine what they taste like, smell like, and what actually consuming them would be like’.

(2) **‘DISTRACT’**. This strategy focuses on distraction as used in CBT and is similar to strategies taught in behavioral weight loss treatment,

‘As you see the foods come up on the screen, change your thoughts by distracting yourself with thoughts of something else such as imaging doing something you enjoy, or thinking about what you have to do today.’

(3) **‘ALLOW’** This strategy stems from mindfulness and acceptance concepts of ACT.

‘Try to observe your thoughts and recognize these thoughts as creations of your mind, a part of a mental process that is happening that you do not need to do anything about. For example, if you find yourself having thoughts about the foods or feeling like you want to eat, try to notice these thoughts. You may practice by mentally noting “I’m having the thought that...” or even picture each thought going through your mind like a tickertape or seeing those thoughts up on a screen like at a movie theater, where you don’t try to change them or direct them in any way.’

4) **‘LATER’**; This strategy is adopted from smoking literature and was used previously by Kober et al.(5).

‘As you see the foods come up on the screen imagine the long-term negative consequences of repeatedly eating these foods. For example, you might think about how eating these foods could affect your appearance, your quality of life and mobility, and/or lead to health problems such as diabetes or cardiovascular disease.’

Mindset Training

All participants completed a single in-person training session. Participants first provided ratings to identify their highly tempting foods (see Supplement for more detail). For each mindset, the experimenter explained the strategy, discussed the mindset with the participant specifically targeting personally relevant information that may be helpful in his/her use of the mindset, and provided an opportunity for the participant to practice using the mindset while viewing the tempting foods selected previously. During this practice, the name of the mindset appeared, followed by presentation of the three images in random order, each for 20 seconds, during which time the participant was to view the food images and think according to the mindset. Participants were then asked to describe the thoughts they had during practice, giving the experimenter opportunity to assess the participant’s use of the mindset and address any difficulties the participant may have had. If the participant or the

experimenter deemed it necessary for more practice, the exercise was repeated for that mindset until both the participant and experimenter were confident with the participant's use of the mindset. fMRI sessions were scheduled for participants demonstrating ability to think according to all of the mindsets and switch between the 4 strategies. A summary of the mindsets was provided for participants to review and they were encouraged to practice prior to their fMRI session.

fMRI Paradigm.—Participants were asked to limit their intake of caffeine and alcohol to no more than two beverages 24 hours prior to scanning. On the day of the fMRI session all participants were required to fast, consuming nothing other than water, for 3 hours prior to their scan. Immediately preceding the scan participants again rated temptation levels for foods. The 5 images selected as the most tempting were selected for use in scanning, and prior to the scan they again practiced each of the mindsets as they had in training (see Supplement for greater detail). Participants then performed the cognitive strategy task in 4 functional scanning runs. During each run participants used each of 4 strategies once in random counter-balanced order, thus each strategy was used a total of four times.

During each strategy block (Fig. 1), the name of the strategy to be used during that block (e.g., 'NOW') appeared on the screen for 5 seconds, followed by the 5 food images presented for 6 seconds each in random order.

To assess cravings, at the end of each block a screen appeared asking participants to rate their current 'urge to eat' on a 4-point Likert scale (very low-very high). Responses were made via a 4-button MRI-compatible response pad and were recorded via E-prime. Blocks were followed by periods of fixation baseline (45 seconds).

Imaging Parameters.

All MRI scans were conducted at the Brown University MRI Research Facility on a Siemens 3-Tesla Tim Trio Scanner. Further details are available in supplemental material. The paradigm of interest included 4 functional BOLD runs with 190 timepoints each using a gradient-echo echo-planar sequence (TR = 2000 ms; TE = 30 ms; flip angle = 90°; 40 axial slices, 3 × 3 × 3 mm voxel size).

Statistical Analyses

Baseline participant characteristics were described using means and standard deviations (SD) for continuous variables or percentages for categorical variables. Differences in self-reported cravings as a function of condition were assessed via ANOVA followed by pairwise comparisons between each of the conditions. All behavioral data were analyzed using PASW Statistics software, Version 18.0 (IBM, Armonk, N.Y.).

Preprocessing and data analysis were performed using Statistical Parametric Mapping Software (SPM8; Wellcome Trust Centre for Neuroimaging, University College London, UK; <http://www.fil.ion.ucl.ac.uk/spm/>). Standard preprocessing methods were employed (see supplemental material).

