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Jing Chen Date

Effects of brief mindfulness training on the neural activity associated with processing food cues

By

Jing Chen
Doctor of Philosophy

Psychology

Lawrence W. Barsalou, Ph.D
Advisor

Stephan Hamann, Ph. D
Advisor

Linda Craighead, Ph.D
Committee Member

Kaundinya Gopinath, Ph.D
Committee Member

Esther K. Papies, Ph.D
Committee Member

Accepted:

Lisa A. Tedesco, Ph.D.
Dean of the James T. Laney School of Graduate Studies

Date

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Jing Chen
B.S. Beijing Normal University, China, 2008
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Advisor: Lawrence W. Barsalou, Ph.D
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Abstract

Effects of brief mindfulness training on the neural activity associated with processing food cues

By Jing Chen

A functional magnetic resonance imaging experiment assessed effects of a brief mindfulness intervention on the neural mechanisms that underlie food cue processing. In a blocked design, an initial training phase asked participants to either normally view or mindfully attend to images of tasty and healthy foods. In a fast event-related design, a subsequent choice phase asked participants to make speeded choices about whether to eat pictured foods (both tasty and healthy, half from the training phase, half novel). The results largely supported our hypotheses. Using the breadth of activation relative to well-matched active baselines (rather than signal intensity relative to resting state baselines), we established a large distributed neural network for food processing that grounds the diverse aspects of food consumption simulations, including the ventral food reward network (taste, olfaction, reward, attention), mentalizing (along the cortical midline), and embodiment including action (across the motor system). This distributed network was active for both training and choice, for both tasty and healthy foods, for both repeated and novel foods. Left-hemisphere language areas were also active (although not predicted), implicating linguistic processing of food cues, especially during the training phase for the mindful attention group. As predicted, tasty foods produced greater neural activity across food processing areas than healthy foods during the training phase. Surprisingly the choice phase exhibited the opposite pattern, with healthy foods producing larger activations. Most importantly, mindful attention, relative to normal viewing, produced more neural activity while processing foods during the training phase, but much less neural activity during the subsequent choice phase. Increased up-front processing for mindful attention during training later led to a large processing off-load during food choice. Moreover, this effect of mindful attention was much larger for tasty foods than for healthy foods, perhaps because tasty foods offer more conceptual content for mindful attention to process. Finally, mindful attention operated both as a general cognitive set (generalizing to novel foods) and also via food-specific memories (repetition effect), suggesting two mechanisms that underlie mindful attention effects. These results shed new light on the mechanisms that underlie early mindfulness practice, while raising many issues for future research.

Key words: food cue processing, eating, grounded cognition, mindful attention, mindfulness, fMRI

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1. Introduction

1.1. The problem

Obesity has become an increasingly challenging public health problem worldwide, not only because of its high prevalence in both children and adults, but also because of its serious health consequences. According to Flegal, Carroll, Ogden, and Curtin's (2010) report, more than two-thirds of US adults are overweight (body mass index, BMI of 25.0 to 29.9 kg/m^2), and one-third of US adults are clinically obese (BMI ≥ 30kg/m^2). Also, obesity in children and young people is at a very high rate. Lobstein, Baur, and Uauy (2004) showed that about 10% of the world's school-aged children are estimated to be overweight and a quarter of them are obese. The prevalence of overweight/obesity is significantly higher in developed countries, and is rising significantly in most parts of the world. For example, in 2009-2010, 16.9% of children and adolescents aged from 2 to 19 years in US were obese (BMI ≥ 95th percentile of the BMI-for-age growth charts) (Ogden, Carroll, Kit, & Flegal, 2012). The problem of childhood obesity is getting worse in many countries. Surveys during the 1990s showed that in the USA, an additional 0.5% of the entire child population became overweight each year. In many other countries, such as Canada, Australia and parts of Europe, the rates were even higher, with an additional 1% of all children becoming overweight each year (Lobstein et al., 2004). In other words, the number of overweight children and adolescents has doubled in the last two to three decades in the US, and similar doubling rates are being observed worldwide (Deckelbaum & Williams, 2001).

Moreover, most of these overweight/obese individuals are unable to lose weight, even after many serious dieting attempts (e.g., Mann et al., 2007). More disturbingly, obesity is now the fifth leading risk factor for global deaths and is strongly associated with increased risks for cancer (Adams et al., 2007; Batty et al., 2005; De Pergola & Silvestris, 2013). Comorbidities associated with obesity and overweight are similar in children as in the adult population. These frequent comorbidities include elevated blood pressure, dyslipidemia, and a higher prevalence of factors associated with insulin resistance and type 2 diabetes in the overweight and obese pediatric population (Deckelbaum & Williams, 2001).

Although the origins of obesity are complicated and hotly debated, the fundamental cause of obesity is energy intake in excess of energy expenditure (Gortmaker et al., 2011). The high prevalence of obesity is thought to be caused largely by industrialized environments that promote excessive food intake and that discourage physical activity (Hill & Peters, 1998). On the one hand, energy expenditure has probably not increased much for many modern humans and may actually have decreased in relatively sedentary societies, because of the reduced need for physical activity in daily life. On the other, industrialized environments, where highly rewarding, high-calorie, high-fat, and high-sugar junk foods are marketed aggressively and readily available nearly everywhere, promote overeating (Wadden, Brownell, & Foster, 2002). Systematic review of fast food consumption and weight gain has begun to elucidate a positive link between them (Rosenheck, 2008). To make it worse, these high energy-dense poor-nutrient junk foods often tend to substitute for, rather than supplement, more nutrient-dense healthy foods, which results in, not surprisingly, high energy intake as well as marginal micronutrient intake (Kant, 2000).

People often experience foods high in calories, fat, and sugar as being high in sensory appeal, mostly because they supply high amounts of energy, produce strong reward responses, and provide satisfying emotional experiences (e.g., Drewnowski, 2003; Gilhooly et al., 2007). Additionally, humans have a poor ability to recognize junk foods so as to appropriately down-regulate their desire for them, leading to a link between junk food consumption and obesity (Prentice & Jebb, 2003). As a result, encountering cues to these attractive foods in the environment can induce overwhelming impulses to consume them, even when doing so is unhealthy (Veling, Aarts, & Papies, 2011). Because we are constantly bombarded with highly attractive compelling cues to unhealthy foods, how we react to them is crucial to our health. Furthermore, research that helps establish effective strategies for regulating impulses to consume them are likely to benefit public health.

1.2. The neural mechanisms that underlie the processing of food cues

A “food cue” is any information associated with a particular kind of food that is capable of activating cognition about it (while not actually eating it). Such cues include, for example, pictures that represent the food, words that label the food, smells of the food, sounds of eating the food, etc. In the real world, people are frequently exposed to food cues, such as food pictures on websites, smells of food when passing by restaurants, the logos of restaurants that serve junk foods, and many other constant sources of food information and signals. Thus, exploring the neural responses to these cues is essential for understanding the neural mechanisms that underlie food intake, together with how these cues motivate and regulate eating. And indeed, the large majority of the studies used food pictures to investigate neural activity related to eating, with a few using food words.

1.2.1. Adopting the perspective of grounded cognition. The perspective of grounded cognition offers an account of how people process food cues (e.g., Barsalou, 2008; Barsalou, 2009). According to the grounded perspective, when people cognize about entities, events, and internal states that are not present, they simulate the processing performed on these things when they are present. As a result, modal simulations, bodily states, and situated action underlie cognition about things in the world. When, for example, people conceptualize the color of an object, such as a banana, they reactivate color processing systems that are active when actually perceiving the object. While experiencing bananas, the color processing that occurs becomes stored in memory, such that it can later be reactivated or simulated while thinking about bananas conceptually. Much evidence supports this view. Using a property verification task, Simmons et al. (2007) found that color concept knowledge was grounded in the brain areas that are active during an actual color perception task (also see Hsu, Frankland, & Thompson-Schill, 2012). When verifying that a banana is yellow, for example, brain areas that process color became active while processing the color word. Many other findings more broadly demonstrate that higher cognitive processing is grounded in this manner (e.g., Barsalou, 2008).

As reviewed in Chen, Papies, and Barsalou (2016), research shows that the processing of food cues is grounded. When people process a food cue, they reactivate brain areas similar to those that are active while they are actually eating the food. In other words, memories of eating produce later simulations of eating the food associated with a current food cue. As a result, a food cue may reactivate experiences of a food's specific properties, including its shape, smell, taste, and reward. The food cue may also activate simulations that represent the health consequences of eating the food. For these reasons, we generally assume that cognitive responses to food cues often include simulations, grounded in food-specific processing areas associated with actual food consumption (for another review, see Papies & Barsalou, 2015).

1.2.2. The neural network underlying food consumption. As just described, the grounded perspective proposes that processing food cues reactivates brain areas similar to those that become active while actually eating food. Here we first establish the brain networks that underlie actual food consumption in humans and then review how similar brain networks become active while processing food cues. Since Frank et al. (2003)'s pioneering methods for measuring neural activity to taste stimuli in an fMRI scanner, the majority of subsequent experiments have administered sweet liquids through tubes to participants as stimuli (e.g. milkshake), thereby establishing the neural mechanisms that underlie actual eating. As demonstrated in Kaye, Fudge, and Paulus (2009) Figure 3 and Chen et al., (2016) Figure 1, there are two important neurocircuits involved in actual eating: the ventral reward neurocircuit and the dorsal regulatory neurocircuit. The "ventral (limbic) reward neurocircuit" for eating includes the insula and frontal operculum (primary gustatory cortex), amygdala (affective relevance), the ventral anterior cingulate cortex (ACC, incentive learning), the orbitofrontal cortex (OFC, reward anticipation), and ventral striatum (reward), and promotes approach ("eat") behavior to food. In contrast, the second dorsal regulatory neurocircuit includes the dorsolateral prefrontal cortex (dlPFC), parietal cortex, and dorsal ACC, and is responsible for regulatory activity during eating behavior, especially when regulating unhealthy eating impulses, orienting eating toward healthy goals, and resolving conflicts between impulsive and regulatory goals. Signals from both the ventral reward circuit and the dorsal regulatory circuit can be integrated in various ways, resulting, for example, in approach ('to eat') behaviors or avoidance ('not to eat') behaviors.

Previous research on actual food consumption mainly has primarily observed activations in the ventral reward pathway, especially for the insula and OFC. Frank et al. (2003), for example, reported greater OFC activation when comparing receipt of glucose solution to receipt of artificial saliva in females. Kringelbach, O'Doherty, Rolls, and Andrews (2003) showed increased activation for liquid foods in bilateral insula/operculum, the caudal OFC, and the ACC in healthy males. Additionally, when participants consumed liquid foods to satiety, activity in OFC activity decreased significantly, indicating that OFC plays an important role in representing the reward value of food, which decreases as satiation increases. When comparing fasted to satiated states, Uher, Treasure, Heining, Brammer, and Campbell (2006) observed greater activations in the left anterior insula and frontal operculum when fasted. Similarly, Stice, Burger, and Yokum (2013) found a positive correlation between the duration of acute calorie deprivation and brain activity in the insula when participants received milkshake (compared with tasteless solution). Other experiments, however, have reported the opposite effect, showing stronger insula activation to the receipt of chocolate milk during the satiated state than the fasted state in healthy females (Vocks, Herpertz, Rosenberger, Senf, & Gizewski, 2011). In this experiment, individuals with AN, showed greater brain activation in the extrastriate body area (EBA) to chocolate milk consumption while satiated than fasted, reflecting fear of weight gain in this population and again demonstrating the role of dorsal regulatory pathway in food consumption.

In summary, during food consumption, the ventral reward pathway, especially the insula/frontal operculum and OFC, plays important roles in representing the taste and reward of food, respectively. In contrast, the dorsal pathway plays important regulatory roles in food consumption, which will be addressed later.

1.2.3. The neural network underling food cue processing. According to grounded cognition, the brain areas that represent a cued food in the absence of actual food consumption should be closely related (but not necessarily identical) to the brain areas that actually process eating food. Thus, the network that becomes active on perceiving a food cue should be similar to the network that is active while actually consuming foods, as demonstrated in reviews (Chen et al., 2016; Papies & Barsalou, 2015). As we will see, much evidence from behavioral and neuroimaging supports the proposal that cognitive responses to food cues are grounded in actual eating experiences.

Behavioral evidence shows that perceivers spontaneously imagine the specific properties of a cued food, such as its taste, smell, and texture, and become increasingly motivated to obtain and consume it (Harvey, Kemps, & Tiggemann, 2005; Kemps & Tiggemann, 2009; Papies, 2013). In Harvey, Kemps and Tiggemann (2005), food craving intensity increased following instructions to imagine eating a food (relative to imagining a holiday), especially for dieters. Furthermore, food craving intensity correlated positively with image vividness, whereas competing visual imagery tasks interfered with food craving. Similarly, Kemps and Tiggemann (2005) found that coffee cravings were characterized predominantly by sensory images in the visual, olfactory, and gustatory modalities, and that a competing visual or olfactory imagery task reduced these cravings. In Papies (2013), participants were asked to generate features that are typically true of tempting foods and neutral foods (i.e., the feature listing task). The results showed that participants listed more eating simulation features for the tempting foods (e.g. the taste and texture of the food, eating situations, the hedonic experience of eating the food). Together, these behavioral results demonstrate that food cues activate eating simulations that lead to food craving, and that competing visual and/or olfactory imagery tasks can decrease these simulations, resulting in reduced food craving.

Accumulating evidence from neuroimaging studies similarly demonstrates that the neural network associated with processing food cues is similar to the eating network (for a review, see Chen et al., 2016). Simmons, Martin, and Barsalou (2005), for example, observed brain responses to food pictures (compared to buildings) in right insula/operculum (gustatory processing region), left OFC (reward area), and visual cortex (food recognition and shape). The involvement of brain areas associated with taste and reward in both actual food consumption and food picture processing supported the proposal that the processing of food cues is grounded in the same general brain areas that underlie actual eating. Similar brain activity for food pictures has been found in many subsequent experiments, across different tasks and with different populations of participants (e.g., Beaver et al., 2006; Cornier, Von Kaenel, Bessesen, & Tregellas, 2007; Cornier et al., 2009; Davids et al., 2010; Führer, Zysset, & Stumvoll, 2008; Holsen et al., 2005; Holsen et al., 2006; Killgore et al., 2003; Killgore & Yurgelun-Todd, 2005; LaBar et al., 2001, Miller et al., 2007, Rothemund et al., 2007; Santel, Baving, Krauel, Münte, & Rotte, 2006; Schur et al., 2009; St-Onge, Sy, Heymsfield, & Hirsch, 2005). Other types of food cues, food-related words (Barros-Loscertales et al., 2012; Pelchat, Johnson, Chan, Valdez, & Ragland, 2004), and food-related odors (Bragulat et al., 2010; Eiler, Dzemidzic, Case, Considine, & Kareken, 2012) also activate similar brain regions.

To sum up, different food cues, no matter whether they are food pictures, food words, or food-related odors, appear to activate the same general brain areas as actual eating, including the inferior temporal gyrus and the fusiform gyrus (visual processing of foods), the insula and frontal operculum (food taste), the OFC (food reward), amygdala (food relevance), and striatum (food reward). These brain areas largely overlap with the ventral reward pathway during actual food consumption, supporting the notion that the processing of food cues is grounded in actual experiences of consuming foods. From the grounded perspective, these brain areas can be viewed as simulating the likely experience of what it would be like to consume the cued food across the visual, gustatory, and somatomotor modalities, and how rewarding it would be to do so.

The evidence for the dorsal regulatory pathway mainly comes from studies on eating disorders and on studies that focus on the health (regulatory) implications of consuming food (in contrast to the reward/hedonic value on the food). In Siep et al. (2012), for example, when participants were asked to suppress thoughts about food palatability and food craving, they showed decreased activity in the ventral reward pathway (e.g. ventral striatum) and increased activity in regulatory areas (e.g. anterior prefrontal cortex (PFC), dlPFC). Similarly, higher activity in the dorsal pathway, (e.g. dlPFC, dorsal ACC, inferior frontal cortex) occurred when participants were asked to regulate their personally-craved foods (Giuliani, Mann, Tomiyama, & Berkman, 2014). Hare, Malmaud, and Rangel (2011) further demonstrated the neural consequences of focusing on long-term health. When participants received exogenous cues that directed attention to food healthiness, they made healthier food choices. Furthermore, when cues associated with healthy eating goals were present, activations in ventral medial PFC (vmPFC) became more strongly correlated with food healthiness (relative to when no eating goal was primed). One interpretation of this finding is that vmPFC represents healthy eating goals that can override eating impulses in the ventral reward pathway. Hare et al. further found that dlPFC modulated these vmPFC activations, suggesting that exogenous cues activate cognitive control areas of dlPFC, which in turn activate healthy eating goals in vmPFC, thereby reducing hedonic impulses. In a related experiment, Hollmann et al. (2012) asked participants to think of negative long-term health-related goals and the social consequences of eating high-calorie non-healthy foods. Relative to desiring these foods, thinking about the long-term consequences of consuming them produced stronger responses in brain areas associated with cognitive control and response inhibition (dlPFC, pre-supplementary motor areas, inferior frontal gyrus (IFG), dorsal striatum, bilateral OFC, anterior insula, temporo-parietal junction). In a study by Yokum and Stice (2013), participants were either asked to think about the long-term costs of eating a food vs. the long-term benefits of not eating it. Both strategies increased activation in inhibitory regions (dlPFC, superior frontal gyrus), and reduced activation in vision and attention regions (precuneus, PCC). In Stice et al. (2015), normal weight adults received a seven-week minding health program, in which they practiced using cognitive reappraisal to increase consumption of healthy food and to reduce consumption of high-calorie food. As a result of this training, participants showed greater activations in inhibitory control regions and reduced activations in hedonic regions to high calorie food pictures.

In summary, the literature demonstrates two basic pathways for processing food cues processing: a ventral pathway for food reward processing, and a dorsal pathway for regulatory processing. Information from the two pathways can be integrated to produce an overall approach “to eat” or avoidance tendency “not to eat” toward the anticipated food.

1.2.4. Enhanced activations in (part of) the ventral reward pathway for high-calorie food cues. High-calorie, highly attractive food cues generate especially strong activations in the ventral reward pathway, which may explain why individuals find it difficult to down-regulate their impulses to these foods when encountering them. In a behavioral task, Papies (2013) found that words for unhealthy high-calorie foods produced more elaborate situated eating simulations than did words for healthier foods. Similarly, Papies, Barsalou, and Custers (2012) and Papies, Pronk, Keesman, and Barsalou (2015) showed stronger approach tendencies towards unhealthy foods than towards healthy ones.

Increasing evidence from neuroimaging studies demonstrates stronger neural activity in (part of) the ventral pathway for high-calorie, high-fat, high-sugar junk foods cues, including the striatum (Beaver et al. 2006; Cornier et al., 2007; Goldstone et al., 2009; Passamonti et al., 2009 ; Schur et al., 2009; for review, see van der Laan, de Ridder, Viergever, & Smeets, 2011), the amygdala (Beaver et al. 2006; Goldstone et al., 2009; Passamonti et al., 2009), and the OFC (Goldstone et al., 2009).

To sum up, when individuals encounter high-calorie attractive food cues, stronger activations occur in reward-related regions, which are likely to promote consuming these foods. Because individuals are constantly exposed to high-calorie food cues in the real world, it can be difficult to resist and regulate impulses to them, resulting in over-eating and weight gain.

1.2.5. Altered activations in food networks with increased BMI (body mass index). As Chen et al. (2016) found in their review, and as Brooks, Cedernaes, and Schiöth (2013) found in an earlier meta-analysis, individuals with high BMI (obesity) tend to show increased activations in the ventral reward pathway relative to individuals with lower BMI. Additionally, altered activations (higher in children and lower in adults) in the dorsal regulatory pathway to food cues may also increase with BMI, thereby causing them to overeat when exposed to foods cues, further leading to energy imbalance, and ultimately to overweight and obesity.

1.2.6. Enhanced activations in (part of) the ventral reward pathway when hungry. When hungry, participants find food cues more rewarding and salient (e.g. Papies et al., 2014), direct enhanced attention to food cues (Stockburger, Weike, Hamm, & Schupp, 2008; Stockburger, Schmälzle, Flaisch, Bublatzky, & Schupp, 2009), and show stronger activations in the ventral reward pathway (e,g., amygdala, OFC), especially for high-calorie cues (Goldstone et al., 2009; for a review, see Chen et al., 2016; for a meta-analysis on neuroimaging studies, see van der Laan et al., 2011).