Statistical contrasts derived from the general linear model compared activity during use of each of the mindsets vs. NOW, then compared each condition to one another (i.e., LATER vs. DISTRACT, LATER vs. ALLOW, and DISTRACT vs. ALLOW). All contrasts were thresholded at $p < 0.0001$ uncorrected, with an extent threshold (k) of 10 contiguous voxels.

RESULTS

Cravings Ratings

Ratings of participants' food cravings varied significantly among each of the four mindsets ($p < 0.001$; Figure 2). As expected, participants reported the highest urge to eat following use of the NOW mindset (mean = 3.2 ± 0.7). Cravings were significantly lower for ALLOW (2.3 ± 0.9 , $p < 0.001$), further reduced for DISTRACT (1.9 ± 0.7 , DISTRACT vs. NOW $p < 0.001$; vs. ALLOW $p = 0.009$), and were lowest with the LATER mindset when participants considered long-term negative consequences (1.7 ± 0.7 , all pairwise comparison p 's < 0.05).

fMRI Results

Paralleling the differential behavioral responses associated with each mindset, brain imaging data also revealed significantly different patterns of activation in response to the same food images while participants used different mindsets (Figure 3, Supplemental Table S1).

LATER – Considering long-term negative consequences—The LATER mindset, which resulted in the greatest reduction in cravings, yielded greater activity in regions of PFC associated with inhibitory control when compared to the NOW mindset, including a region of left DLPFC within BA 9 ($-33, 27, 36$) as well as BA 46 ($-30, 27, 27$) and adjacent regions of BA 8/10. This was coupled with relatively less activity in regions of visual cortex, inferior parietal lobule, and precuneus, suggesting greater inhibitory control and less sensory and attention processing while thinking of long-term consequences of over-consuming the foods relative to thinking about their immediate rewarding properties.

Relative to DISTRACT, LATER yielded relatively less activity in regions involved in reward processing (ventromedial prefrontal cortex [vmPFC]), attention (precuneus), executive function (i.e., superior frontal regions), and working and recognition memory, (inferior temporal cortex [BA 20], cingulate cortex). The LATER mindset was also associated with greater activation in bilateral lingual gyrus than DISTRACT, which suggests enhanced visual processing for LATER compared to distraction, and possibly greater visual imagery.

Compared to ALLOW, LATER was associated with less activity in posterior cingulate, superior and medial, and middle frontal gyrus (BA 8, 10, and 11), inferior parietal lobule, parahippocampal gyrus, anterior cingulate, insula, and caudate. No brain regions exhibited greater activity in response to LATER relative to ALLOW.

CBT-based DISTRACT – Attempting to avoid thoughts about food—Relative to NOW, DISTRACT was associated with greater activity in superior frontal regions within left PFC (Brodmann Area [BA] 9; $-24, 45, 15$) as well as posterior cingulate (9, $-60, 12$), angular gyrus (45, $-72, 30$), and putamen (21, 3, 3), suggesting greater executive function

and mental reasoning, as well as greater reward-processing in response to food cues. This was coupled with less activity in visual processing regions within inferior occipital cortex, fusiform gyrus, superior and inferior parietal lobules, and precuneus, as well as a region of right DLPFC within BA 46 (48, 36, 15).

Compared to ALLOW, DISTRACT was associated with less activation in the cuneus, lingual gyrus, superior and inferior parietal lobules, along with greater activity in middle, inferior, and superior frontal gyri. There were no regions whose activity was significantly greater for DISTRACT than ALLOW.

ACT-based ALLOW – Allowing/accepting thoughts—ALLOW, which produced the least reduction in cravings, was associated with greater brain activity overall than any other mindset. Relative to NOW, ALLOW was associated with greater activity in left superior frontal gyrus (BA 10; -27, 54, 18), right middle frontal gyrus (33, 18, 39), right inferior frontal gyrus within BA 11 (51, 33, -12) and left inferior frontal gyrus within BA 47 (-42, 30, -12), cingulate cortex, regions of inferior parietal lobule (-54, -42, 45), precuneus (-6, -51, 30), posterior cingulate cortex, middle temporal areas, basal ganglia reward-related regions of caudate and putamen, as well as regions within the cerebellum. There were no regions whose activity was significantly greater for NOW than ALLOW. This pattern of activity suggests the ALLOW mindset is associated with a host of cognitive processes, including executive functioning, reward processing, sensory and processing, and activations within the default mode network indicate the potential for internally directed thoughts.