1.3. Interventions designed to moderate food cue processing

As described earlier, the fundamental cause of obesity is energy intake in excess of energy expenditure. Therefore, in order to maintain or lose weight, more and more people are chronically dieting to reduce the energy intake (Weiss, Galuska, Khan, & Serdula, 2006). Dieting, however, is notoriously unsuccessful in the current obesogenic environment of our culture (e.g., Mann et al., 2007). Healthy eating and dieting intentions typically have little long-term impact, especially when ubiquitous food cues produce strong impulses that override healthy eating intentions (Marteau, Hollands, & Fletcher, 2012; Papies & Hamstra, 2010; Stroebe, van Koningsbruggen, Papies, & Aarts, 2013). For example, despite their dieting intentions, chronic dieters often make unhealthy food choices (Papies, 2012). Longitudinal studies on preadolescents and adolescents show that during three years of follow-up, dieters gained more weight than non-dieters (Field et al., 2003). Furthermore, dieting is thought to make dieters vulnerable to disinhibition, and consequently, to overeating and binge eating (Polivy & Herman, 1985).

Another way to maintain or lose weight is to increase physical activity or to increase energy expenditure. Systematic review, however, shows no consistent results between increased physical activity and weight change. Furthermore, adhering to a prescribed exercise program for maintaining one's weight can be quite difficult for many individuals

(Fogelholm & Kukkonen-Harjula, 2000). A systematic review on weight loss maintenance demonstrated considerable difficulty in weight management through healthy eating and increased physical activity, given that they require constant cognitive effort, which leads to cognitive fatigue and finally to weight regain (Greaves, Poltawski, Garside, & Briscoe, 2017).

Important advances have been made in developing interventions to promote healthier eating behavior, including health education and the availability of healthy options (Glanz, Rimer, & Viswannath, 2008; Gortmaker et al., 2011; Marteau et al., 2012). Nevertheless, health education and healthy options alone often do not suffice for preventing unhealthy eating behaviors, given the difficulty people have controlling their impulses to attractive food cues. Thus, it has recently been suggested that lifestyle interventions for healthy eating should target the underlying impulsive reactions to unhealthy foods that contribute to obesity (Marteau et al., 2012; Sheeran, Gollwitzer, & Bargh, 2013).

1.4. Mindfulness interventions relevant to food cue processing

Mindfulness offers a promising intervention that is well-suited for targeting impulsive reactions toward attractive food, where mindfulness is often characterized as present-centered non-evaluative awareness of one’s thought, emotions, and other experiences in the moment (Bishop, 2004). Increasing evidence demonstrates the benefits of mindfulness across different aspects of well-being, including decreased stress, less negative affect, and better coping (Bishop, 2004; Brown & Ryan, 2003; Greeson, 2009; Grossman, Niemann, Schmidt, & Walach, 2004). Mindfulness has been implemented effectively in many clinical interventions (Didonna, 2009) and shows benefits in a variety of populations, including patients experiencing anxiety and depression (Hofmann, Sawyer, Witt, & Oh, 2010) and with eating disorders (Baer, Fischer, & Huss, 2005). Systematic review of mindfulness effects on eating disorders has reported preliminary evidence that supports the effectiveness of mindfulness-based interventions. This particular application of mindfulness suggests that it offers a promising approach worthy of further research, as demonstrated by reductions in eating concern, increased eating awareness, and improvements in emotion regulation (Wanden-Berghe, Sanz-Valero, & Wanden-Berghe, 2010). Another review shows similarly that mindfulness approaches can improve and extend long term health outcomes associated with reduction in overall food consumption, healthier food choices, and practices that slow down the eating process among obese populations (Godsey, 2013).

A significant limitation of this work so far, however, is that mindfulness interventions have tended to be relatively abstract and non-specific, primarily advising practitioners to become more aware of their moment-to-moment eating experiences, which can make it difficult for non-meditators to learn this technique. In addition, mindfulness training in these studies tends to be relatively time-consuming, (e.g. 8-week mindfulness based stress reduction (MBSR), or trainings that can be even longer and more effortful, thereby limiting applicability in large-scale interventions.

Regarding the cognitive mechanisms of mindfulness, Bishop (2004) proposed that attentional awareness and perspective shifting constitute two basic components. Whereas the attentional awareness component focuses on present experience by regulating attention and inhibiting elaborative processing, the perspective shifting component approaches thoughts and reactions with curiosity, openness, and acceptance, observing all reactions without efforts to change them.

The second perspective component is of primary interest here. Typically, when people experience thoughts, they immerse themselves in them, time travelling to an imagined situation. On becoming immersed in a thought, the thought often appears to adopt the quality of seeming subjectively real, as if it were happening in the moment. When seeing a tempting food cue, for example, people may often immerse themselves in rewarding simulations of consuming the respective food via time travel.

When practicing mindfulness, shifting perspective typically refers to no longer being immersed in the thought, simply viewing it as a transitory mental state in the moment. Shifting perspective in this way on the same basic thought blocks time travel by remaining in the moment with the thought. Once the perceiver is no longer "centered" in the thought, the perceiver becomes "decentered", viewing the thought as a passing mental state rather than as a subjectively real experience. As people become skilled at decentering, they increasingly realize that thoughts, feelings, and reactions are transitory patterns of mental activity, rather than as seemingly real experiences.

It is perhaps useful to note that decentering is typically viewed as different from classic emotion regulation processes and also from classic cognitive behavioral therapy. In emotion regulation, a common strategy is to reappraise or reconceptualize a problematic event or stimulus. In cognitive behavioral therapy, attempts are made to replace problematic mental habits with new healthier ones. In contrast, decentering doesn't explicitly attempt to change the initial appraisal of an event or stimulus, nor to change habitual ways of thinking about it (or acting on it). Instead, decentering focuses attention on the appraisals and habits that are present, and simply attempts to watch them arise and dissipate without acting on them. On the one hand, this decreases the chances that these typical appraisals and habits will actually produce behavior. On the other, they create new opportunities for thinking and responding differently, which may come to mind once the original ones dissipate.

1.4.1. Brief mindful attention training on other aspects. Interestingly, a few experiments have demonstrated that very brief mindfulness training (instead of the more typical long-term effortful mindfulness courses) can have surprising effects, suggesting that it is not difficult for non-meditators to learn and adopt the ability to decenter. Rather than having to learn decentering, people may often perform it under various non-meditation circumstances, with meditation practice strengthening what is already a basic cognitive skill.

For example, a brief 12 minute mindfulness training led participants to remember fewer negative words, relative to controls who did not receive mindfulness training (Alberts & Thewissen, 2011). Similarly, a brief 8 minute mindfulness training improved mood after a negative mood induction (Broderick, 2005), and a brief 10 minute mindful training decreased responses to negative events (Singer & Dobson, 2007). Still other experiments have found that a brief mindfulness trainings focused on decentering affected emotion regulation (Erisman & Roemer, 2010) and stereotype biases in labeling actions (Tincher, Lebois, & Barsalou, 2016).

1.4.2. Brief mindful attention training on food cue processing. Most relevant to the work proposed here, recent work has reported that a brief 12-minute mindfulness training can reduce approach impulses toward attractive food cues. In Papies et al. (2012), participants in the mindful attention condition (with no prior training in mindfulness or meditation) were taught to decenter from food (and other) pictures during an initial training period. As these participants viewed pictures of tasty foods (and other affective stimuli) on the computer, they were asked to mindfully attend to any anticipatory thoughts that arose about consuming these foods, and to simply view them as passing mental states. Thus, participants observed their mental reactions to the pictures, watching them arise and disappear, while being aware of their transitory nature, without judging or suppressing them. In various control groups, other participants were asked to immerse themselves in the pictures or to simply view them.

Following the initial training period, participants in both groups were asked to perform a second task in which they made implicit approach-avoidance responses to attractive and neutral food items. When a picture appeared in a blue (purple) frame, participants pressed a key to make the food move toward (away) from them (in one counter-balancing). The speed of participants' responses toward the food cues served as a measure of approach toward them. With attractive food stimuli, approach responses typically speed up and avoid responses typically slow down. With neutral food stimuli, no such difference occur. As expected, control participants exhibited strong implicit approach impulses towards tasty food pictures (i.e., because the natural response to a food cue is to immerse oneself in a simulation of eating it). In contrast, the 12 minute mindful attention training eliminated the spontaneous approach response to the attractive food stimuli, with approach and avoidance responses no longer differing. Additional experiments demonstrated that effects of the brief mindful attention training effects were maintained over a 5-minute distraction period, and that they affected explicit judgments of food attractiveness as well. These initial findings suggest that mindful attention offers a potentially powerful and efficient method for helping non-meditators regulate their impulses to attractive food cues.

Following the same procedure for brief mindful attention training and immersion instructions and for approach-avoidance task, Baquedano et al. (2017) observed decreased salivation during exposure to food cues, as well as decreased automatic food bias towards tasty unhealthy food cues, in both meditators and participants with no meditation experiences before. In meditators, Papies, van Winckel, and Keesman (2016) founded that more food-specific decentering experiences in one’s past were associated with fewer food cravings in daily life, suggesting that decentered thoughts about foods can decrease food cravings.

Subsequent experiments have replicated these effects of brief mindful attention training on food responses. In Marchiori and Papies (2014), participants were either asked to listen to an audio book (control group) or to perform a body scan (i.e., a mindfulness exercise that guides attention to different parts of the body, simply observing the sensations in each body part in an open and nonjudgmental way). Participants were then allowed to eat chocolate chip cookies freely as they wished. Results showed that the control group ate more unhealthy food when hungry than when not hungry and that the mindfulness group did not, demonstrating that brief mindful training reduces unhealthy eating when hungry.

Similarly in Papies, Pronk, Keesman, and Barsalou (2015), hunger especially motivated participants toward unhealthy food items in the control group, with this effect being eliminated after applying mindfulness training, with preferences shifting slightly toward healthy foods. Additionally, a field experiment in a cafeteria found that brief mindful attention training resulted in healthier food choices when participants were unaware that their food choices were being observed. Participants who had earlier performed a brief mindful attention exercise were less likely to choose an unhealthy snack and more likely to choose a salad from the lunch buffet than were control participants. These two experiments again demonstrate that brief mindful attention training on non-meditators can help them regulate their impulses to attractive foods and make healthier food choices.

Fisher, Lattimore, and Malinowski (2016) also observed that brief mindful attention training reduced the amount of unhealthy food intake. In this experiment, compared to participants who were asked to direct their attention to the hedonic properties of food, participants who followed a mindful attention induction ate significant fewer cookies 10 min after the food-cue exposure, although they did not differ in appetitive and craving measures.

In summary, from the grounded perspective, when participants process food cues, they tend to automatically simulate possible experiences of eating the cued foods (e.g. the taste of the food, how rewarding it is to consume, etc.). After practicing the mindful attention perspective, however, participants often appear to simply view these simulations as transitory mental states in the moment instead of as subjectively real experiences, thereby becoming "decentered" from these simulations. As this growing literature shows, brief mindful attention training can reduce impulses to foods, decrease the actual food consumption, and promote healthy eating (Keesman, Aarts, Häfner, & Papies, 2017).

1.4.3. Neural mechanisms that underlie brief mindful attention training in emotion regulation and smoking. Recently, research has begun to explore the neural mechanisms that underlie brief mindful attention training in emotion regulation and the perception of stress. No work thus far, however, has assessed the neural mechanisms that underlie mindfulness benefits for healthy eating. In Lutz et al. (2014), applying mindful awareness, (remaining non-judgmental, and being open to experience) during anticipation of negative pictures was associated with greater emotion regulation (increased activity in dorsal mPFC, dlPFC), and with decreased emotional responses (decreased activity in the amygdala and parahippocampal gyrus), compared to a control group. When participants were asked to apply mindful attention and view the experiences as passing mental events while recalling negative autobiographical memories, Kross, Davidson, Weber, and Ochsner (2009) observed decreased neural activity in regions associated with self-referential, emotional, and visceral state integration (e.g., mPFC, subgenual anterior cingulate cortex (sgACC)), relative to a ruminative condition. Moreover, self-reported negative affect was significantly correlated with activity in mPFC and sgACC, while decreasing with mindful attention. When smokers were asked to maintain a non-judgmental attitude towards subjective responses to smoking pictures, Westbrook et al. (2013) found decreased brain activity in subgenual anterior cingulate cortex (sgACC) compared to passive viewing, but did not observe any increased activations. Furthermore, using psychophysiological interaction analysis (PPI), they found functional decoupling between sgACC and other craving-related regions (e.g. insula, ventral striatum) during mindful attending to the smoking pictures, indicating a ‘bottom-up’ attention to internal experiences.

1.5. Assessing the neural mechanisms that underlie a brief mindfulness intervention for stress processing

Lebois et al. (2015) investigated the neural mechanisms underlying mindful attention effects on the processing of stressful events. The experiment presented here closely followed the approach taken by Lebois et al. (2015) and similarly assumed that a brief mindfulness intervention has significant effects on neural activity. Whereas their experiment focused on stress, however, the current experiment focused on food cues. Because the current methods and analyses followed those in Lebois et al. closely, their experiment is described in some detail next.

1.5.1. Summary of Lebois et al.'s (2015) methods. The critical fMRI scanning session of their experiment was a complete repeated-measures design, with three independent variables: perspective (mindful attention vs. immersion) X situation (stressful vs. non-stressful) X period (reading vs. perspective). Prior to the scanning session, 30 participants underwent extensive training outside the scanner over the course of two days. First, participants learned the immersion perspective, in which they were asked to practice becoming completely absorbed and immersed in the experience of the scenarios, mentally time travelling to the situations and experiencing sensory details, physical sensations, feelings, emotions and bodily states as if they were really happening at the moment.

Second, participants learned to perform the complete trials and catch trials that would later occur in the scanner, and then practiced a few trials to become familiar with the two kinds of randomly intermixed trials. The complete trials included a reading period to read and comprehend the presented situation (either stressful or non-stressful), a perspective period to adopt an assigned perspective (either the immersion or mindful attention perspective), and a rating period to rate how well the perspective was applied to the current block of events. The catch trials only included the reading period.

Third, participants learned the active baseline task for the experiment (detecting a visual target on the left or the right of a sentence). At a randomly jittered interval, the word "left" or "right" appeared somewhere superimposed over the sentence, "Find the cue and then get ready to press the direction indicated by it." Participants pressed a button to make a response.

An active baseline task was deemed more appropriate than a resting state baseline for two reasons. First, a resting state baseline would likely produce mind wandering, which is associated with self-related thought (e.g., Mason et al., 2007). Because self-related thought is central to stress (e.g., Dedovic, D'Aguiar, & Pruessner, 2009; Dickerson & Kemeny, 2004), using a resting state baseline would have removed potentially interesting activations associated with self-related thoughts relevant to stress. Second, Lebois et al. wanted the baseline to contain comparable processes to those in the critical reading and strategy periods that were not of interest, so that they could be subtracted out with the baseline. Thus the active baseline task contained visual, decision making, and response components similar to those in reading and strategy periods that were not of interest. Subtracting the baseline should leave processes of interest associated with perspectives and stress not relevant for the active baseline task.

Fourth, participants learned the key concepts of the mindful attention perspective, with instructions adapted from previous experiments (Papies et al., 2012; Papies et al., 2015). For this perspective, participants were asked to remain aware of their current physical location as they were reading and imagining the scenarios. Similarly, they were asked to notice the diverse cognitive, affective, and bodily responses that they experienced in response to the stressful and non-stressful situations, and to simply observe these responses and view them as transitory mental states. Participants then practiced a run to familiarize themselves with the perspective.

Finally, in the critical scanning session, participants performed the immersion and mindful attention perspective in different blocks, where the blocks contained either stressful or non-stressful events only. At the start of each block, a perspective was assigned (immersion or mindful attention) and participants then performed it on several events. For both complete and catch trials, participants first read and understood a situation (i.e., reading period), and then (on complete trials) were asked to practice the currently assigned perspective on the situation (i.e., perspective period) and rate how well they were able to do so. For both catch and complete trials, participants then performed the active baseline task for a randomly jittered interval. For each of six runs, one mindful attention block and one immersion block were included. Within each block, one mini-block of 5 stressful events (4 complete trials and 1 catch trial) and one mini-block of 5 non-stressful events (4 complete trials and 1 catch trial) were presented.

1.5.2. Summary of Lebois et al.'s (2015) results. During mindful attention to stressful situations, participants showed much more unique neural activity above baseline during the reading period than during the perspective period (Figures 3 and 4 in Lebois et al., 2015). As participants initially processed stressful situations, the mindful attention perspective activated much more of the brain than did the immersion perspective, including the visual, sensorimotor, and limbic networks, and to lesser extents, the dorsal attention and default mode networks (DMN). During the subsequent perspective period, when participants applied the mindful attention perspective to stressful situations, the activations in these areas decreased substantially, suggesting that initial processing during the reading phase had "decentered" participants from the situations. Notably, this effect only occurred for stressful situations, not for non-stressful ones, which showed the reverse pattern (greater activation during the strategy phase than during the reading phase).

Thus, the striking result from this experiment was that the stressful situations immediately engaged much more activity all over the brain than did the non-stressful situations. Analogous to effects of motivation in Papies et al. (2015), mindful attention processing became much more engaged with stressful situations than with non-stressful situations, perhaps because there was so much more affective material to process, relative to non-stressful situations. As people applied the mindful attention perspective to stressful situations, they appeared to generate and process the more intense thoughts and emotions associated with them. Conversely, the non-stressful situations did not induce similar processing reactions during the reading period.

Notably, the immersion perspective exhibited the opposite pattern, exhibiting much more unique neural activity during the perspective period than during the reading period, for both stressful and non-stressful situations (across the sensorimotor, limbic, default mode, and ventral attention networks). Relative to an active baseline, mindful attention down-regulated the processing of stressful events over time from the reading period to the perspective period, whereas immersion up-regulated processing over time.

Additionally, direct comparisons between mindful attention and immersion during the perspective period showed that mindful attention increased activity in brain regions associated with perspective shifting and effortful attention (e.g. angular gyrus, lateral PFC, medial PFC), whereas immersion increased activations in areas associated with self-processing and visceral states (e.g. subgenual cingulate cortex, ventral ACC, ventromedial PFC, medial OFC). These results suggest that mindful attention produced decentering by engaging regulatory resources that disengaged self-related, emotional and visceral states from imagined situations.

1.6. Experiment overview and hypotheses

1.6.1. Experiment goals. As just mentioned, a few behavioral studies have demonstrated that brief mindful attention training in non-meditators can help regulate impulses to unhealthy foods and produce healthier food choices both in the laboratory and in the field. No work so far, however, has assessed the neural mechanisms that underlie brief mindfulness training for food cues. Therefore, the primary purpose of this experiment was to establish the neural mechanisms that underlie the decentering component of mindful attention as people process foods. Better understanding these mechanisms will help us to develop effective interventions for regulating impulses to consume attractive foods, thereby better regulating weight.

The current experiment had four aims. First, consistent with the grounded cognition perspective reviewed above, we wanted to replicate previous findings showing that food cues activate the same brain areas as eating (Aim 1). Specifically, we assumed that these activations would fall within both the ventral reward and dorsal control pathways that have previously been found important for food cue processing (Chen et al., 2016). We also expected to see areas associated with action and embodiment activated as well, following the grounded cognition perspective, as people simulate eating behaviors. Finally, we predicted that foods would activate the cortical midline (in the default mode network), perhaps to represent self-relevance and other forms of mentalizing about foods. Using an active baseline enabled this assessment, given that it was unlikely to activate the cortical midline.

Second, we wanted to assess whether we could replicate the early vs. late effects of mindful attention on food cue processing, analogous to the pattern that Lebois et al. (2015) observed for stressful events (Aim 2). Specifically, we wanted to assess whether the mindful attention perspective recruits much more processing throughout the brain initially when first applied to food cues, relative to a normal viewing control condition (Aim 2a). Conversely, and also analogous to Lebois et al. (2015), we wanted to assess whether activations during a subsequent food choice phase were much less for the observe perspective than for the normal viewing control condition (Aim 2b). Combining Aims 2a and 2b, we wanted to assess whether a cross-over interaction occurs for food cues between perspective (normal viewing, observe) and phase (training, choice), in terms of total brain activity, analogous to the cross-over interaction in Lebois et al. (2015) for stressful events.

Third, motivated by findings in previous experiments (e.g., Lebois et al., 2015; Papies et al., 2015), we wanted to assess whether the mindful attention perspective has its strongest effects on tasty foods relative to healthy foods (Aim 3). Specifically, we wanted to assess whether the initial increase in neural activation for the mindful attention strategy was larger for tasty foods than for healthy foods (Aim 3a), and conversely, whether the decrease in activation from initial training to subsequent food choice was larger for tasty foods than for healthy foods (Aim 3b).

Fourth, we wanted to explore whether the mindful attention perspective, once learned during the training phase, would be applied spontaneously during the later food choice task, when participants were not asked explicitly to adopt the perspective (and were led to believe that it was no longer relevant; Aim 4). If participants did apply the mindful attention perspective spontaneously, we further wanted to assess whether it is implemented as a general cognitive set (Aim 4a) or is instead implemented via food-specific training memories (Aim 4b). Papies et al. (2012, Experiment 3) found evidence for a general cognitive set, with the mindful attention being applied to both repeated and novel test stimuli. At the same time, many theories predict that memories should be established during training with specific foods that later become active implicitly during the food choice task (e.g., Barsalou, 2016; Jacoby 1983; Reber, 2013). If so, then the trained foods should exhibit the mindful attention perspective but not novel foods.

1.6.2. Experiment overview. In this experiment, hungry participants were randomly assigned to one of two perspective groups: the observe group or the normal viewing group (20 participants in each, for a total of 40 participants). Because participants assigned to the mindful attention perspective were told that they were learning the “observe perspective,” we will refer it this way for the remainder of this experiment (and also because this description captures the “observe” process that participants were taught to perform on their responses to food cues).

Unlike Lebois et al. (2015), each participant only performed one perspective in a between-group design (i.e., not the repeated-measures design used previously). Lebois et al. (2015) found considerable regulatory processing during their immersion task, suggesting that combining it with mindful attention pre-empted the simple natural processing that people perform normally. To ensure that participants here in the normal viewing condition adopted their normal perspective on foods, we did not ask them to constantly switch between this perspective and the observe perspective, but to only perform the natural viewing perspective alone for the entire experiment.

In a brief preliminary training period outside the scanner, participants in the observe group were introduced to the perspective for disengaging and decentering from presented food pictures, whereas participants in the normal viewing group practiced looking at the same pictures in the manner that they normally do. The instructions for learning the two perspectives were closely matched. Participants then practiced a few trials to become familiar and comfortable with adopting their assigned perspective. Minimal practice with each perspective occurred outside the scanner, so that we could observe the neural activity associated with learning the perspective in the scanner, something not attempted in previous experiments.

Subsequently, participants entered the scanner where they completed two tasks. First, in the main training phase, participants were asked to adopt their learned perspective (either normal viewing or observe) while they viewed tasty food images, healthy food images and scrambled non-food objects as control stimuli. Figure 1A illustrates the procedure of the training phase (explained fully in the Methods). The tasty and healthy food images were closely matched except for a few characteristics on which they naturally differ. The scrambled images were used for the active baseline task, described further shortly.

Second, in the food choice phase, all participants received food pictures and judged whether or not they would like to eat each one at the moment. Figure 1B illustrates the procedure of the choice phase (again explained fully in the Methods). Participants were induced to view this as a second task that assessed neural activations to foods that were of interest to the experimenters, unrelated to the first task. Participants were not instructed to adopt their earlier perspective, and nothing was said about it. Of primary interest was whether participants in observe group spontaneously adopted their learned perspective, and whether it had effects on neural activity during food choice trials (see 1.6.4 for the specific predictions).

Following the scanning session, participants provided data on a variety of individual differences measures, including BMI, hunger before and after the scan, eating restraint, healthy eating, decentering, self-control, food consumption frequency, and food attractiveness. As reviewed in Chen et al. (2016), BMI, hunger, and other measures often have effects on neural activations to food cues. For this reason, these variables were treated as covariates to be controlled in both the behavioral and neuroimaging analyses.

1.6.3. Methodological similarities and differences with Lebois et al. (2015). Because this experiment closely followed the approach taken by Lebois et al. (2015), there were many methodological similarities, which are addressed first, followed by differences.

1.6.3.1. The observe perspective. Similar to Lebois et al., we contrasted a group who received brief mindful attention training (the "observe" perspective) with a group who adopted a normal viewing perspective (the "normal viewing" perspective). The key strategy underlying the "observe perspective" was essentially the same as the mindful attention perspective in Lebois et al. (2015) (which was actually called the "observe strategy" for participants, with nothing ever said about mindful attention, mindfulness, decentering, etc.). This perspective in both experiments emphasized observing one's thoughts, emotions, and bodily responses to stimuli that arise and dissipate, seeing these responses as fleeting states of mind, and just observing them as they come and go.

1.6.3.2. Active baseline tasks. Also similar to Lebois et al., active baseline tasks were implemented during both the training phase and the choice phase for several reasons. First, we didn't want the baseline task to remove potential activations of interest, especially along the cortical midline. Because self-identity appears highly important for the foods that people choose to eat (e.g., Dean, Raats, & Shepherd, 2012; Fox & Ward, 2008; Hackel, Coppin, Wohl, & Van Bavel, 2018; McCarthy, Collins, Flaherty, & McCarthy, 2017; Michaelidou & Hassan, 2008; Strachan & Brawley, 2009), we wanted to assess whether foods activate brain areas along the cortical midline associated with self-identity (e.g., Mason et al., 2007; Northoff & Bermpohl, 2004; Northoff et al., 2006; Qin & Northoff, 2011; Whitfield-Gabrieli et al., 2011). If we had used a resting state baseline, it would have probably removed many of these activations. By using an active baseline unlikely to activate the cortical midline, we not only made it possible to assess self-identity activations to food cues, but to see whether they varied as a function of observe vs. normal viewing perspectives, tasty vs. healthy foods, and training vs. choice phases. Because previous research on food cues has not explicitly addressed self-identity activations along the cortical midline, we wanted to do so here, with the active baselines in both the training and choice phases making this possible.

A second reason for not using a resting state baseline is that observe participants might continue practicing the observe perspective during baseline periods. As a consequence, establishing activations to foods relative to the baseline would remove activations associated with the observe perspective. Again, an active baseline should shift processing away from the observe perspective, such that we can detect activations for this perspective during food trials.

A third reason for using active baselines is that they allowed us to remove activations for processes that were not of interest for establishing differences in neural activation between the observe vs. normal viewing perspectives, tasty vs. healthy foods, and training vs. choice phases. In particular, we were not interested in activations associated with low-level visual processing, choice cognition, or manual responses. By designing a baseline that engaged these processes, we removed them from activations of interest in the critical manipulations. Thus, for both the training phase and the choice phase, we constructed baseline tasks that were comparable to the critical tasks in low-level processing of visual images, cognitive evaluation and choice, and manual behavior. As a result, activations for these kinds of processes should not be observed.

1.6.3.3. Scrambled non-food object images in the active baseline tasks. In designing active baseline tasks, a critical decision was what kind of stimuli to use. We opted for scrambled images of non-food objects for several reasons. First, images of intact (non-scrambled) non-food objects would have produced activations associated with semantics and self-relevance along the cortical midline (e.g., Binder, Desai, Graves, & Conant, 2009; Binder, 2016; Fernandino et al., 2016), and also activations in areas associated with embodied action (e.g., Chao & Martin, 2000; Lewis, 2006; Martin, 2016), with both kinds of processes potentially important for foods. Because we wanted to establish the full range of brain areas associated with processing food cues (something that hasn't been attempted previously), we wanted to use active baselines that didn't remove these kinds of activations. By using images of scrambled objects, we didn't remove activations associated with high-level visual processing, self-identity, and embodied action. Perhaps more importantly, we wanted to investigate how observe vs. normal viewing perspectives, tasty vs. healthy foods, and training vs. choice phases all affected these activations. If we had used non-food objects as stimuli in the active baseline tasks, it would have become more difficult and complicated to assess the differential effects of these manipulations.

Additionally, we decided not to use scrambled images of foods, because the color profiles of these images activate food processing areas in the brain (Simmons et al., 2005).

Instead, we used scrambled images of non-food objects, so that food areas would not become active. Figures 1A and 1B illustrate the active baseline stimuli and tasks used in the training phase and the choice phase respectively.

1.6.3.4. Breadth of activations above the active baseline. A final similarity between Lebois et al. (2015) and our experiment is that we both focused on the breadth of the activations above baseline, rather than on linear contrasts in intensity between different conditions. In Lebois et al., major differences emerged between these two measures, with the breadth of activation above baseline being much more informative. Often differences existed in the breadth of activation between conditions, when linear contrasts in intensity revealed no differences. In analyses that we do not report here, we observed a similar difference between activation breadth and intensity.

Figure 2 illustrates the underlying issues associated with these two measures. In each panel, BOLD activation (the Y axis) is assessed along a one-dimensional row of spatially-contiguous (green) voxels for two conditions (C1 and C2). Thresholds are shown for activation above baseline (the dashed red line) and for contrast differences in intensity (the red bracket). To the right, significant activations for the two conditions are depicted in two spatial dimensions, showing the original row of green voxels across the middle. Activation breadth above baseline is shown in the third column, and differences in contrast intensity are shown in the fourth column.

Panel A of Figure 2 illustrates how focusing on linear contrasts in intensity can miss significant activations above baseline. Panel B provides an example of how a significant contrast can miss additional activations above baseline that may be of interest. Panels C and D provide examples of how clusters can emerge from contrasts in intensity, even when the more active condition is not significantly active above baseline, or even lies below baseline, respectively. As the examples in this figure demonstrate, areas relevant for a task may be active above baseline but not differ in intensity, and linear contrasts between conditions often miss activations important for a task. Most significantly, important differences between conditions in breadth may exist where differences in intensity do not. Because, Lebois et al. (2015) observed this pattern (and also Lebois, Wilson-Mendenhall, Simmons, Barrett, & Barsalou, 2018), we decided to focus on breadth of activation, here, and also because it offered an effective approach for addressing our experimental aims (1.6.1).

1.6.3.5. Departures from Lebois et al. (2015). Finally, we turn to differences between Lebois et al. (2015) and our experiment here. These two experiments differed in three main respects. First, we assessed the effects of mindful attention intervention on foods, rather than on stress. Second, the perspective for the control condition differed across the two experiments. Whereas Lebois et al. (2015) compared the observe perspective with an immersion perspective, we compared the observe perspective with a normal viewing perspective. As described earlier, the normal viewing perspective should implement how people interact with food naturally, without engaging atypical regulatory processing. Third, our experiment manipulated perspectives between groups, rather than within participants, as in Lebois et al. (2015). As described earlier, Lebois et al. found that shifting between two perspectives required considerable use of frontal executive processes. We believed that a between-group manipulation would minimize any possible and unnecessary regulatory processing and so switched from a repeated measures design to a group design.

1.6.4. Hypotheses. The specific hypotheses for the experiment originate from our aims in 1.6.1, coupled with our experimental design in 1.6.2 and 1.6.3. As described in 1.6.3.4, all hypotheses will be assessed using activation breadth above the active baseline.

Hypothesis 1. From the perspective of grounded cognition, when people encounter a food cue, they simulate the taste and reward associated with consuming the food, which, in turn, can motivate consumption (Papies & Barsalou, 2015). Because these simulations can be so realistic and compelling, they motivate approach tendencies towards the respective foods, even when someone is not hungry or has dieting intentions. Following Aim 1, we predicted that food cues would activate the same general brain areas associated with eating, as reviewed in Chen et al. (2016). Specifically, food images should activate areas in the ventral reward pathway, such as the insula (primary taste area), OFC (predicted reward), amygdala (attentional salience), as well as the areas in the dorsal control pathway, including the lateral frontal cortex and medial pre-frontal cortex. Furthermore, food images should activate areas associated with action and embodiment, including areas in pre-central and post-central gyrus, basal ganglia, and cerebellum. Finally, we predicted that food images would activate the cortical midline as it processes self-relevance of the respective foods.

A related prediction was that all these activations should tend to be stronger for tasty foods than for healthy ones (Chen et al., 2016; van der Laan et al., 2011). Although one might expect tasty foods to primarily activate areas in the ventral reward pathway more than do healthy foods, we also expected greater activations in all brain areas related to eating, including areas for embodied action, self-relevance, and self-regulation. Furthermore, when participants are in hunger state (as ours were), hunger enhances attention and a variety of other processes (Chen et al., 2016).

Hypothesis 2. Following Aim 2, and as found in Lebois et al. (2015), we predicted a cross-over interaction between perspective and phase in overall brian activation. According to Hypothesis 2a, the observe perspective should recruit more neural resources during the training phase, relative to the normal viewing perspective, as participants applied the observe perspective to each food. Conversely, according to Hypothesis 2b, the observe perspective should recruit much fewer neural processing resources during the choice phase than the normal viewing perspective, as effects of performing the observe perspective on the foods during training manifested themselves. Additionally, we predicted that these effects would occur across brain areas in the ventral reward, dorsal control pathway, and other brain regions as demonstrated for Hypothesis 1. Because observe processing potentially affects all aspects of experiencing eating simulations, all these areas could exhibit increases during training, followed by decreases during choice.

Hypothesis 3. Papies et al. (2015) and Lebois et al. (2015) both found that mindful attention exhibited stronger effects on tasty foods and stressful situations, respectively, than on healthy foods and non-stressful situations. Both proposed that mindful attention has more psychological content on which to operate for highly affective stimuli, relative to less affective ones. As the amount of affective content in a psychological state increased, mindful attention had more content to observe as this content became active and dissipated. As a result, highly affective stimuli exhibited the greatest effects of mindful attention.

Based on these previous results and Aim 3, we predicted that the interaction in Hypothesis 2 would be stronger for tasty foods than for healthy foods. Specifically, we predicted that the increase for the observe perspective during the training phase would be larger for tasty foods than for healthy foods. Conversely, we predicted that the decrease for the observe perspective during the choice phase would be larger for tasty foods than for healthy foods.

Hypothesis 4. Because Papies et al. (2012, Experiment 3) found that mindful attention training generalized modestly to new stimuli, we predicted that mindful attention training would be extended to novel non-trained foods, suggesting that mindful attention induces a general cognitive set. Specifically, we predicted that, for the choice phase, the novel food stimuli would exhibit a decrease in neural activation similar to repeated foods.

Based on large literatures that demonstrate diverse implicit memory effects (e.g., Barsalou, 2016; Jacoby 1983; Reber, 2013), however, we also predicted that, in parallel, we would observe effects of repeating foods. During the choice phase, repeated foods should be processed faster with less activation than novel foods, demonstrating that memories from the training phase were affecting choice processing. We also predicted that the decreased processing expected for the observe perspective on choice trials (relative to training) would be larger for repeated foods than for novel foods.

2. Methods

2.1. Design

After being randomly assigned into two groups for the observe and normal viewing perspectives, participants received brief initial training outside the scanner, followed by two fMRI tasks in the scanner: (1) a training task, (2) a food choice task. The mixed design for the training task consisted of the following variables: perspective (observe, normal viewing) x food type (tasty, healthy), with perspective as a group variable and food type as the within-participant variable. Thus, the participants in each group received tasty food images as well as healthy food images. The training task used a blocked design, with each group receiving 6 blocks of tasty foods, 6 blocks of healthy foods, and 12 blocks of color warmth task (serving as an active baseline; see section 2.4.1 for details).

The mixed design for the food choice task consisted of three variables: perspective (observe, normal viewing) x food type (tasty, healthy) x repetition (repeated, novel). Thus, participants in each group received tasty food images and healthy food images, half of each food type being repeated (received during the training phase) and the other half being novel (not received during the training phase). The choice phase used a fast event-related design, with the tasty and healthy foods images presented randomly and mixed with a jittered active baseline task (see section 2.4.5 for details). For both the training and choice phases, an active baseline was used instead of a resting state baseline, which was deemed more appropriate in this experiment (1.6.3.2).

Individual difference measures constituted a final set of variables in the design, including measures of BMI, hunger before and after the scan, food consumption frequency, food attractiveness, health orientation, trait restrained eating, trait self-control, and trait decentering.

2.2. Participants

Forty-three right-handed, fluent English speakers with normal hearing and normal or corrected vision were recruited from the University of Glasgow community in Scotland. Three participants were excluded from data analysis because of extreme head motion in the scanner, or equipment failure while recording behavioral responses in the scanner. All participants were randomly assigned to either the observe or normal viewing group. Twenty participants in each group were included in the final experiment. Based on previous experiments using between group designs (e.g., for obesity vs. controls, for anorexics vs. controls), these samples had more than enough power to detect the effects of interest.

All participants were women with a median age of 21.5. Typical scanning exclusion criteria were applied. All participants were right-handed, had no metal implants in their bodies, and were not claustrophobic. No participant had an eating disorder or any other kind of disorder, was taking psychotropic medication, or had experienced significant head injury associated with loss of consciousness. Additionally, participants who had meditation experience were also excluded, given that we wanted to examine the mechanisms underlying mindful attention in non-meditators.

Because BMI is an influential factor that moderates brain activity to food cues as reviewed earlier, participants with a wide range of BMI were included in the experiment. The average BMI for all participants was 23.32, ranging from 17.37 to 36.57. There was no significant difference between two groups (normal viewing: M = 23.60, SD = 4.38; observe: M = 23.03, SD = 4.49, $t(38) = 0.405$, SE = 1.40, $p = 0.688$).

All participants were asked to restrain from eating for at least for 3 hours before the experiment, given that hunger modulates neural responses to food cues considerably (as described earlier), especially in the ventral reward pathway (for reviews, see Chen et al., 2016 ; van der Laan et al., 2011). The average time since last eating for all participants was 8.5 hours, ranging from 3 hours to 15.5 hours (given that most participants were run mid-morning). There was no significant difference between two groups in hours since last eating (normal viewing: M = 7.93, SD = 4.83; observe: M = 9.15, SD = 4.54, $t(38) = -0.83$, SE = 1.48, $p = 0.361$).

2.3. Materials

2.3.1. The training phase. The training phase in the scanner included 30 tasty food images, 30 healthy food images, and 60 scrambled object images as control stimuli (Figures A1 and A2 in Appendix A present the food images). All images were selected from a large database of color photographs (Blechert, Meule, Busch, & Ohla, 2014) to make the food cues as realistic and compelling as possible (especially so that the foods would elicit eating simulations). An additional criterion for the selected food images was that all the pictured foods were ready to eat (i.e., no uncooked meats, unpeeled fruits and vegetables, foods in packages were included). All the food images were selected to be familiar and suitable for the general Scottish population. Both the tasty and healthy food images included savory and sweet foods. Foods in each group were also selected to include as many food types as possible (e.g. whole meals, snacks, desserts).

Blechert, Meule, Busch, and Ohla (2014) provide rich information about the food images in their database. We have used this information to establish images statistics for the food images sampled. Because we only included women in our experiment, and because they did not exhibit special dieting habits (e.g., vegetarian), the ratings for omnivore women in the database were used for the statistics.

Between tasty vs. healthy foods, images were matched for basic visual qualities, including object size, brightness, contrast and complexity, norm complexity and spatial frequency. The tasty and healthy food images, however, differed on measures that differ naturally between these two food types. Specifically, tasty food images were redder than healthy food images, whereas healthy food images were greener than tasty unhealthy food pictures. In Appendix B, see Table B2 for further details.

The tasty and healthy images were further matched on cognitive and affective measures for familiarity, valence, complexity, palatability, and craving. Again, however, the tasty and healthy foods differed on another measure that differs naturally. Specifically, tasty food images had higher arousal ratings than healthy food images (see Table B3 for details).

Finally, the tasty and healthy foods were matched for a variety of nutritional variables, including protein, number of units, and grams of the food in the images. Again, however, tasty food images had significant higher values than healthy food pictures for a few properties that naturally vary between the two food types, including fat, carbs, calories in both 100g and the total of the food presented in the image (see Table B1 for details).

The scrambled control stimuli were created by dividing 60 object images from the same database into 100 square sections and then randomizing the locations of squares within three concentric rings around fixation (Epstein & Kanwisher, 1998). The 60 object images had no relation to eating or to foods, thereby minimizing any possible confounding effects (e.g., via color profiles). The scrambled control images were matched as closely as possible with the critical food images for visual properties, object size, brightness, and complexity.