Discussion

The purpose of this study was to compare responses to food cues in individuals with overweight/obesity while they employed different cognitive strategies adapted from various treatment methods. Use of each treatment-based mindset yielded different patterns of neural activity in response to the same exact food images and significantly different craving responses. Of note, the LATER mindset, which required participants to consider long-term consequences of repeated over-indulgence of foods, led to the lowest craving ratings. This was coupled with relatively greater activity in DLPFC, which has consistently been implicated in inhibitory control. These findings suggest that simply thinking about long-term negative consequences of over-indulgence may reduce urges to eat high-calorie food and increase inhibitory control.

The DLPFC is associated with ability to delay or inhibit responses and exercising self-control in food choices. For instance, the DLPFC has been shown to be more active when individuals select less-tasty foods that have higher health value (e.g., vegetables) or avoid tasty foods that are thought to be less healthy (e.g., candy)(13). Activity in this region has also been shown to increase when participants are explicitly directed to attend to the health value of foods(14). The current finding of increased DLPFC and reduced cravings with the LATER mindset is consistent with previous work in smokers. One study incorporating a similar cognitive strategy to regulate food responses in adolescents also demonstrated increased control-related activity(15). The reductions in cravings and increased inhibitory control activity observed herein suggest the LATER strategy, which has been employed in

anti-smoking campaigns and smoking cessation treatment, may be a promising new direction for behavioral weight control. Future work will explore longer-term effects of using this mindset and how it functions in the context of behavioral weight loss treatment, as well as functional connectivity between cognitive control regions such as DLPFC and reward-processing areas.

DISTRACT, the mindset based upon CBT, also produced reductions in cravings relative to NOW, however these reductions were significantly smaller than those produced by LATER. Neural activity associated with DISTRACT included areas involved in executive functioning, including working memory, goal formation, and prospective memory (i.e., memory to perform a future action or recalling a planned intention) as well as inhibitory control. Activation of these areas may speak to the effort of distraction and the types of thoughts participants reported having while utilizing the DISTRACT mindset. For example, many participants reported thinking about what they had to do later in the day or thinking about exercising later. Interestingly, increased activation in reward-processing regions were also observed during DISTRACT. This elevated reward-related activity may be due to thoughts of other rewarding things as a distraction technique (e.g., imagining something enjoyable). If, however, this activity is in response to the foods, it may help explain the relatively higher craving ratings observed with DISTRACT versus LATER, and may reflect the difficulty of employing cognitive control and thought suppression techniques

In contrast to this current finding, one previous study employing thought suppression (i.e., stop cravings and thoughts of food) compared to a consequences-focused reappraisal strategy found no differences between these conditions in self-reported food craving but did find the thought suppression strategy more effectively decreased reward-processing activity than their consequences condition(16). However, it is important to note these strategies are different from the strategies of the current study, and that participants in this previous work were ‘non-dieters’ of healthy weight. As noted, there are known differences in neural food cue-reactivity between individuals with overweight/obesity and those within healthy weight, and it is also possible that the degree of relevance and/or difficulty of using these strategies may differ across various populations (e.g., individuals currently with overweight/obesity compared to non-dieters with healthy BMI). Therefore, it is plausible that these populations may have markedly disparate responses to such strategies, both behaviorally and neurally. Previous work has not found any moderating effects of BMI in use of various cognitive strategies(15, 17), however, further work in larger samples with a range in BMI, weight loss history, and dieting status is needed.

The ALLOW mindset produced modest reductions in cravings. From the perspective that reducing food cravings is clinically desirable, the ALLOW mindset was less effective than DISTRACT and LATER. It is important to note, however, ALLOW was based upon ACT, which teaches individuals how to refrain from eating when food cravings are present, as opposed to trying to reduce the frequency of food cravings(18, 19). Also of note, ALLOW produced more activation across all brain regions than any other condition, including regions of superior frontal gyrus involved in reasoning and memory. Regions of the default-mode network, those regions that are typically more metabolically active at ‘rest’, in the absence of explicit tasks(20), were also more active during ALLOW. This is likely due to the fact that

there were no constraints on participants' thoughts while they were using this mindset. It is possible that this allowance of a natural flow of thoughts may lead to more neural activity overall and may more closely mimic the type of brain activity and thought patterns individuals evoke during rest periods.