2.3.2. The food choice phase. The food choice phase in the scanner included the 60 images from the training phase (30 tasty and 30 healthy food images) plus 30 new images for each food type, resulting in a total of 60 trained food images and 60 new food images (see Appendix A for the complete set). Each new image was yoked to one trained image, providing another instance of the same food. If, for example, chocolate cake was a trained food, carrot cake served as the new yoked instance. Similarly, if boiled egg was a trained food, fried egg served as the new yoked instance. For both tasty food images and healthy food images, new yoked images and old trained images were matched on all the visual characters, cognitive / affective measures, and nutrient / energy measures (in Appendix B, see Tables B1, B2, and B3 for details).

To create additional control images needed for the new food images, another 60 object images were chosen from the same database and were scrambled and matched as just described for the training phase, resulting in 120 scrambled control images in total.

2.3.3. The pre-scan and post-scan questionnaires. The pre-scan questionnaire included a hunger scale (i.e. "how hungry you are now?"), with values from 1 (not hungry at all) to 7 (very hungry). It also included the question, "When was your last meal?" so that we could calculate the time since last eating. A final open-ended question was asked, "What was your last meal?" to obtain further information about it.

The post-scan questionnaires included a variety of ratings and individual difference measures (see Appendix C for the specific materials). The hunger question was asked again to establish hunger after the experiment. Participants were then asked to judge the frequency and attractiveness for each food image, with the 120 images presented in a different random order for each of the two judgment blocks. For food consumption frequency, participants were asked to judge, "How often do you eat the food shown in the picture?" on a scale that included "x – not recognized, 0 – never, 1 – rarely, 2- sometimes, 3 – often". For food attractiveness, participants were asked to judge, "How attractive do you find the food shown in the picture?" on a scale that ranged from 1 (not at all) to 7 (highly attractive).

Participants then responded to a final set of individual difference measures in the following order. The restraint scale from Dutch eating behavior questionnaire assessed trait restrained eating (van Strien, Frijters, Bergers, & Defares, 1986). Hearty, McCarthy, Kearney, and Gibney's (2007) brief questionnaire assessed participants' attitudes towards healthy eating. The brief trait self-control scale was included to assess participants' trait self-control (Tangney, Baumeister, & Boone, 2004). Papies et al. (2016) food decentering scale assessed participants' awareness of food-related thoughts and their ability to decenter from them. Finally, two open-ended questions asked: "What thoughts did you have during the first task when you were asked to adopt your perspective to pictures?" and "How did you experience your thoughts during the first task when you were asked to adopt your perspective to pictures?" These two questions served to explore how participants experienced their assigned perspective during the training phase. Details for all the individual difference measures can be found in Appendix C.

2.4. Procedure

On initial contact, participants were screened for anything that disqualified them from being scanned. The day before the experiment, the experimenter reminded participants to restrain from eating for at least 3 hr before arriving. On the day of the scan, participants first provided informed consent, indicated their hunger ratings, and provided information about their last meal.

2.4.1. Active baseline task for the training phase. Participants were first told that they would be alternating between two tasks during the first phase of the experiment: the color warmth task (i.e., the active baseline task), and the perspective task (for foods). Participants were told that whenever it was time to perform the color warmth task, they would receive the instruction, "Please judge the average color warmth" (for 3 sec) followed by 5 scrambled object images (5 sec each, followed by a 2 sec blank screen). Following presentation of the fifth picture, participants was asked to rate, "What was the average color warmth of the previous 5 pictures?" from 1 (very cold) to 4 (very warm). Participants practiced a short run for the color warmth task to become familiar with it. Figure 1A summarizes the time course of the active baseline blocks.

2.4.2. Learning the observe or normal viewing perspective. While training participants to adopt either the observe or normal viewing perspective, we included key concepts from the training instructions in our previous research (Lebois et al., 2015; Marchiori & Papies, 2014; Papies et al., 2012; Papies et al., 2015). Appendix D presents the complete instructions for both the observe perspective and normal viewing perspective.

Participants in the observe group were first told that they would view a number of food pictures, and that on seeing each picture, they were likely to experience various kinds of reactions, such as liking or disliking the food, imagining being in the situation, wanting to consume the food in the picture, and so forth. Participants were then asked to consider the character of their thoughts and reactions to these foods, and to try imagining that these thoughts were constructions of their mind that arise and dissipate. Participants were further told that these reactions were not really part of the pictures, but rather what their minds happened to make of them at the moment. Thus, participants were asked to observe their thoughts as transient states of mind.

Participants then practiced the observe perspective on one food image, with the instructions guiding them on how to apply the observe perspective to it. Following this initial practice, the experimenter asked participants whether they had any questions about the observe perspective and how to perform it correctly. Participants then practiced this perspective while viewing a subsequent series of four more food images for further practice, simply observing their thoughts and reactions, without suppressing or avoiding them. All participants had no difficulty adopting the observe perspective before scanning.

Participants in the normal viewing group received instructions that were closely matched with those for the observe group. The amount of text, number of points, and number of practice images were comparable in both sets of instructions. Participants in the normal viewing group were asked to view each food as they normally would when encountering it in the world. These instructions further suggested that participants mentally transport themselves to a situation where they might consume the food. Once in a relevant eating situation, participants were asked to imagine interacting with the food as they usually would, viewing it, eating it, and experiencing it. All the participants had no difficulty adopting the normal viewing perspective. Again, Appendix D presents the complete instructions.

2.4.3. Learning food blocks. After learning their assigned perspective, participants were told about the food blocks that they would see in the scanner, and were asked to apply the perspective they had just learned to the food images in each block. Similar to the color warmth task, each new food block was initialized with an instruction, "Please adopt the observe (or normal viewing) perspective" (3 sec), followed by 5 food images of the same food type (i.e., either 5 healthy foods or 5 tasty foods), with each image presented for 5 sec (to ensure that participants had enough time to adopt the perspective on it), followed by a 2 sec blank screen. Following presentation of the fifth food image in a block, participants were asked to rate, "How well were you able to adopt the observe (or normal viewing) perspective for the previous 5 pictures?" from 1 (not at all) to 4 (very well). Figure 1A summarizes the structure of the food blocks during the training phase, showing a tasty food block on the left, and a healthy food block on the right.

Again, participants were told that food blocks would alternate with the color warmth blocks. Participants performed a short practice run that alternated between the two tasks, with foods not shown later in the scanner.

2.4.4. The training phase in the scanner. Once settled in the scanner, participants were reminded of the key points for performing the food and color warmth tasks, and were asked to apply the perspective that they just learned. As described earlier, participants received 30 tasty food images, 30 healthy food images and scrambled control images presented in alternating ~40 sec blocks. Within each of 3 functional runs, participants received 2 blocks of healthy food images, 2 blocks of tasty food images, alternating with 4 color warmth blocks. At the beginning and end of each run, a fixation cross was displayed for 15 sec to allow the BOLD signal to stabilize. A 12-sec blank occurred between pair of blocks. Each run lasted about 8 min, with the whole training session taking about 24 min.

2.4.5. The food choice phase in the scanner. In the food choice phase, participants were asked to perform a different task (not described earlier) that involved making choices about foods. Participants were not asked to adopt the perspective that they just practiced during the training task. Instead, the instructions stressed that participants would now be performing two new tasks that alternated, namely, a food choice task and a perceptual detection task (i.e., the active baseline). In post scanning interviews, participants showed no awareness that the choice task was related to the perspective they had practiced earlier.

As illustrated in Figure 1B, a food image was presented on each choice trial for 2 sec, with participants making a binary choice as quickly as possible (i.e., whether or not they would like to eat the food in the image right now). To indicate their choices, participants pressed the left most button to indicate that they did not want to eat the food, or pressed the right-most button to indicate that they did. As described earlier, 30 trained images from the training phase and 30 yoked new images were included for each food type (tasty foods and healthy foods), for a total of 120 food images randomly mixed in a fast event-related jittered design. These 120 trials were distributed across three runs, with each run including 10 healthy repeated images, 10 healthy novel images, 10 tasty repeated images, and 10 tasty novel images. Each food image (again presented for 2 sec) was followed by a jittered inter-stimulus interval from 6 to 10 sec, with an average of 8 sec (in increments of 2 sec for durations of 6, 8, and 10 sec). During each jittered interval, participants performed an active baseline task described in a moment. Each run lasted about 7 min, with the whole food choice phase taking about 21 min.

After each food choice trial, a visual detection trial occurred during the jittered interval to implement an active baseline task. To ensure that participants had enough time to indicate the food choice on the previous trial, each jittered interval began with a 2 sec blank screen. To ensure that participants had enough time to prepare for the next food choice trial, each jittered interval ended with a 2 sec blank screen. During the variable period that intervened between blank screens for 0, 2, or 4 sec (for the 6, 8, and 10 jittered intervals, respectively), a scrambled image with a red circle on either the left or the right of the image appeared for 2 sec. Participants were asked to indicate as quickly as possible whether the red circle was on the left or on the right, by pressing the left-most or the right-most button, respectively.

2.4.6. Post-scan questionnaires. After exiting the scanner, participants first provided a second hunger rating. They then provided frequency and attractiveness ratings for each food image, followed by a collection of individual difference questionnaires described earlier. Participants were also asked about eating disorders, other disorders, meditation experience, and the purpose of the experiment. Finally, participants provided their height and weight to calculate BMI, and were then debriefed and paid.

2.5. Image acquisition

All scans were collected on a Siemens 3T Trio scanner with a 32-channel head coil. The functional scans were acquired using a whole-brain multiband slice-accelerated gradient-echo echo planar imaging (EPI) sequence (Feinberg et al., 2010; Moeller et al., 2010): TR / TE / FA = 2000 ms / 26 ms / 80°, FOV = 220 mm × 220 mm; image acquisition matrix = 74 × 74; 72 slices with thickness of 2 mm for a 3 mm × 3 mm × 2 mm voxel resolution. Echo spacing = 47 ms, GRAPPA acceleration factor (R) = 2, mutli-band slice acceleration factor = 2. Short TE, thin slices, and high R were prescribed to minimize artifact susceptibility. A standard gradient echo field map was acquired with same slice parameters as EPI for distortion correction.

High-resolution anatomical scans were acquired using a sagittal 3D T1-weighted MPRAGE sequence (FOV = 240 mm × 240 mm; TR / TE / TI / FA = 2530 ms / 3.03 ms / 1100 ms / 7°; FOV = 256 mm × 256 mm, image acquisition matrix = 256 × 256; 1 mm ×1 mm × 1 mm resolution). These sequences were selected to ensure good segmentation, EPI-to-anatomy registration, and alignment to template.

2.6. Image preprocessing

Image preprocessing and statistical analysis were conducted in AFNI (Cox, 1996) and FSL, which were used to correct spatial intensity bias and to perform segmentation, co-registration, and motion correction (Smith et al., 2004).

Slice-time correction were performed on the functional volumes followed by motion correction and transformation to MNI 152 space. A transformation matrix for motion correction was generated in which functional volumes for each run were registered to a middle volume within that run. Because most motion occurred between runs, registering within each run minimized the extent of motion-related censoring during later analyses. To generate the MNI 152 space transformation matrix, the averaged anatomical image was skull-stripped, bias-field corrected, and aligned to the same functional volume used as the registration base for motion correction. The segmentation was conducted with FSL, in which sub-cortical structures was segmented, as well as grey/white matter and CSF, to increase quality of segmentation. The anatomical image was then transformed to MNI 152 space using an automated procedure. The matrices generated from the transformation of the anatomical dataset were concatenated with the motion correction matrix and applied in a single step to the functional volumes. At this point, the voxel dimensions of the functional volumes were resampled to 3.0 × 3.0 × 3.0 mm. The functional data were smoothed using an isotropic 6 mm full-width-half-maximum Gaussian kernel. Finally, the signal intensities in each volume was divided by the mean signal value for the respective run and multiplied by 100 to produce percent signal change from the run mean. All later analyses were performed on the percent signal change data. Voxels outside the brain were removed from further analysis, as were noisy (high-variability low-intensity) voxels likely to be shifting in and out of the brain as a result of minor head motion. In later regressions, six regressors obtained from motion correction during preprocessing were included to remove any residual signal changes correlated with movement (translation in the X, Y, and Z planes; rotation around the X, Y, and Z axes). Scanner drift was removed by finding the best-fitting polynomial function correlated with time in the preprocessed time course data.

2.7. Data analysis

Regression analyses were performed at the individual level using a canonical fixed-shape gamma function to model the hemodynamic response. For the training phase, food type (tasty vs. healthy), instructions at the beginning of each block, blanks between blocks, ratings at the end of blocks, blanks at the beginnings or the ends of blocks, and 6 motion parameters were modeled. Only active baseline trials contributed to the baseline. Betas of primary interest were calculated from block onsets of 2 food types (healthy, tasty).

For the food choice phase, food type (tasty, healthy), repetition (repeated, novel) and blanks were modeled. Thus, betas of interest were calculated for healthy-repeated foods, healthy-novel foods, tasty-repeated foods, and tasty-novel foods. Again, only active baseline trials contributed to the baseline. In the analysis for each individual, covariates for their binary choice responses, frequency ratings, and attractiveness ratings were included that removed their variance from all later analyses reported (implemented in AFNI with AM regression).

For each of the two phases, the betas for each individual were entered into random-effects group analyses using the general linear model. These analyses were implemented with the 3DLME program in AFNI, which performs mixed-effect modeling in conjunction with the R platform. Separate analyses were performed on the 20 participants in each of the two perspective conditions (observe and normal viewing), with differences between conditions assessed later in the conjunction analyses. Within each group, separate analyses were performed for the training and choice phases. For each of these analyses, hunger before the scan, BMI, restrained eating, healthy eating, trait self-control, and decentering ratings were modeled as covariates, at the individual level. Thus, variance associated with these measures was removed from all reported analyses.

A voxel-wise significance level of $p < .005$ with a spatial extent threshold of 20.3 voxels for the training phase (and 20.4 voxels for the choice phase) was used to threshold the resulting effects, yielding a whole-brain threshold of $p < .05$ corrected for multiple comparisons. The spatial extent thresholds were established using AFNI's Monte Carlo 3dClustSim program, which runs Monte Carlo simulations to estimate extent thresholds needed to exceed cluster sizes of false positives at a given voxel-wise threshold.

In computing cluster thresholds, we followed current best practices informed by Cox, Chen, Glen, Reynolds, and Taylor (2017), Gopinath, Krishnamurthy, Lacey, and Sathian (2018), and Gopinath, Krishnamurthy, and Sathian (2018). Specifically, we used the current version of AFNI's 3dClustSim that implements a mixed ACF function. The result is a false discovery rate that is unbiased for our event-related design, smoothing kernel, and independent voxel threshold (see Cox et al., 2017, Figure 1H).

The analysis pipeline just described established four group-level maps for the training phase (where NV refers to "normal viewing"): NV-tasty, NV-healthy, observe-tasty, observe-healthy. This procedure similarly established eight group-level maps for the choice phase: NV-tasty-repeated, NV-tasty-novel, NV-healthy-repeated, NV- healthy-novel, observe-tasty-repeated, observe-tasty-novel, observe-healthy-repeated, observe-healthy-novel.

2.7.1. Conjunction analyses. The four condition maps at the group level for the training phase were entered into a first set of conjunction analyses, and the eight condition maps at the group level for the choice phase were entered into a second set. In each conjunction analysis, two conditions were compared to establish unique voxels significantly active above the active baseline for each condition, as well as voxels significantly active for both conditions. In other words, each conjunction analysis performed a simple intersection test of logical values, where 1 indicated significant activation above baseline for each condition, and 0 indicated non-significance. The various pairs of conditions assessed are described next.

An initial set of conjunction analyses assessed activations at the whole brain level that bore on the hypotheses in 1.6.4. A second set of analyses further assessed activations within 17 regions of interest (ROI) related to eating. As described in section 1.6.3.4, all analyses focused on the differing breadth of significant activations above baseline between conditions, rather than on linear contrasts in signal intensity (1.6.3.4; Figure 2).

2.7.2. Binomial tests between conditions. To further assess the hypotheses in 1.6.4, we performed binomial tests on the unique voxels in the two conditions that each conjunction analysis established. Of interest was whether the two conditions were symmetrical in activating the whole brain (or an ROI), or whether one activated the brain (ROI) more than the other. As will be seen later, these tests were used to assess our original hypotheses.

It is important to note that we were not using these binomial tests to assess significance with respect to the null hypothesis. Thus, we did not establish an alpha level for rejecting the null hypothesis. Instead, we simply viewed each binomial test as producing the probability that the two voxel frequencies being compared would have occurred by chance ($p = .5$). In other words, each binomial test can simply be viewed as representing the strength of the asymmetry between the two voxel frequencies, if any.

Finally, the binomial tests assumed that the binary events assessed were independent. Because the binary events assessed here were voxels, it is important to address whether the unique voxels active for a condition constituted a set of independent events. We assumed that they did for the following reasons. First, the correlation between voxels was taken into account when earlier applying the cluster threshold to establish significant activations above baseline. Specifically, all the unique voxels tested had already been found to differ significantly above baseline both because of their independent signal intensity ($p < .005$) and their participation in a sufficiently large group of spatially contiguous voxels (approximately 20, $p < .05$). Thus, in assessing whether two conditions differ in their breadth of activation, it was not necessary to take the spatial correlation between voxels into account again.

Second, when the number of unique voxels for two conditions was compared in an ROI (or whole brain), the null hypothesis assumed that both conditions activated essentially the same cluster(s) inside the ROI with some random noise (or essentially activated the same set of clusters in the whole brain). Thus, in the case of both conditions activating a single cluster in the same ROI, the two clusters should, on average, be the same size in the same location. Because of noise, however, there should be some difference in size and placement of the two clusters on a given occasion.

As a result, unique voxels in each condition emerged on the edges of the jointly active voxels in the shared cluster. Typically, in our conjunction analyses, the most frequent unique voxels were isolated singletons that fragmented around the edges of two overlapping clusters. From the perspective of the null hypotheses, these fragments simply reflected random variation in the size and placement of two clusters that had been generated in the same manner. To the extent that unique voxels resulted from this random variation, the different numbers of unique voxels for two conditions should have been relatively symmetrical. It should have become increasingly unlikely that one condition had many more unique voxels than the other. The binomial test assessed the probability that the unique voxels for two conditions simply reflected random variation in cluster size and placement.

2.7.3. Conjunction analysis overview. Three sets of conjunction analyses were performed. First, conjunction analyses of tasty vs. healthy foods were performed for each perspective (normal viewing, observe) within each phase (training, choice). Figures 6 through 9 present images from these analyses, with Tables 2 and 3 presenting the associated binomial tests. Second, conjunction analyses of the normal viewing vs. observe perspectives were performed for each food type (tasty, healthy) within each phase (training, choice). Figures 10 through 13 present images from these analyses, with Tables 4 and 5 presenting the associated binomial tests. Finally, conjunction analyses of repeated vs. novel choice trials were performed for each food type (tasty, healthy) within each perspective (normal viewing, observe). Figures 14 through17 present images from these analyses, with Tables 6 and 7 presenting the associated binomial tests.

2.7.4. Region of interest masks. For each of the three figure sets, the same 17 ROIs were assessed in each. One set of ROIs reflected important brain areas associated with eating (Chen et al., 2016), including the insula, OFC, amygdala, and olfactory cortex (piriform, uncus). Another set included the cortical midline, given our interest in assessing the self-relevance of foods, together with language areas (IFG and left lateral temporal gyrus) that could potentially be associated with describing foods to oneself, especially in the observe condition (the ability to describe one's mental states is often assumed to be an important component of mindfulness; Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). Still another set of ROIs established visual areas associated with processing food images in the occipital, temporal, and parietal lobes. A final set of ROIs assessed brain areas associated with embodiment and action, including pre- and post-central gyrus, the supplemental motor area (SMA), the basal ganglia, the thalamus, and the cerebellum.

To measure the number of voxels in an ROI, masks for it were first identified in AFNI and then used to establish and count the significantly active voxels falling within it. Appendix E presents the specific set of masks in AFNI used to assess these ROIs.

3. Results

We first present the preliminary behavioral results, followed by the critical behavioral results from mixed-effects regressions for food choice trials in the scanner. We then turn to the neuroimaging results, beginning with the whole brain analyses, followed by the ROI analyses. Because the whole brain results assessed Hypotheses 2, 3 and 4, we addressed these hypotheses first. Hypotheses 2, 3, and 4 did not depend on results in specific brain areas but instead depended on results across the whole brain. In contrast, Hypothesis 1 depended on results in particular ROIs. For this reason, we hold off assessing Hypothesis 1 until the ROI analyses. Because the ROI analyses also assessed Hypotheses 2, 3, and 4, we return to these hypotheses as well in that section.

3.1. Preliminary behavioral results

In Appendix F, Table F1 presents the preliminary behavioral results described next, including the hunger measures, individual difference measures, food measures, and training measures.

3.1.1. Hunger measures. As Table F1 illustrates, the hunger ratings before the scan, as well as hours since last eating, indicated that all the participants arrived in a moderately hungry state. The hunger ratings after the scan were significant higher than those before the scan, indicating that both groups felt more hungry after the scan. As *t* tests illustrate in the fourth column, no significant difference occurred between perspective groups for any hunger measure. Most importantly, hunger did not differ for the two perspectives at either point. An additional analysis found no interaction between perspective and hunger before vs. after the scan.

3.1.2. Individual difference measures. As Table F1 shows, the two perspective groups did not differ on any of the individual difference measures, including BMI, restrained eating, healthy eating, trait self-control, and food decentering (measured trait instead of state food decentering).

3.1.3. Food measures. For food consumption frequency, Table F1 shows that both groups found tasty foods and healthy foods equally familiar and consumed them with similar frequencies. Although the tasty foods and healthy foods were matched on palatability and craving in the food database (section 2.3, Table B3), both groups found tasty foods more attractive than healthy foods after the scan. Again, no significant difference occurred between the two perspective groups for any measure.

3.1.4. Ratings on perspective effectiveness during the training phase. As Table F1 illustrates, participants' ratings on perspective effectiveness for both tasty and healthy foods indicated that both perspective groups applied their learned perspective equally well. Interestingly, however, participants found it easier to adopt both perspectives on tasty foods than on healthy foods (cf. Papies et al., 2015; Lebois et al., 2015). No group difference occurred for any measure during the training phase.

3.2. Mixed-effects regressions on the behavioral data during the choice phase

Mixed-effects regressions were performed on the choice data, using the lme4 package in R to assess a series of three models. In Model 1, we included the primary predictors of interest, namely, perspective, food type, and repetition, along with all the interactions between them and random intercepts for participants and foods. As covariates, Model 1 also included frequency and attractiveness at the trial level, along with hunger before, BMI, dietary restraint, and healthy eating at the individual level. Because these covariates were primarily included for control purposes, no interactions with them were included. In Model 2, we further assessed any main effect or interaction from Model 1 whose estimated regression coefficient $|t|$ was greater than $|1.96|$. In a unique Model 2 for each of these main effects and interactions, we included only the random slope(s) that tested it maximally (Barr, Levy, Scheepers, & Tily, 2013). All random slopes were not tested simultaneously in a single model because it became too large to converge. A unique Model 3 further assessed any main effect or interaction whose estimated regression coefficient $|t|$ was greater than $|1.96|$ in its Model 2. In each Model 3, we dropped only the main effect or interaction tested in Model 2 (with its random slopes) and held everything else constant, thereby assessing how much variance the main effect or interaction explained as a fixed effect. Table 1 presents the results of these analyses, first for the choice responses (logistic regression) and then for the RTs.

As Table 1 illustrates for choice responses, there was no effect of perspective, showing that both groups chose similar numbers of foods to eat. Food type had a strong effect on food choices, with tasty foods chosen more often than healthy foods overall (77% vs. 55%; see Table F1 for further details). Importantly, however, there was no perspective × food type interaction, indicating that both perspective groups chose more tasty foods than healthy foods. Contrary to the behavioral results reviewed earlier (1.4.2), the observe perspective did not increase healthy food choices or decrease tasty food choices relative to normal viewing. Later in the Discussion section, explanations will be offered for this lack of effect of perspective on behavior (coupled with a strong effect of perspective on neural activity, presented shortly).

Expected effects of frequency, attractiveness, and hunger ratings before the scan were observed. Foods were chosen more often to the extent that they are frequently eaten and attractive. Additionally, the hungrier participants were before the scan, the more foods they chose to eat. The factors of repetition, BMI, restrained eating, and healthy eating did not significantly predict food choice responses.

For choice RTs, there was again no effect of perspective, indicating that perspective did not affect RTs for food choices. Similar to choice responses, food type had a strong effect on choice RTs, with tasty foods being faster than healthy foods overall (870 vs. 963; see Table F1 for further details). As will be seen shortly, the large 93 ms effect of food type has important implications later for understanding the neuroimaging results associated with tasty vs. healthy foods. Similar to the choice responses, there was again no perspective × food type interaction for the RTs. Repetition significantly affected choice RTs, with repeated foods being responded to faster than novel foods overall (893 vs. 940; see Table F1 for further details). Again this large 47 ms effect of repetition has important implications later for understanding the neuroimaging results for repeated vs. novel foods.

A significant food type × repetition interaction for RTs indicated that the repetition effect was larger for tasty foods than for healthy foods (see Table F1 for details). Attractiveness significantly predicted RTs, with faster responses for more attractive foods. Other factors for frequency, hunger ratings before the scan, BMI, restrained eating, and healthy eating were not significantly related to choice RTs.

3.3. Whole brain analyses

3.3.1. Overview. Using results from whole brain analyses, we assessed Hypotheses 2, 3 and 4 from section 1.6.4 (Hypothesis 1 will primarily be assessed in the next session on ROI analyses). To assess these hypotheses, we first established 12 whole brain maps of clusters significantly activate above the active baseline at the group level (see section 2.7 for further details), with 4 maps for the training phase and 8 maps for the choice phase. As described earlier, activations were obtained using an independent voxel threshold of $p < .005$ and a cluster threshold set at alpha = .05, determined to be 20.3 voxels for the training phase and 20.4 voxels for the choice phase.

The four maps for the training phase, presented in Appendix G's Table G1, were for the NV-tasty, NV-healthy, observe-tasty, and observe-healthy conditions (where NV is Normal Viewing). Similarly, Table G2 presents the analogous four maps for repeated foods during the choice phase, and Table G3 the analogous four maps for the novel foods. In each table, clusters for the normal viewing perspective are shown first, followed by clusters for the observe perspective. Within each perspective, clusters for tasty foods are shown first, followed by clusters for healthy foods. In addition, negative clusters that were significantly below the active baseline are also included for completeness.

The activations in these 12 maps (Tables G1, G2, and G3) exhibited large overlapping clusters throughout the brain. As we will see later in the ROI analyses (3.4), these maps typically contained clusters in gustatory and reward areas (insula, OFC), olfaction areas (piriform cortex, uncus), the amygdala, left-hemisphere language areas (IFG, lateral temporal lobe), the cortical midline, the motor system (pre- and post-central gyri, SMA, cerebellum, basal ganglia, thalamus), medial temporal areas (hippocampus, parahippocampal gyrus), and visual areas (ventral and dorsal streams).

3.3.2. Hypothesis 2. This hypothesis predicted a cross-over interaction between perspective and phase in overall brain activation. Specifically, the observe perspective should have recruited more neural resources during the training phase, but recruited fewer neural processing resources during the later choice phase, relative to the normal viewing perspective. To assess Hypotheses 2, we counted the total number of brain voxels activated significantly above the active baseline in each of the 12 group-level maps. Figure 3A presents the total number of voxels in significant clusters active above baseline in the critical perspective (NV, observe) × phase (training, choice repeated, choice novel) interaction.

As Hypothesis 2 predicted, a cross-over interaction between perspective and phase emerged. For the training phase, nearly two times as many voxels were active for the observe perspective as for the normal viewing perspective (14,624 vs. 8,096). Conversely, the choice phase exhibited the opposite pattern, with nearly two times as many voxels active for the normal viewing perspective as for the observe perspective, both for repeated foods (12,230 vs. 6,050 voxels) and for novel foods (13,765 vs. 8,528).

Within the observe perspective, nearly two times as many voxels were active during the training phase (14,624) than during the choice phase (6,050 repeated, 8,528 novel). Conversely, within the normal viewing perspective, over 50% more voxels were active during the choice phase (12,230 repeated, 13,765 novel) than during the training phase (8,096). As Hypothesis 2 predicted, the observe perspective recruited more neural resources during the initial training phase and much fewer neural processing resources during the later choice phase, whereas the normal viewing perspective displayed the opposite pattern.

To assess this interaction statistically, we assessed it at the level of individual participants. For each participant, we computed the numbers of voxels significantly active in the training phase and in the choice phase (both repeated and novel), and then assessed whether individual participants within each perspective showed the same effect as found at the group level in Figure 3A. Again, activations were obtained using an independent voxel threshold of $p < .005$ and a cluster threshold set at alpha = .05, but with cluster sizes unique to each individual. As would be expected, fewer voxels were significantly active above the active baseline at the individual level than at the group level due to less power (as can be seen by comparing the Y axes of Figures 3A, 3B, and 3C). Nevertheless, we still had sufficient power to observe many significant clusters for each individual.

For the normal viewing and the observe perspectives, Figures 3B and 3C present the number of significant voxels for each individual across the training phase and the choice phase (both repeated and novel). For the observe perspective, all 20 participants showed the group level effect. For the normal viewing group, 15 of the 20 participants showed the group level effect.

We performed mixed-effects regressions (again with lme4) to assess whether the predicted interaction between perspective and phase at the group level was significant across individuals. For the repeated choice trials, the interaction between perspective (normal viewing vs. observe) and phase (training vs. choice) was significant (standarized estimated regression coefficient for the interaction = -.279 with SE = .092, *t* = -3.036). The same interaction was also significant for the novel choice trials (standarized estimated regression coefficient for the interaction = -.268 with SE = .088, *t* = -3.044). Thus, the predicted perspective × phase interaction for Hypothesis 2 was significant across individual participants for both repeated and novel choice trials. As we will see later, binomial tests at the group level further demonstrate the strength of these interactions (3.4).

3.3.3. Hypothesis 3. This hypothesis predicted that the interaction in Hypothesis 2 would be stronger for tasty foods than for healthy foods (because the observe perspective has more psychological content on which to operate for highly affective stimuli, as found in Lebois et al., 2015 and Papies et al., 2015). Specifically, we predicted that the increase for the observe perspective during the training phase would be larger for tasty foods than for healthy foods. Conversely, we predicted that the decrease for the observe perspective during the choice phase would be larger for tasty foods than for healthy foods. As Figures 4A, 4B, and 4C illustrate, this hypothesis received support. Within the results for the observe perspective (on the right of Figure 4), tasty foods exhibited a large increase in whole brain activity during the training phase, relative to normal viewing, whereas healthy foods did not. Conversely, during the choice phase, tasty foods in the observe condition exhibited considerable reduction in whole brain activation, more than did healthy foods, which actually increased slightly, relative to training. Thus, the effect of observe training was larger for tasty foods, as exhibited by more activation during training and a larger reduction during choice.

Importantly, however, the observe condition exhibited much less activation for healthy foods during the choice phase than did the normal viewing condition, both for repeated foods (Figures 4B) and for novel foods (Figure 4C). Although the observe perspective didn't affect healthy foods as much as it did tasty foods, it nevertheless had a considerable impact.

When we used mixed-effects modeling to assess the interactions between phase (training vs. choice) and food type (tasty vs. healthy) for the observe group, these interactions did not reach significance, largely because the effects at the individual level were weaker than those at the group level (as can be seen by comparing the magnitude of the food type effect for the observe perspective in Figures 4 and 5). Later, when we assess group-level effects using binomial analyses, we will see stronger support for these interactions.

3.3.4. Hypothesis 4. This hypothesis predicted that observe training would affect food choices via both a general cognitive set and memory effects. Specifically, we predicted that, during the choice phase, the novel food stimuli would exhibit a decrease in neural activation similar to repeated foods (a general cognitive set). We also predicted that the decreased processing expected for the observe perspective on choice trials (relative to training) would be larger for repeated foods than for novel foods, additionally reflecting memory effects. The whole-brain data offer support for both mechanisms. As the results in Figure 3 show, the same basic perspective and phase interaction occurred for both repeated and novel choice trials. These results implicate a general set mechanism, whereby novel choice trials exhibited the same perspective × phase interaction as repeated choice trials. Because novel choice trials exhibited the predicted interaction at both the group (Figure 3A) and individual levels (Figures 3B and 3C), the general cognitive set component of Hypothesis 3 received support.

Additionally, however, we also observed a memory effect for repeated trials, as Hypothesis 4 further predicted. Earlier in the behavioral data (3.2), we reported a memory effect for the choice RTs, with repeated trials being faster than novel trials. Here, at the whole brain level, novel trials exhibited greater activation at both the group and individual levels (Figure 3). In mixed-effect regressions, novel choice trials activated significantly more voxels than repeated trials, exhibiting a main effect across the two perspective groups (standarized estimated regression coefficient for the main effect = -.149 with SE = .036, t = -4.111). The perspective × repetition interaction was not significant, indicating that the repetition effect was constant across perspectives. As concluded for the earlier repetition effect on RTs, repeated trials appeared to benefit from training, thereby requiring less effort than novel trials, and also requiring less neural activity.

3.3.5. Assessing whole brain activations for tasty vs. healthy foods. Although we primarily assess Hypothesis 1 in the next section on ROI analyses (3.4), we assess one claim of Hypothesis 1 using the whole-brain analyses presented here. This particular claim of Hypothesis 1 predicted that tasty foods would produce more activation than healthy foods, especially in food-related areas. More generally, however, one might further expect that tasty foods would produce more activation across the brain, given the greater attention and importance that people often devote to them, especially when hungry.

To assess this hypothesis, we contrasted the original 12 maps for the 12 conditions within 6 conjunction analyses of tasty vs. healthy foods. Specifically, we preformed one conjunction analysis of tasty vs. healthy foods for each of the two perspective groups (the normal viewing group, the observe perspective), in each of the three phases—training, choice repeated, choice novel—yielding a total of six conjunction analyses. Each analysis established the number of shared voxels between tasty and healthy foods, the numbers of unique voxels for tasty foods, and the numbers of unique voxels for healthy foods. These six conjunction analyses were performed once at the group level, and then once for each of the 40 participants. Figure 4 presents the results of the group analyses, and Figure 5 presents the results of the individual analyses.

As both Figures show, the prediction that tasty foods would produce more activation than healthy foods only held during the training phase, especially for the observe perspective (as already discussed for Hypothesis 2). We will see later (section 3.4) that this effect occurred throughout brain areas associated with eating that have previously shown more activation for tasty foods (along with additional brain areas of interest as well).

During the choice phase, however, healthy foods unexpectedly produced much more activation than tasty foods, especially for the normal viewing perspective. This larger activation was consistent with the much longer RTs for healthy foods than for tasty foods (see section 3.2). One possibility is that the initial training phase created stronger memories for tasty foods than for healthy foods that later facilitated choices for tasty foods more than for healthy foods (as can be seen from the significant interaction between food type and repetition in section 3.2). Because no other study has assessed the effect of prior training on neural activations during subsequent food choices, this explanation is highly speculative. We further address this possibility later in the Discussion, exploring various explanations for why this effect occurred, and suggestions for how future work could assess these explanations.

Figures 5A, 5B and 5C present the results for individual participants, corresponding to the analogous panels for the group-level effects in Figure 4. For each participant, we computed the significantly active clusters in the perspective × food type interaction during both the training and choice phases (for repeated and novel choice trials separately). Similarly as before, activations were obtained using an independent voxel threshold of $p < .005$ and a cluster threshold set at alpha = .05, but with cluster sizes unique to each individual. Although fewer voxels were obtained than at the group level due to less power, we still observed many of significant clusters at the individual level. From the individual maps, we then computed the same six conjunction analyses described earlier at the group level for each of the 40 individuals. For each conjunction analysis, we contrasted maps for tasty vs. healthy foods, and assessed the number of uniquely active voxels for each. As Figures 5A, 5B, and 5C show, participants in both perspective groups generally showed the same group level effects presented in Figure 4. During the training phase, participants tended to activate more voxels for tasty foods than for healthy foods. During the choice phase, participants tended to activate more voxels for healthy foods than for tasty foods.

Again, we performed mixed-effects analyses with lme4 to assess whether the interactions at the group level were significant across individuals. For the repeated choice trials, the interaction between phase (training vs. choice) and food type (tasty vs. healthy) was significant (standarized estimated regression coefficient for the interaction = .243 with SE = .007, t = -3.459). The same interaction was also significant for the novel choice trials (standarized estimated regression coefficient for the interaction = .200 with SE = .007, t = 2.767). Thus, the observed phase × food type interaction was significant across individual participants for both repeated and novel choice trials.

Notably, the phase × food type interaction held for both the normal viewing and observe perspectives (i.e., there was no three-way interaction between them). Whereas participants adopting both perspectives showed more activation for tasty foods during training, they all showed more activation for healthy foods during choice. As we will see later, binomial tests at the group level further demonstrate the strength of these interactions (3.4).

3.4. ROI analyses

3.4.1. Overview. Using results from ROI analyses, we primarily focus on Hypothesis 1, although the results reported also continue to bear on Hypotheses 2, 3, and 4 (Section 1.6.4). Hypothesis 1 stated that food cues would activate the same general brain areas associated with eating, as reviewed in Chen et al. (2016). Specifically, food images should activate areas in the ventral reward pathway for taste and reward, such as the insula (primary taste area), OFC (predicted reward), amygdala (attentional salience), as well as areas in the dorsal control pathway for self-regulation, including the lateral frontal cortex and medial pre-frontal cortex. Furthermore, food images should activate areas associated with action and embodiment, including areas in pre-central and post-central gyrus, basal ganglia, and cerebellum. Finally, we predicted that food images would activate the cortical midline as it processes self-relevance of the respective foods.

As noted earlier (1.6.3), we used active baselines matched to the critical tasks, and then focused on the breadth of activation above these baselines (not intensity), so that we could establish as many brain areas associated with food processing as possible. Thus, only relatively low-level processes associated with vision, choice, and motor responses were removed with the baselines. As will be seen in the results to follow, this approach did indeed reveal a broad set of processes associated with processing food cues. As will also be seen, this approach further yielded substantial differences between the normal viewing and observe perspectives, between tasty and healthy foods, and between repeated and novel choice trials.

A related prediction was that all these activations should tend to be stronger for tasty foods than for healthy ones (Chen et al., 2016; van der Laan, 2011). Although one might expect tasty foods to primarily activate areas in the ventral reward pathway more than do healthy foods, we generally expected greater activations across all brain areas related to eating, including areas for self-regulation, embodied action, and self-relevance.

To assess these hypotheses, we first assessed activations in ROIs typically active for food cues and eating, including insula (gustation), OFC (reward), amygdala (salience and attention), and visual processing areas (ventral and dorsal stream areas in occipital, temporal, and parietal cortex). Secondly, as described in the Introduction (Section 1.6.3.2, 1.6.4), we also expected to see activations in brain areas associated with self-related thought and mentalizing (cortical midline), and with embodiment and action (motor areas).

During the analyses, we noticed large and stable activations in other areas of potential interest, not anticipated (and not reported much in previous studies), including olfaction areas (piriform cortex and uncus) and language-related areas (left IFG, left lateral temporal gyrus). It is, however, not surprising to see activations in these areas, especially those areas for olfaction (as addressed further in the Discussion section). Because of their potential interest, we added these additional ROIs to our analyses. Therefore, there were a total of 17 ROIs in these analyses. As described earlier (2.7.4), these ROIs were assessed statistically using maps for the respective brain areas in AFNI (see Appendix E for the complete set of masks used).

The ROI analyses used the same activation maps described earlier for the whole brain analyses (as described in 2.7 and 3.3). Again these maps can be found in Tables G1, G2, and G3 of Appendix G. The ROI analyses further analyzed results from conjunction analyses described earlier (2.7.1, 2.7.2, 3.3). Rather than assessing these results at the whole brain level, however, they were assessed within individual ROIs. Similar to the whole brain analyses, three sets of conjunction analyses were performed within each ROI, contrasting tasty vs. healthy foods, normal viewing perspective vs. observe perspective, and repeated vs. novel choice trials.

Within each ROI, for each conjunction analysis, we computed the number of unique voxels significantly active above baseline for each of the two conditions in the analysis, the number of shared voxels between the two conditions, and the total number of voxels across them (section 2.7.4). We then performed binomial tests within each ROI for each conjunction analyses (section 2.7.2). Of primary interest was whether the relative distribution of unique voxels within each ROI for the two conditions of interest supported our original hypotheses. The specific nature of these assessments will become clearer when results of specific tests are presented.