Strengths of this work include the use of brain imaging to objectively measure responses to food, the within-subjects design, and the inclusion of mindsets based on multiple treatment modalities, however, there are limitations to note. For instance, one potential limitation is, despite training, there is no way to know exactly how participants were using the strategies during scanning. Another limitation is that cravings were assessed via self-report. In a different design, caloric intake following use of each mindset could be directly measured. This would be an important future study, as it is possible, especially within the context of ACT, that reduction of cravings may not translate directly to healthier eating behavior. More research is needed to demonstrate how differences in food cue-responsivity across each of these mindsets relate to intake. Hunger ratings were not assessed prior to scanning and it is possible that variability in hunger may impact response to food cues as well as how a participant uses a given cognitive strategy. However, all participants were required to fast for 3 hours prior to scanning, which may have reduced such potential variability. Additionally, this study did not assess longer-term effects of using these mindsets. Although a mindset such as LATER may be simple to grasp and have a powerful effect initially, it is possible that a different strategy, such as ALLOW, may take more practice to master, and/or may prove to be more sustainable over time. Future studies will address this. Lastly, the sample was middle-aged and predominantly female, which may impact generalizability of these findings to other demographics. Future work should investigate how these cognitive strategies may affect cravings and food cue-reactivity in other populations and whether these strategies are effective in the context of either weight gain prevention or long-term weight control (e.g., weight loss maintenance).

The current study is an important initial inquiry on the effectiveness of cognitive strategies conceptualized from treatments. Although it is not surprising that the CBT-based strategy reduced urges to eat and was associated with greater PFC activity, it is promising that an alternative strategy, focusing on long-term consequences, was able to produce even greater reductions in food cravings and relatively increased inhibitory-control-related activity in DLPFC. Treatments focusing on long-term consequences (LATER) have been effective in substance abuse interventions yet this strategy is not typically included in behavioral weight loss treatment. Thus this work suggests that simply thinking according to a different mindset can produce significant changes in desire to eat and neural food cue-responsivity. In addition to longer-term assessment, based on findings from this study, our future research will investigate how behavioral weight loss interventions incorporating LATER strategies will affect neural food cue-reactivity and weight loss. Given the grave impact of obesity on the world today it is necessary to identify and test these possible improvements to obesity treatment and weight gain prevention.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements:

This work was supported by an Early Career Research Grant from The Obesity Society awarded to Dr. Demos. Further support for Dr. Demos comes from an NIH NIDDK K01 Mentored Research Scientist Award (5K01DK090445-04). We would like to thank Dr. E. Whitney Evans and Denise Fernandes for their assistance.

Funding: This work was supported by an Early Career Research Grant from The Obesity Society awarded to Dr. Demos. Further support for Dr. Demos comes from an NIH NIDDK K01 Mentored Research Scientist Award (5K01DK090445-04).

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What is already known?

- Obesity and weight gain are associated with greater reward-related brain activity and reduced inhibitory control activity in response to food cues.
- Standard behavioral treatment for obesity is rooted in cognitive behavioral therapy and more recently acceptance and commitment therapy has also been used, yet neither typically incorporates strategies to focus on the long-term negative consequences of foods or behaviors.
- In other populations (i.e., smokers, adolescents, individuals in healthy BMI ranges) certain cognitive strategies, including focusing on the long-term negative consequences, have been shown to alter cravings and neural response to food cues.

What does this study add?

- This study directly compares 3 treatment-based cognitive strategies in adults with overweight/obesity, finding that these strategies alter responses to tempting food cues both behaviorally and neurally.
- Using a mindset focused on long-term negative consequences significantly reduced food cravings more so than cognitive strategies based upon cognitive behavioral or acceptance and commitment therapies.
- Thinking about long-term negative consequences of over-consuming high calorie foods was associated with increased inhibitory control-related brain activity in dorsolateral prefrontal cortex (DLPFC).

Figure 1.

Fig. 1 is a display of the fMRI paradigm depicting one functional run. Strategy order was randomly counterbalanced across each run for each participant, and participants each completed four runs, therefore each strategy was used a total of four times.

Figure 2.

Fig. 2 depicts mean cravings ratings across the four mindsets. Error bars represent standard error of the mean. Cravings were significantly different between each of the conditions (* denotes $p < 0.05$).

Figure 3.

Fig. 3 depicts statistical maps representing significant BOLD activation associated with the contrasts of each mindset relative to the NOW control condition: (A) LATER > NOW, (B) DISTRACT > NOW, and (c) ALLOW > NOW.