Because we performed a large number of binomial tests, the issue of correcting for false positives must be addressed. Importantly, however, we decided not to use *p* values from these tests to assess the null hypothesis that two conditions did not differ. Instead, we decided to view each *p* as representing the strength of the evidence that two conditions differed in the direction that we predicted. Specifically, as the *p* for a binomial test became increasingly small in the predicted direction, we viewed it as offering increasing evidence for the conclusion that the two conditions differed in the predicted direction.

It is important to bear in mind several points when evaluating these tests. First, all the specific tests within ROIs were subsumed within larger whole-brain binomial tests, shown at the bottom of Tables 2 to 7. Within each related set of tests, the direction of the predicted difference was the same across all 17 ROIs, as determined by the predicted direction of the overall difference at the whole brain test level. Second, we performed many tests. If these tests had been independent of each other and performed without predictions, 5% of them would have been significant by chance (if one were assessing the null hypothesis with an alpha of 5%). If the reader wishes to view the ROI tests in this manner, then some sort of correction for false positives should be applied, such as the Bonferroni correction. Because, however, all tests within a related set were subsumed under a single whole-brain prediction, an alternative approach is to simply assess the significance of the binomial test at the whole brain level, across all ROIs, and then view the binomial tests within each ROI as providing some sense of the specific effect in that particular ROI. Third, more weight should be given to tests for which many voxels were tested. In ROIs where a small number of voxels was tested, the *p* values should be viewed with less confidence than in ROIs where many voxels were tested. Fourth, we assumed that the independence assumption of the binomial test was satisfied for reasons given in section 2.7.2. These points should come into greater focus when presenting the specific results.

3.4.2. Contrasting tasty vs. healthy foods. First, we assessed activations for food type in the 17 ROIs. Tables 2 and 3 present the voxel counts and binomial tests from conjunction analyses between tasty vs. healthy foods during the training phase and the choice phase, respectively (repeated choice trials only; novels trials will be assessed in section 3.4.4). Figures 6 through 9 illustrate activations in the 17 ROIs.

As described earlier, the use of an active baseline for scrambled objects, together with assessing breadth of activation, enabled seeing all the higher level areas that become active while processing foods (1.6.3.2, 1.6.3.3, 1.6.3.4). The results shown in Tables 2 and 3, illustrated in Figures 6 through 9, offer strong support for Hypothesis 1. Across all conditions, we observed large bilateral activations in classic eating areas for gustation (insula), olfaction (piriform cortex, uncus), amygdala, and reward (OFC). Activations in these areas occurred for both tasty and healthy foods, for both the normal viewing and observe perspectives, during both the training and choice phases. We also found strong activations to food images in other areas associated with eating. Both the ventral and dorsal visual pathways became active. In the ventral stream, activations occurred from early visual areas in occipital cortex, through the fusiform, into the parahippocampal gyrus, and hippocampus. In the dorsal stream, activations occurred in the angular gyrus and precuneus. Food cues also activated area associated with action (SMA, pre-central and post-central gyrus, cerebellum, thalamus, basal ganglia).

As expected, strong activations along the cortical midline were observed during both the training and choice phases, presumably implementing self-related food thoughts and other forms of food-related mentalizing. Observing these activations was made possible through the use of an active baseline with scrambled objects that did not remove these activations (as a resting state baseline would have). Of particular interest is the contrast between the extensive activations along the cortical midline for the observe condition during training vs. the substantial drop in these activations during choice. On the one hand, adopting the observe perspective during training engaged considerable activity in brain areas associated with self-related thoughts and mentalizing. On the other, this large increase in processing foods "up-front" was followed by a considerable decrease in this kind of processing during choice (relative to the normal viewing perspective). We explore this result further in the Discussion.

We also observed strong activations in left hemisphere language areas (left IFG, lateral temporal gyrus), suggesting the presence of linguistic processing, perhaps describing foods and their consumption. Of particular interest is that the contrast between the large activations in these areas during the training phase, especially for the observe perspective, versus much smaller activations during the choice phase. One possibility is that during the training, participants tended to describe foods to oneself, especially in the observe condition (the ability to describe one's mental states is often assumed to be an important component of mindfulness; Baer et al., 2006). We explore the implications of these results further in the Discussion.

We observed partial support for Hypothesis 1's proposal that tasty foods would activate eating areas more than the healthy foods. As shown in Table 2, this was clearly true during the training phase, for both the normal viewing perspective and the observe perspective. It was clearly not true, however, for the choice phase (as already noted earlier; 3.3.5, and addressed later in the Discussion). Table 3 documents the unpredicted reversals, with healthy foods activating many more voxels than tasty foods during the choice phase.

We also observed strong support for Hypothesis 2, which again predicted a perspective × phase interaction. The interaction presented earlier in the whole brain analyses (3.3.2) was also clearly apparent in the ROI analyses. During the training phase, many more voxels were active for the observe perspective than for the normal viewing perspective (8,952 vs. 5,509 total voxels in Table 2, with the relevant binomial tests discussed shortly in Section 3.4.3). Conversely, during the choice phase, many more voxels were active for the normal viewing perspective than for the observe perspective (7,407 vs. 4,081 total voxels in Table 3, with the relevant binomial tests for each ROI also discussed in Section 3.4.3).

When further comparing the results for the observe perspective in Tables 2 and 3, we observed support for the Hypothesis 3, which predicted that the crossover interaction would be stronger for tasty foods than for healthy foods. As Tables 2 and 3 illustrate, the primary support for Hypothesis 2 came from tasty foods, not from the healthy foods. From the training phase to the choice phase, the total unique voxels for tasty foods dropped from 2,872 to 331, whereas for healthy foods, they increased slightly from 425 to 1,087.

3.4.3. Contrasting the normal viewing vs. observe perspective. We next assessed activations for the two perspectives in the 17 ROIs. Tables 4 and 5 present the voxel counts and binomial tests for conjunction analyses between the normal viewing and observe perspectives during the training phase and the choice phase (repeated choice trials only; novels trials will be assessed in section 3.4.4). Figures 10 through 13 illustrate activations in the 17 ROIs.

We observed strong support for Hypothesis 2, which predicted a crossover interaction between perspective and phase. As Tables 4 and 5 show, together with Figures 10 through 13, the predicted perspective × phase interaction observed at the whole brain level (3.3.2) was also highly apparent in the ROI analyses. As the binomial tests in Table 4 show, during the training phase, many more voxels were active for the observe perspective than for the normal viewing perspective across most ROIs, both for tasty foods (4,378 vs. 990 total unique voxels) and healthy foods (3,125 vs. 956 total unique voxels). Conversely, during the choice phase (repeated food trials only), many more voxels were active for the normal viewing perspective than for the observe perspective across most ROIs. As Table 5 illustrates, this effect was much stronger for healthy foods (4,005 vs. 440 total unique voxels) than for tasty foods (1,296 vs. 663 total unique voxels).

3.4.4. Contrasting repeated vs. novel trials during the choice phase. Finally, we assessed activations for repeated vs. novel choice trials in the 17 ROIs. Tables 6 and 7 present the voxel counts and binomial tests for conjunction analyses between repeated and novel food trials during the choice phase for the normal viewing and observe perspectives. Figures 14 through 17 illustrate activations in the 17 ROIs.

We observed strong support for the memory component of Hypothesis 4, which predicted decreased processing for repeated foods relative to novel foods. As the binomial tests in Table 6 and 7 show, there were generally more activations for novel trials than for repeated trials across most ROIs. This pattern suggests that food memories established during the training phase later increased the efficiency of processing the same foods again on choice trials. The repetition effect was generally strong across conditions, with the exception of healthy foods in the normal viewing perspective, where for many ROIs, there were more unique activations for repeated foods than for novel foods (see Table 6 and Figures 14-17). This finding receives further discussion shortly.

4. Discussion

4.1. Summary of results

In general, results from the behavioral data (3.2), the whole brain analyses (3.3) and the ROI analyses (3.4) supported Hypotheses 1, 2, 3, and 4. The findings that bear on each are addressed next in turn.

4.1.1. Hypothesis 1. This hypothesis predicted that food images would activate the same two general pathways that become active for eating (Chen et al., 2016). First, food cues should activate the ventral reward pathway, including the insula (primary taste area), OFC (predicted reward), amygdala (attentional salience). Second, food cues should activate the dorsal control pathway, including the lateral frontal cortex and medial pre-frontal cortex. We further predicted that food images would activate areas associated with action and embodiment (SMA, pre-central and post-central gyrus, basal ganglia, and cerebellum), and areas associated with self-relevance (cortical midline).

As noted in the Introduction (1.6.3), we used active baselines matched to the critical tasks, and then focused on the breadth of activation above these baselines (not intensity), so that we could establish as many brain areas associated with food processing as possible. Thus, only relatively low-level processes associated with vision, choice, and motor responses were removed with the baselines. As the ROI results in Section 3.3 demonstrated, this approach did indeed reveal a broad set of processes associated with processing food cues. As we also saw, this approach further yielded substantial differences between the natural viewing and observe perspectives, between tasty and healthy foods, and between repeated and novel choice trials.

Across ROIs, the results in section 3.4 generally supported Hypothesis 1 (Tables 2 through 7, Figures 6 through 17). Specifically, we observed large activations in brain areas associated with eating and food cues (insula, OFC, amygdala, piriform cortex, uncus), visual processing (dorsal and ventral stream), self-related thought (cortical midline), language processing (L IFG, L lateral temporal gyrus), and action (SMA, pre-central and post-central gyrus, cerebellum, thalamus, basal ganglia), for both tasty and healthy foods, for both the normal viewing and observe perspectives, and for both the training and choice phases.

Hypothesis 1 further predicted that tasty foods would produce more neural activity across eating areas than healthy foods. Results from both the whole brain analyses and the ROI analyses showed that this proposal was clearly true during the training phase, for both the normal viewing perspective and the observe perspective. This proposal was clearly not true, however, for the choice phase, with healthy foods activating many more voxels than tasty foods.

Finally, we observed activations in olfactory areas (piriform cortex and uncus) that could clearly be related to eating. In the literature that Chen et al. (2016) reviewed on food cue processing, no studies reported activations in the uncus and only one reported activation in the right piriform cortex, which was uncorrected (Malik, McGlone, Bedrossian, & Dagher, 2008). One possibility is that activations in these areas weren't observed because a focus on activation intensity along with the use of a resting state baseline, obscured these effects. We may have been able to see them here because we assessed breadth of activation relative to well-matched active baselines instead. Other work has found activations in piriform cortex, but in different kinds of tasks, including sniffing two foods (pizza, beef) (Eiler et al., 2012) and processing words with strong olfactory associations (e.g. aroma, coffee, flower, cinnamon) (González et al., 2006).

4.1.2. Hypothesis 2. This hypothesis predicted a cross-over interaction between perspective and phase, with the observe perspective exhibiting more activation during the initial training phase but less activation during the later choice phase, relative to the normal viewing condition (similar to Lebois et al., 2015). We observed the predicted cross-over interactions in both the whole brain analyses and the ROI analyses. Both sets of results indicated that during the training phase, the observe perspective activated many more voxels than the normal viewing perspective. Conversely, during the choice phase, the pattern was reversed, with the normal viewing perspective activating many more voxels than the observe perspective. As predicted, the observe perspective induced much more "up front" processing of foods that resulted in much less processing later during food choice.

4.1.3. Hypothesis 3. This hypothesis predicted that the interaction in Hypothesis 2 would be stronger for tasty foods than for healthy foods. Specifically, we predicted that the increase for the observe perspective during the training phase would be larger for tasty foods than for healthy foods. Conversely, we predicted that the decrease for the observe perspective during the choice phase would be larger for tasty foods than for healthy foods. The prediction again received support from both the whole brain analyses and the ROI analyses, with the observe perspective exhibiting more activation during training and a larger reduction during choice for tasty foods.

4.1.4. Hypothesis 4. This hypothesis predicted that the observe perspective would affect food choices via both a general cognitive set and memory effects. The whole-brain data and the ROI analyses offered support for both mechanisms. Specifically, the same basic perspective × phase interaction occurred for repeated food choice trials and for novel food choice trials. During the choice phase, the novel foods exhibited a decrease in neural activation similar to repeated foods, which indicated the presence of a general cognitive set. On the other hand, repeated foods were responded to faster than novel foods, and also generally activated fewer voxels, additionally reflecting memory effects.

4.2. Possible roles of the cortical midline and self-relevance in food processing

For the extensive activations observed along the cortical midline (dmPFC, vmPFC, sgACC, PCC), we observed a substantial difference between the training and choice phases for the observe perspective, relative to the normal viewing perspective (especially in vmPFC, sgACC, PCC). On the one hand, adopting the observe perspective during training engaged considerable activity in brain areas associated with self-related thoughts and mentalizing. On the other, this large increase in processing "up-front" was followed by a considerable "off-load" in this kind of processing during the choice phase. Additionally, during the training phase, tasty foods recruited more resources along the cortical midline than did healthy foods, for both the normal viewing and observe perspectives (as can be seen in Figure 7), indicating more self-relevance processing for tasty foods.

4.2.1. The cortical midline and self-relevance processing. In much previous work, the cortical midline structures (especially ventral and dorsal medial frontal cortex, anterior and posterior cingulate cortex extending to the precuneus) have been centrally implicated in self-referential processing (Amodio & Frith, 2006; Mason et al., 2007; Northoff et al., 2006; Northoff & Bermpohl, 2004; Qin & Northoff, 2011; Schneider et al., 2008). The extensive activations in these areas during the training phase for both perspectives potentially implicate self-relevance as a central factor in processing food cues, for several reasons described next .

4.2.2. The importance of self-identity for foods. Increasing research shows that self-identity is important for the foods that people choose to eat. In Dean et al. (2012), participants' self-identity significantly predicted their intention to purchase both fresh and processed organic foods (e.g. "I think of myself as a green consumer"). Michaelidou and Hassan (2008) similarly found that participants' ethical self-identity affected their attitudes and intention to purchase organic foods (e.g. "I think of myself as an ethical consumer"). Related results show that having a healthy-eater identity is a significant predictor of healthy eating (Strachan & Brawley, 2009). Conversely, Hackel et al. (2018) found that food experience may be shaped by social self-identity, with participants reporting that they find foods more representative of their identity to be tastier.

Previous studies on food processing have consistently reported activations along the cortical midline, including mPFC (Holsen et al., 2005; Holsen et al., 2006; Killgore et al., 2003; Malik et al., 2008; Miller et al., 2007; Schienle, Schäfer, Hermann, & Vaitl, 2009; Uher et al., 2006), ACC, and PCC (Beaver et al., 2006; Cornier et al., 2009; Führer et al., 2008; Killgore et al., 2003; Killgore et al., 2005; Malik et al., 2008; Schienle et al., 2009). Interestingly, however, none of these researchers explicitly interpreted these activations as related to self-relevance during food processing. Typically, little interpretation of activations along the cortical midline has been offered, with some implicating ACC as conflict monitoring and attentional selection (Killgore et al., 2005; Schienle et al., 2009), and mPFC as food motivation (Holsen et al., 2005; Holsen et al., 2006), and others suggesting that these activations reflect evaluating the biological and affective relevance of food stimuli (Killgore et al., 2003).

4.2.3. How might participants have been mentalizing about food? One possibility is that participants were mentalizing about the health consequences of eating specific foods, namely, how healthy or unhealthy they might be to consume. As Papies (2013) demonstrated, people frequently generate health features for foods (e.g., nutritious, vitamins, makes you fat, bad for your teeth). Additionally, health features are generated for both tasty and healthy foods, with more negative health features for tasty foods and more positive health features for healthy foods. Because the participants in our experiment were young females in a University community, this kind of health feature may have been typical for them, especially during the training phase when they had enough time to think about the health consequence of eating the foods received. Another possible type of self-relevant thought that participants could have generated is whether a pictured food is liked or disliked, and why.

The post-scan interview asked participants what kind of thoughts they had during the training phase. Often, participants reported having thoughts about the healthiness of the foods presented, either related to their healthiness or unhealthiness. Participants also mentioned often that they thought about whether they would eat the food more or less in the future.

4.2.4. Previous studies on mindful attention and the cortical midline. Previous research on mindful attention has reported inconsistent results along the cortical midline.

Whereas some experiments report increased activity in these areas during mindful attention, others report decreased activity.

In Lebois et al. (2015), the mindful attention group showed large activations along the cortical midlines for both the initial reading and later perspective periods while processing stressful situations. These results implicate the initial and later involvement of self-relevance processing when applying mindful attention to stressful situations.

Mindful attention has been associated with higher activity along the cortical midline in other experiments as well. When participants were asked to apply mindful awareness (being non-judgmental and open to experience) during anticipation of negative pictures, Lutz et al. (2014) found increased activity in dmPFC and dlPFC relative to controls, along with decreased emotional responses (decreased activity in the amygdala and parahippocampal gyrus). Moreover, Lutz et al. found that the activity in dmPFC was negatively correlated with participants' trait mindfulness scores. Increased activations in dmPFC have also been found in experienced meditators compared to controls during self-related tasks (Lutz, Brühl, Scheerer, Jäncke, & Herwig, 2016) and during mindful breathing (Hölzel et al., 2007), perhaps indicating increased awareness and regulatory processing in meditators.

Other work, however, has found mindful attention to be associated with decreased activity along the cortical midline (Farb et al., 2007; Kross et al., 2009; Westbrook et al., 2013). Farb et al. (2007) found decreased activation in dmPFC and PCC when novice participants were asked to focus on momentary experiences. Additionally, more marked and pervasive reductions in the dmPFC and vmPFC were observed in trained meditators (who had performed an 8-week meditation course).

When participants were asked to apply mindful attention and view experiences as passing mental events while recalling negative autobiographical memories, Kross et al. (2009) observed decreased neural activity in mPFC and sgACC, relative to a ruminative condition.

Moreover, self-reported negative affect was significantly correlated with activity in mPFC and sgACC, with lower self-reported negative affect in the mindful attention condition, suggesting that mindful attention decreased self-referential processing, which in turn decreased self-reported negative affect.

Decreased activity in sgACC was also found when smokers were asked to maintain a non-judgmental attitude towards their subjective responses to smoking pictures, compared to passive viewing (Westbrook et al., 2013). Additionally, a functional decoupling between sgACC and other craving-related regions (e.g. insula, ventral striatum) was also observed during mindful attending to the smoking pictures, suggesting that mindful attention may attenuate the relation between self-relevance and craving. Decreased activations along the cortical midline have also been found in meditators compared to controls across different types of meditation tasks, suggesting that meditation experience, in general, may diminish self-relevance processing (Brewer et al., 2011).

One interesting difference that distinguishes the increased vs, decreased activity in the previous studies is that increased activity typically occurs in more dorsal midline areas (dorsal mPFC; e.g. Lutz et al., 2014; Lutz et al., 2016), whereas decreased activity typically occurs in more ventral areas (e.g., vmPFC, sgACC; e.g., Farb et al., 2007; Kross et al., 2009; Lebois et al., 2015; Westbrook et al., 2013). One possibility is that more dorsal mPFC activity is related to regulatory control, whereas more ventral mPFC and ACC activity is related to self-relevance processing. If so, then mindful attention may decrease the activity in self-related processing (vmPFC) as the result of increased regulatory processing on the other (dmPFC). This may be a productive direction for future research.

4.2.5. Self-relevance processing during the choice phase. During the training phase, both perspectives produced extensive activations along the cortical midline (e.g., vmPFC, dmPFC, ACC, PCC). Additionally, tasty foods produced more activity than healthy foods, suggesting that the tasty foods were associated with more self-relevant thought than were the healthy foods. Of additional interest is that mindful attention exhibited much activity in more dorsal mPFC (similar to the areas found in Lutz et al. 2014), suggesting that mindful attention recruited more regulatory resources during the initial training phase, compared to the normal viewing group.

Conversely, during the later choice phase, there was a large decrease in activation along the cortical midline for the observe group, including vmPFC, sgACC, and PCC. Activity in these areas increased considerably from training to choice for the normal viewing group (Figure 7). Whereas self-relevant processing appeared to decrease substantially for the observe group from training to choice, it appeared to increase just as much for the normal viewing group. A possible interpretation is that regulatory processing decreased as benefits from the observe perspective during training became manifest during choice, whereas regulatory processing increased for the normal viewing condition as eating simulations generated during training had to be regulated during choice.

4.3. Language areas and their roles in food processing (especially during the training phase)

Another finding of interest is the extensive neural activations in left IFG, right IFG, and left lateral temporal gyrus during the training phase, followed by much less activation in these areas during the choice phase. Additionally, the observe perspective produced much more activity in these areas during training than did the normal viewing group, whereas the normal viewing group activated them more during choice. During the training phase, there was little difference between tasty and healthy foods for both perspectives, but during the choice phase, healthy foods produced more bilateral activations for both perspectives.

4.3.1. Roles of the left IFG and left lateral MTG in language processing. The function of the IFG is multifaceted, with spatially different subareas supporting different kinds of processing (Liakakis, Nickel, & Seitz, 2011). The R IFG is typically involved in response inhibition and self-control (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Tabibnia et al., 2001; Swick, Ashley, & Turken, 2011; Verbruggen & Logan, 2008). While many studies show that the L IFG also plays an important role in response inhibition (Alvarez & Emory, 2006; Swick, Ashley, & Turken, 2008), it is generally viewed as a classical language processing area (Berwick, Friederici, Chomsky, & Bolhuis, 2013; Fedorenko & Thompson-Schill, 2014; Friederici & Gierhan, 2013; Friederici, 2011; Friederici, 2012; Hagoort, 2014; Martin, 2003; Musso et al., 2003; Nishitani, Schürmann, Amunts, & Hari, 2005; Perani et al., 2011; Poeppel & Hickok, 2004; Thompson-Schill, 2005; Vigneau et al., 2006).

The lateral middle temporal cortex is also viewed as an important part of the language processing network (Berwick et al., 2013; Fedorenko & Thompson-Schill, 2014; Friederici, 2011; Friederici, 2012; Hagoort, 2014; Martin, 2003; Perani et al., 2011; Poeppel & Hickok, 2004; Saur et al., 2008).

4.3.2. Language processing during mindful attention. Speculatively, the activations in language just described could be playing the following roles in our experiment. The ability to describe one's mental states is often assumed to be an important component of mindfulness (Baer et al., 2006), Describing cognitive and affective states encourages practitioners, especially novices, to note and label their subjective experience covertly using words (Baer, Smith, & Allen, 2004). Additionally, previous work has found that the ability to describe one's experience is related to educational level (Baer et al., 2008; Van Dam, Earleywine, & Danoff-Burg, 2009). Because many meditators are often well educated, it is reasonable and perhaps inevitable that language-related areas will become active when processing one's internal experiences. Even though our participants were not experienced meditators, they were all highly educated.

Finally, previous studies on the feature listing task have demonstrated a fast, relatively involuntary, early word association process, which tends to precede situated simulations that follow (Barsalou, Santos, Simmons, & Wilson, 2008; Papies, 2013; Santos, Chaigneau, Simmons, & Barsalou, 2011). At least some of the activations we observed in language areas could have been the result of fast involuntary linguistic associates to the food images. In the training phase, however, when participants had more time to process the images, additional activations in language areas could have reflected more strategic descriptions of situated simulations that developed over time.

4.3.3. Differences between perspectives and phases in language-related areas. During the training phase, both perspectives demonstrated large activations in language-related areas, with the observe perspective activating them more than the normal viewing perspective, especially for tasty foods. These activations later decreased considerably during the choice phase, especially for the observe perspective. Interestingly, during the choice phase, healthy foods activated language areas more than tasty foods for both perspectives, especially for normal viewing. Decreased activation during the choice phase for the observe perspective, especially for tasty foods, may reflect the overall effects of mindful attention training, which were found across all brain areas that exhibited increased activation "up-front," followed by large "off-loads" later during choice.

During the training phase, there was plenty of time for participants to think about each food and possibly use words to describe their subjective experience about it (7s total for each food image). The observe perspective may have especially encouraged language processing, as participants observed their reactions to food images. In contrast, the normal viewing perspective encouraged viewing food images as usual, imagining normal interactions with the pictured foods. As a consequence, normal viewing may have produced less linguistic description.

The large decrease in these areas during the later choice phase may have resulted from two factors. First, during the choice phase, participants were asked to respond to each food image as quickly as possible. Because this processing was relatively fast (~900 ms), and because it was not necessary for participants to describe their thoughts before making a choice, much less activation may have resulted. Second, the activations that remained in these areas may primarily reflect the relatively fast, involuntary language processing associated with initially processing the food images (Barsalou et al., 2008; Binder et al., 2009; Santos et al., 2011).

Finally, the greater language activations during the training phase for tasty foods (only for the observe perspective), followed by the greater language activations during the choice phase for healthy foods is of interest. During the training phase, observe participants may have had much more “hot” subjective experience to work with for tasty foods, leading to greater linguistic description (Lebois et al., 2015; Papies et al., 2015). During the choice phase, the much longer processing of healthy foods may have allowed (or resulted from) greater linguistic description, especially for normal viewing (but also for observe). Another possibility is that the training phase increased the attractiveness of the healthy foods (given the attractive images presented), thereby generating more related language during choice that described these earlier experiences. Assessing these possibilities is an important direction for future research.

4.4. Grounded cognition and food processing

According to the perspective of grounded cognition (e.g., Barsalou, 2008; Barsalou, 2009), when people cognize about entities, events, and internal states that are not present, they simulate the processing performed on these things similar to when they are present. As a result, multimodal simulations, bodily states, and situated action underlie cognition as people represent knowledge about entities and events, both present and absent. Thus, when people process a food cue, they reactivate brain areas similar to those that are active while actually eating the food (Chen et al., 2016). In other words, memories of eating later support multimodal simulations of eating the food associated with a current food cue. As a result, cognitive responses to food cues often include simulations, which are grounded in food-specific processing areas associated with actual food consumption, including a food's visual appearance, smell, taste, consumptive actions, predicted hedonic rewards, and long-term health consequences.

4.4.1. Establishing the breadth of activations associated with food processing. We observed large activations across brain areas frequently associated with eating and food (insula, OFC, amygdala, piriform cortex, uncus), visual processing (dorsal and ventral stream), self-related thought (the cortical midline), language processing (L IFG, L lateral temporal gyrus), and action (SMA, pre-central and post-central gyrus, cerebellum, thalamus, basal ganglia), for both tasty and healthy foods, for both the normal viewing and observe perspectives, for both the training and choice phases. The breadth of these activations grounds the simulations associated with food cue processing across diverse brain areas associated with the situated action that occurs while eating.

To our knowledge, no previous work on food cue processing has established the breadth of activations observed here. Again, our ability to establish this breadth most likely resulted from assessing breadth of neural activity relative to well-matched active baselines, rather than focusing on contrast differences in BOLD intensity. As Chen et al. (2016) document, the taste, reward, and visual appearance of food cue processing has been demonstrated frequently. Other aspects of food simulations associated with olfaction, embodiment, and situated action either have received much less attention or not shown at all (along with self-relevance processing, as addressed earlier; 4.2). We address these additional types of activation next in turn.

4.4.2. Olfaction and food processing. We observed large activations in olfactory areas (piriform cortex and uncus) that could clearly be associated with food and eating (Kringelbach, Stein, & van Hartevelt, 2012). In the literature that Chen et al. (2016) reviewed on food cue processing, no studies reported activations in uncus and only one reported activation in right piriform cortex, which was uncorrected (Malik et al., 2008). One possibility is that activations in these areas weren't observed because these studies focused on activation intensity relative to a resting state baseline, thereby obscuring these effects (Figure 2). We may have been able to see them here because we assessed breadth of activation relative to well-matched active baselines instead.

Other work has found activations in piriform cortex, but in different kinds of tasks, including sniffing foods (pizza, beef) (Eiler et al., 2012), comprehending words with strong olfactory associations (e.g. aroma, coffee, flower, cinnamon) (González, et al., 2006), and smelling odorants (Bengtsson, Berglund, Gulyas, Cohen, & Savic, 2001; Cerf-Ducastel & Murphy, 2004; Royet, Plailly, Delon-Martin, Kareken, & Segebarth, 2003).

Smell has been found to be a feature that participants generate when asked to generate features of the foods (Papies, 2013). During the interview after scanning in our experiment, participants reported that they thought of food smells during the training phase. Thus, the activations we observed in these areas could reflect simulations of smelling pictured foods.

4.4.3. Embodiment and food processing. According to the grounded cognition perspective (Barsalou, 2008; Barsalou, 2009), representations of familiar situations that contain embodiments become established in memory (e.g., when receiving a gift, smiling and feeling happy). When part of this situation occurs (e.g., receiving a gift), it activates the remainder of the situational pattern, producing associated embodiments (e.g., smiling). Similarly when people eat a tempting food, its visual appearance, how it tastes and smells, the actions performed while consuming it, how rewarding it is, and the resulting emotional experiences all become established in memory together as a situational pattern. Later, when visually perceiving a cue associated with this food, it activates the remainder of the situational pattern (e.g. taste, reward, smell) and primes associated actions (e.g. approach the food). Tasty foods are typically associated with more situated simulations than healthy foods (Papies, 2013), accompanied by strong tendencies to approach them, relative to healthy foods (Baquedano et al., 2017; Papies et al., 2012), especially when hungry (Goldstone et al., 2009; Papies et al., 2015; for a review, see Chen et al., 2016; for a meta-analysis of neuroimaging studies, see van der Laan et al., 2011).

We observed considerable activations in areas associated with action (e.g. SMA, pre-central and post-central gyrus, cerebellum, thalamus), for both the normal viewing and observe perspective. During the training phase, tasty foods activating these areas more than healthy foods, suggesting that tasty foods are more associated with actions than healthy foods. Conversely, the choice phase showed opposite pattern, with healthy foods activating action areas more than tasty foods.

Previous studies have also observed activations in action areas for food cue processing, including pre-central and post-central gyrus (Beaver et al., 2006; Conier et al., 2009; Holsen et al., 2005; Killgore et al., 2003; Malik et al., 2008), SMA (Davids et al., 2010), thalamus (Führer et al., 2008; Killgore et al., 2005; Schur et al., 2009), cerebellum (Beaver et al., 2006; Führer et al., 2008; Holsen et al., 2005; Killgore et al., 2003), and putamen (Davids et al., 2010; Killgore et al., 2005b; Rothemund et al., 2007; Schur et al., 2009), however, with little interpretation of activations in these areas offered.

4.4.4. The parahippocampal gyrus and food processing. The parahippocampal gyrus is typically thought to be an area that processes places and scenes (e,g., Epstein & Kanwisher, 1998). We observed significant activations in this area for both perspectives. Other food processing studies also demonstrated the activations in the areas, when comparing tasty foods with healthy foods (Beaver et al., 2006; Holsen et al., 2005), and when tasty foods and healthy foods were combined (Killgore et al., 2005; Malik et al., 2008; St-Onge et al., 2005). Parahippocampal gyrus also becomes more active when people are hungry, compared to when they are satiated (LaBar et al., 2001).

The interview after the scan indicated that many participants thought about the situations associated with foods during the training phase (e.g. "where I would eat it", "I was always picturing myself interacting with the food in my kitchen", "imagining myself eating that food at school or at home", "where it was most commonly found", "environment where food would be prepared"). Research on feature listing for foods has also found that people associate situations (or places) with foods, especially tasty foods (Papies, 2013).

From the grounded perspective, when people eat a food, the situation where the food is consumed becomes established in memory, along as its taste, smell, consumptive actions, mentalizing, and reward. Later, when people encounter cues associated with the food, situations where the food has been eaten become active, together with other inferred features. Tasty foods may become associated with situations because these situations are where the pleasure and reward associated with eating is experienced (Papies, 2013). In contrast, healthy foods may be more associated with long-term health consequences and thus be less associated with specific eating situations.

4.4.5. Summary. The perspective of grounded cognition proposes that multimodal simulations, bodily states, and situated action underlie cognition about entities and events in the world. When people process a food cue, they reactivate brain areas similar to those that are active while actually eating the food. Using an active baseline, we observed a broad breadth of activations that are likely to ground the diverse aspects of consumption simulations.

4.5. How does mindful attention work?

4.5.1. Decentering and mindful attention. As described above, when seeing a tempting food cue, people simulate the experience of eating the food. As a consequence, they may often immerse themselves in rewarding simulations of consuming the food via mental time travel. On becoming immersed in a thought, the thought often appears to adopt the quality of seeming subjectively real, as if it were happening in the moment (Papies et al., 2012, 2015). When practicing mindfulness, however, people instead view these simulations as transitory mental states in the moment. A "shift in perspective" results from no longer being immersed in the thoughts and feelings that result from processing the food cue (Lebois et al., 2015). Shifting perspective in this way disrupts time travel by remaining in the moment with the thought. Once the perceiver is no longer "centered" in the thought, the perceiver becomes "decentered", viewing the thoughts, feelings, and reactions as a passing mental state rather than as a subjectively real experience (Bishop, 2004; Brown, Ryan, & Creswell, 2007).

4.5.2. Mindful attention in the training and choice phases: Up-front vs. off-loaded processing. As predicted, mindful attention induced much more "up front" neural processing of foods than normal viewing that later resulted in much less processing during food choice across brain areas associated with food processing. This pattern was also found in Lebois et al., (2015), who showed stronger activations during an initial reading period followed by much decreased activations during the subsequent perspective period for participants who adopted the mindful attention perspective on stressful situations.

Two important issues follow from this replicated pattern of results. First, what kind of "up front" processing occurs as people practice mindful attention on foods and stress? Second, what effects does this initial processing have on "off-loading" processing later during food choice and stress experience?

The broadly distributed pattern of activations across the brain here suggests one possible approach to addressing these issues. Adopting the observe perspective during training induced participants to generate more content of eating simulations than during normal viewing, and further induced much more mentalizing about it and describing it linguistically. Whereas greater activations for the observe condition in visual, taste, smell, and action areas implicate greater activation of simulation content, greater activations along the cortical midline and in language areas implicate greater mentalizing and linguistic description.

A further consequence of all this increased initial “up-front” processing may have been to establish a clearer evaluation overall of each food’s features and desirability. Thus, later during the choice phase, much less processing was required for reaching a food choice decision. Although being non-judgmental is an important component for mindfulness, our instructions didn’t mention it and instead emphasized being non-reactive and observing reactions arise and dissipate. Therefore, it is possible that participants performed some evaluative processing during the training phase, as found in the exit interviews when some participants mentioned they should eat more healthy food.

Another possibility is that participants did not perform evaluative processing during the training phase but instead just observed all simulations of eating. Because so much information about each food was active during training for the observe perspective, much less processing was required to represent its features during choice, to evaluate their relevance for eating, and to finally make a choice. The especially large decrease along the cortical midline during choice for the observe perspective suggests that much less mentalizing took place later as a result of mentalizing so much about each food earlier.

Clearly, this speculative account of how mindful attention operated during the observe perspective requires further investigation. Besides attempting to verify the above account, much remains to be learned about how mindful attention operates initially, and the effects that it produces subsequently.

4.5.3. “Top-down” or “bottom-up” processing. Some researchers view mindful attention as a form of “bottom-up” processing, without any evidence for “top-down” regulatory processing whereby mindfulness decreases the bottom-up flow of information about appetitive stimuli (Westbrook et al., 2013). As reviewed earlier, however, other researchers view mindful attention as engaging top-down processes (4.2). Next we explore how “top-down” processing may play central roles in decreasing bottom-up processing.

One possibility, consistent with our account in the previous section, is that mindful attention initially engages top-down processing heavily, as it generates and processes subjective experience, both with respect to mentalizing and linguistic description. Once this initial top-down processing has occurred, it tends to drop away on later occasions, allowing bottom-up processing to proceed with less accompanying top-down processing. The overall amount of bottom-up processing may also decrease as the result of less top-down processing of it.

If this account is correct, then it suggests that there may be a constant dynamic interplay between top-down and bottom-up processing as mindful attention is practiced. Of further interest is how this interplay develops over the course of extended practice, especially whether there’s an eventual decrease in top-down processing, accompanied perhaps by an additional decrease in “unencumbered” bottom-up processing.

4.5.4. Mindful attention exhibits stronger effects for tasty foods. As found in Lebois et al. (2015) and Papies et al. (2015), mindful attention exhibited stronger effects as the hedonic and affective strength of stimuli increased. Because tasty foods are generally associated with stronger activations and affective responses (Chen et al., 2016; van der Laan et al., 2011), mindful attention has more subjective content on which to operate. As simulations of consuming tasty foods become active, and as their content receives mindful attention, much more activity occurs initially to process it, followed subsequently by a much larger decrease in processing activity (and potentially, desire), as these simulations dissipate. In other words, the process of decentering from tasty food simulations produces considerable up-front processing to represent, mentalize, and describe all the processing taking place. Subsequently, however, the result of all this initial processing is a considerable reduction in representing and evaluating the food the next time it's encountered.

In contrast, healthy foods are associated with sparser eating simulations, such that there is less mental content (especially affective) on which mindful attention can operate (Papies, 2013). Furthermore, people usually know that it is good to consume healthy foods, such that decentering from hedonic simulations of consuming them is not necessary. For both reasons, mindful attention may show weaker effects on healthy foods than on tasty foods.

4.5.5. Repetition effects for mindful attention training. We found that mindful attention training affected food choices via both a general cognitive set and food-specific memories. During the choice phase, the novel foods exhibited a decrease in neural activation similar to repeated foods, indicating the presence of a general cognitive set. In behavioral experiments, mindful attention training has been found to generalize modestly to new stimuli (Papies et al., 2012, Experiment 3), and also in a field setting when participants shifted their food choices from tasty foods to healthy foods (Papies et al., 2015). These results indicate that after learning the mindful attention perspective, participants can spontaneously apply the perspective to the new stimuli in real settings, at least within a short time frame. This result is encouraging and promising, and has potentially useful applications in real world applications. One possibility may be that once repeated foods trigger the mindful attention perspective, it then becomes applied to novel foods encountered while the perspective is still in place. This possibility constitutes an important direction for future research.

Additionally, however, repeated foods were responded to faster than novel foods, and also generally recruited fewer brain activations, additionally reflecting food-specific memory effects. Although a general cognitive set affected the processing of novel foods, they still required additional processing given the lack of a memory benefit. This pattern suggests that novel foods can benefit from food-specific training if the general cognitive set is in place. If it's not, however, no benefits may be experienced. Again, this is another possibility for future research. For tasty foods that are eaten frequently, it may be especially important to practice mindful attention on them, both to be sure that the mindful attention perspective becomes active, and to maximize the total amount of benefit obtained from both general and specific effects.

4.5.6. Summary. When applying mindful attention, simulations related to the food experiences are reactivated. If the mindful attention perspective becomes active—either as a general set or via food-specific memories—people decenter themselves from these simulations by observing simulation content, including mentalizing, and describing it, thereby experiencing them as transitory mental states instead of as subjectively real experiences that engage desire and action. For the tasty foods, mindful attention has more psychological content on which to operate and to observe, such that as this content becomes active and then dissipates, greater effects of mindful attention follow. This processing may be realized by a dynamic interplay between both "top-down" and "bottom-up" processing.

4.6. Stronger activations for healthy foods during the choice phase (especially for the normal viewing group)

As predicted by the large literature on food cue processing, we observed more activations for tasty foods than for healthy foods only during the training phase. During the later choice phase, however, we observed an unexpected and intriguing result: Healthy foods produced greater activations across the brain than did tasty foods, especially for the normal viewing perspective. Quite strikingly for normal viewing perspective, there was a very large increase from the training phase to the choice phase in the total voxels active for healthy foods (Figure 4). There was also an increase from training to choice for the observe perspective as well, but it was much smaller. What is striking about both effects, though, is that more voxels were active during choice than during training, even though choice typically required much less processing in a shorter time period than did training. Lebois et al. (2015) reported a similar pattern for non-stressful situations, with greater activation generally occurring for non-stressful situations during the later strategy phase, for both the mindful attention and immersion perspectives.

Because no other experiment has assessed the effect of prior training on neural activations during subsequent foods choices, we can bring no previous literature to bear. Next, however, we propose a few possible reasons for the pattern observed here. Again, further work is needed to understand the effects of prior training on healthy vs. tasty foods.

One possible explanation is associated with the longer RTs for healthy foods. As reported in 3.2, healthy foods took 93 ms longer to process during the choice phase than tasty foods (963 vs. 870 ms). This difference in RTs, together with greater neural activity for healthy foods, suggests that more cognitive resources and processing were required for making choices about the healthy foods.

Another possible explanation is that the initial training phase created stronger memories for tasty foods than for healthy foods that later facilitated choices for tasty foods more than for healthy foods. As described in 3.2, there was a significant interaction between food type and repetition for the RTs. For tasty foods, the repeated foods were responded to faster than were the novel foods. For healthy foods, however, there was no difference between repeated and novel foods, implicating stronger memory effects for tasty vs. healthy foods. If this account is correct, then it is necessary to explore why stronger memories were established for tasty foods than for healthy foods. One possibility is simply that the tasty foods engaged more attention and deeper processing, given their hedonic relevance, that produced better memories.

Still another possibility is that participants may have reconsidered the importance and consequence of eating healthy foods. The interviews after scanning often observed a changed awareness to “eat more healthy foods for my health” in many participants. After encountering many food pictures during the training phase, a healthy eating orientation may become activated, and then lead to higher activations for healthy foods during the choice phase.

Finally, encountering the healthy foods during training—especially via attractive pictures of them—may have created unusually attractive memories as well. As these memories later became active during choice, they may have competed with other less attractive memories. To resolve the conflict and reach a food choice, greater processing may have been required, as reflected in both longer RTs and greater neural activity.

Clearly, all these explanations require further examination to better understand the findings for healthy foods, and also to further foster healthy choices in industrialized environments where unhealthy foods are marketed aggressively.

4.7. Limitations

This study, for the first time, demonstrated the breadth of activations for food processing by using active baselines and assessing the breadth of activations above the active baseline (instead of differences in contrast intensity). These findings further reveal the neural mechanisms of mindful attention, with stronger activations “up front” across the whole range of the food processing areas most likely grounded in eating experience. Additionally these findings suggest the possible roles of greater initial mentalizing and linguistic description in this greater “up-front” processing that decenters individuals from eating simulations. There are, nevertheless, various limitations of the study that are important to note.

One limitation is that we only included young females in the experiment. Obviously, it is important to generalize to other groups (e.g. males) and to different age groups (e.g. children, adolescents, the elderly).

Another important limitation of our experiment is the lack of a no training baseline. In future work, it would be quite useful to include a no training baseline so that the individual effects of observe and normal viewing can be assessed with respect to it, rather than to each other. We are likely to develop more precise accounts of each perspective from these comparisons. Another important reason for including a no training baseline is to assess whether tasty or healthy foods produce more neural activity during choice, when memories aren't created beforehand in a training phase. Of particular interest is whether tasty foods now produce greater neural activity, as found in much previous research (Chen et al., 2016). If so, then this further highlights the importance of understanding how initial training affects the processing of healthy vs. tasty foods later during food choice.

Another limitation of our experiment was the lack of a perspective effect on food choice behavior. Although we found strong effects of perspective on neural activity, we found no accompanying effect on behavioral choice, as found in previous behavioral experiments (Baquedano et al., 2017; Papies et al, 2012; Papies et al., 2015). Although mindful attention generally increased healthy foods choices relative to the normal viewing condition (34.8 vs. 30.75 over 60 trials), the difference was not significant.

One potential explanation for our lack of behavioral effects concerns the task that we used here. Papies et al. (2012) used an implicit approach-avoidance task to show that mindful attention can decrease the impulsive approach to tasty foods (as did Baquedano et al., 2017). Other studies (Fisher et al., 2016; Marchiori & Papies, 2014; Papies et al., 2015) used the amount of food consumption as the indicator, with mindful attention decreasing the amount of tasty foods consumed (e.g. cookies). In our experiment here, participants were asked to judge whether they would like to eat or not to eat the food right now.

Our binary yes-no choice task differs from the task of eating cookies in the real world in many aspects (although Papies et al., 2015, found effects of mindful attention on a binary food choice task). First, during a yes-no choice task, participants were only focusing on eating each food individually instead of comparing foods and selecting one or more foods from them, which is how natural decision making typically occurs in the real world. Second, in real eating situations, people may still want to eat tasty foods but have to choose more healthy foods because of health or other considerations. Third, the yes-no choice task in the experiment had no physiological feedback from the early trials related to decreased hunger (because participants weren't actually eating). In real eating situations, however, when participants are asked to consume a food, they receive the feedback from eating, which leads to eating more or stopping eating. These observations suggest that mindful attention may be more likely to reveal behavioral effects in other tasks more closely related to actual eating.

Still another explanation for a lack of behavioral effects concerns our participants' hunger state. The hunger ratings just after the scanning indicated that participants were in highly hungry states (6.35 and 6.15 out of 7 for normal viewing and observe respectively, compared to 4.22 in Papies et al., 2015). Post-experiment interviews also revealed extremely high hunger levels in most participants. In extremely hungry states, it may be more difficult to avoid tasty foods and choose healthy foods instead, leading to decreased behavioral effects (even though very large neural effects remained). This possibility, however, needs further investigation in other laboratory experiments and field studies.

Finally, many other aspects of our experiment differed significantly from previous behavioral experiments. Our experiment here included 60 training foods, which is much more than previous experiments have used. Additionally, our training and choice phases occurred in an fMRI scanner, with participants lying supine in a highly technical and noisy environment. Together, all of these differences, as well as previous ones just mentioned, may have contributed to lack of a behavioral effect. Clearly, this is a set of issues to explore further. It will be of particular interest to increasingly establish relations between neural activity and eating behavior, not only in the laboratory, but also in the real world.

4.8. Future directions

In many previous sections, we have noted important areas for future research. Here we focus on several that we believe are particularly important.

4.8.1. Short-term effect vs. long-term effects of mindful attention training. As suggested in Tang, Hölzel, and Posner (2015), there are roughly three different stages of mindful meditation practice that require different amounts of effort: an early stage with effortful doing, a middle stage with effort to reduce mind wandering, and an advanced stage with effortless being. Studies have shown both structural (Hölzel et al., 2008; Fox et al., 2014) and functional (e,g., Hölzel et al., 2008; Lutz et al., 2016) differences between advanced meditators (many years of meditation) and meditation-naïve controls. As demonstrated in a very different kind of research, however, people have a strong pre-existing disposition to learn and apply the skills to decenter (e.g. Baquedano et al., 2017; Fisher et al., 2016; Lebois et al., 2015; Papies et al., 2012, 2015; Marchiori & Papies, 2014). People who have never practiced meditation readily adopt the mindful attention perspective such that it influences both behavior, neural activity, and bodily activity. Further studies are needed to better understand how these initial skills develop, together with the trajectory of changes that follow with more mindful attention practice.

Another important question is whether mindful attention is stimulus-specific. Some research indicates it may be stimuli-specific (Papies et al., 2016), which found that more food-specific decentering experiences in one’s past were associated with fewer food cravings in daily life for meditators. Further studies investigating whether mindful attention training on one type of stimuli (e.g., food) can have benefits for another type (e.g., emotional situations) will be helpful to clarify this question.

In previous mindful attention research, a brief mindful attention training was found to reduce the effects of hunger on unhealthy food consumption (Marchiori & Papies, 2014; Papies et al., 2015). In the mindful attention group, being hungry no longer boosted the attractiveness of unhealthy foods. In our experiment, however, we found no such effect following mindful attention practice. As noted earlier, our participants were in a highly hungry state that may have made mindful attention ineffective. Research typically appears to assess the immediate effects of mindful attention training, within a relatively short time frame, before participants have become very hungry. Thus another set of questions concerns how effective mindful attention is for different levels of hunger, how much brief training (if any) would be sufficient to overcome high levels of hunger, and how long brief training effects last? Perhaps most importantly, how much extended (as opposed to brief) mindful attention training is required for people to develop and maintain a significant, stable, and persistent change in perspective when they choose foods and attempt to maintain healthy eating habits.

4.8.2. Other populations. Because only females were included in the experiment here, whether its findings can be applied to other populations remains unknown. Further studies are needed to investigate whether and how the mechanisms of mindful attention operate in other populations, such as individuals with binge eating disorder, anorexia nervosa, and bulimia nervosa. Also of interest are the effects of mindful attention vary across SES.

4.8.3. Functional connectivity during mindful attention processing. A few experiments have established differences in functional connectivity between brain areas that process self-relevance and craving during mindful attention (e.g., Westbrook et al., 2013). Other experiments have found that mindfully attending to the breath changes connectivity between the amygdala and dorsal prefrontal cortex while viewing aversive pictures (Doll et al., 2016). Similarly, three days of intensive meditation training was found to decrease the functional connectivity between amygdala and sgACC during the resting state (Taren et al., 2015). All these findings indicate that relatively short-term mindfulness training can promote changes in functional connectivity. Additionally, long-term meditation experience has found to increase the coupling between PCC and areas associated with self-monitoring and cognitive control (dorsal ACC and dlPFC), both at rest and during meditation (Brewer et al., 2011). Hasenkamp and Barsalou (2012) similarly observed effects across distributed control networks following long-term meditation experience. Further research exploring patterns of functional connectivity during both task and the resting states, will be useful for better understanding how mindful attention operates. Because little research has addressed functional connectivity in eating networks, doing so offers another important direction for future research.

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Appendix A

Food images used in the training and choice phases

All of the food images were sampled from a food image database developed and maintained by Blechert, Meule, Busch, and Ohla (2014). Figure A1 presents the 60 tasty food images used in the experiment, and Figure A2 presents the 60 healthy food images. For both the tasty and healthy food images, 30 were used both for the training session and the choice session (i.e., “Training and choice repeated”), and the other 30 were only used in the choice session (i.e., “Choice novel”). Thus, 30 tasty and 30 healthy food images, were used in the training session (60 total), whereas all 120 food images were used in the choice session.

Figure A1. Tasty food images used in the experiment

Training and choice repeated

Choice novel

Figure A2. Healthy food images used in the experiment

Training and choice repeated

Choice novel

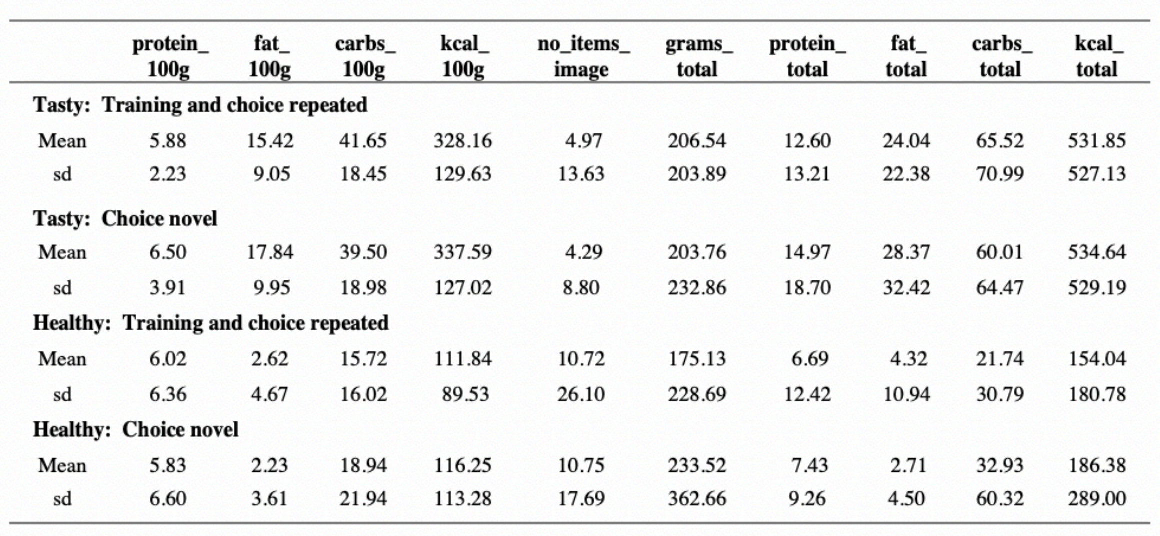
Appendix B

Food image statistics

Blechert, Meule, Busch, and Ohla (2014) provided rich information about the food images in their data base. We have used this information to establish images statistics for the food images that we sampled. Because we only included women in our experiment, and because they did not exhibit special dieting habits (omnivore vs. vegetarian), the ratings for omnivore women in the dataset were used for the statistics.

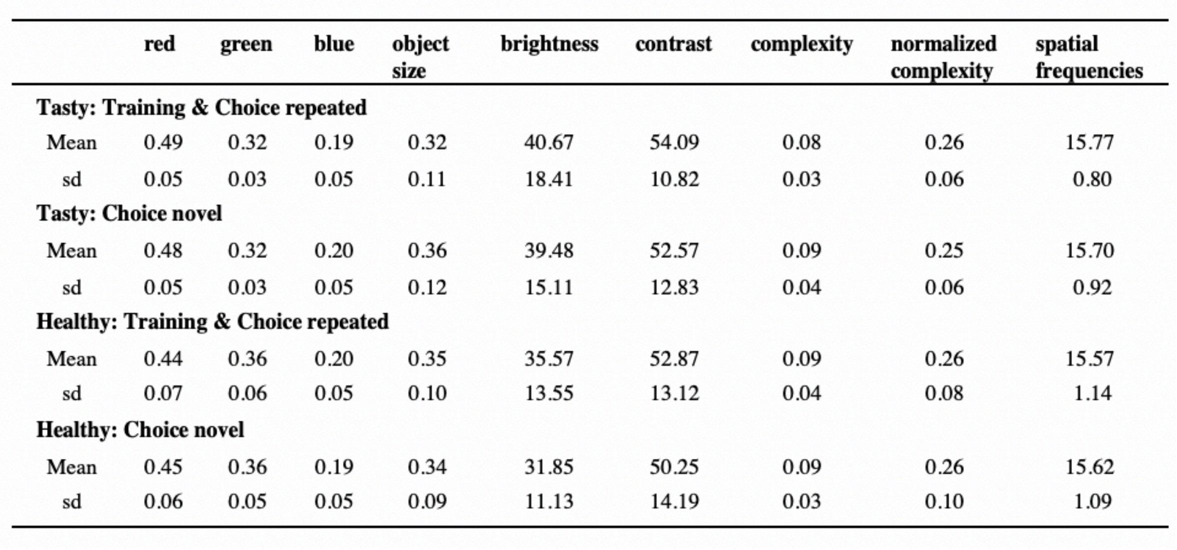
Tables B1, B2 and B3 present nutrition and energy characteristics, visual characteristics, and additional properties of the tasty and healthy foods sampled. For each table, "Training and choice repeated" refers to images used in both the training phase and on the choice repeated trials, whereas "Choice novel" refers to images only used on the choice novel trials (see Appendix A). All image statistics were matched for the Training and choice repeated images and the Choice novel images. Tasty and healthy foods were matched as closely possible, except for a few properties that naturally vary between the two food types (e.g. red, green, fat_100g, Kcal_100g, fat_total, Kcal_total; see the Methods section for details).

Table B1. Nutrition and energy characteristics for tasty and healthy food images used in the experiment.



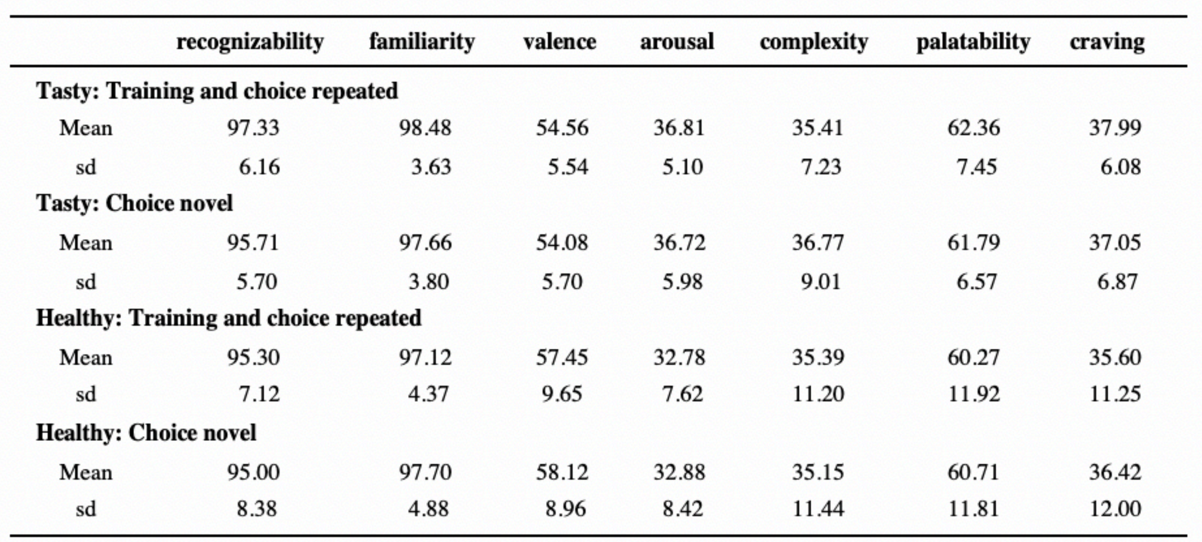
	protein_ 100g	fat_ 100g	carbs_ 100g	kcal_ 100g	no_items_ image	grams_ total	protein_ total	fat_ total	carbs_ total	kcal_ total
Tasty: Training and choice repeated										
Mean	5.88	15.42	41.65	328.16	4.97	206.54	12.60	24.04	65.52	531.85
sd	2.23	9.05	18.45	129.63	13.63	203.89	13.21	22.38	70.99	527.13
Tasty: Choice novel										
Mean	6.50	17.84	39.50	337.59	4.29	203.76	14.97	28.37	60.01	534.64
sd	3.91	9.95	18.98	127.02	8.80	232.86	18.70	32.42	64.47	529.19
Healthy: Training and choice repeated										
Mean	6.02	2.62	15.72	111.84	10.72	175.13	6.69	4.32	21.74	154.04
sd	6.36	4.67	16.02	89.53	26.10	228.69	12.42	10.94	30.79	180.78
Healthy: Choice novel										
Mean	5.83	2.23	18.94	116.25	10.75	233.52	7.43	2.71	32.93	186.38
sd	6.60	3.61	21.94	113.28	17.69	362.66	9.26	4.50	60.32	289.00

Table B2. Visual characteristics for tasty and healthy food images used in the experiment.



	red	green	blue	object size	brightness	contrast	complexity	normalized complexity	spatial frequencies
Tasty: Training & Choice repeated									
Mean	0.49	0.32	0.19	0.32	40.67	54.09	0.08	0.26	15.77
sd	0.05	0.03	0.05	0.11	18.41	10.82	0.03	0.06	0.80
Tasty: Choice novel									
Mean	0.48	0.32	0.20	0.36	39.48	52.57	0.09	0.25	15.70
sd	0.05	0.03	0.05	0.12	15.11	12.83	0.04	0.06	0.92
Healthy: Training & Choice repeated									
Mean	0.44	0.36	0.20	0.35	35.57	52.87	0.09	0.26	15.57
sd	0.07	0.06	0.05	0.10	13.55	13.12	0.04	0.08	1.14
Healthy: Choice novel									
Mean	0.45	0.36	0.19	0.34	31.85	50.25	0.09	0.26	15.62
sd	0.06	0.05	0.05	0.09	11.13	14.19	0.03	0.10	1.09

Table B3. Additional properties for the tasty and healthy food images used in the experiment.



	recognizability	familiarity	valence	arousal	complexity	palatability	craving
Tasty: Training and choice repeated							
Mean	97.33	98.48	54.56	36.81	35.41	62.36	37.99
sd	6.16	3.63	5.54	5.10	7.23	7.45	6.08
Tasty: Choice novel							
Mean	95.71	97.66	54.08	36.72	36.77	61.79	37.05
sd	5.70	3.80	5.70	5.98	9.01	6.57	6.87
Healthy: Training and choice repeated							
Mean	95.30	97.12	57.45	32.78	35.39	60.27	35.60
sd	7.12	4.37	9.65	7.62	11.20	11.92	11.25
Healthy: Choice novel							
Mean	95.00	97.70	58.12	32.88	35.15	60.71	36.42
sd	8.38	4.88	8.96	8.42	11.44	11.81	12.00

Appendix C

Individual measures used in the experiment

Table C1 presents the materials used to obtain the individual difference measures, including hunger, frequency of consuming the foods, food attractiveness, restrained eating, healthy eating, trait decentering, and trait self-control. The hunger question was asked twice, once before the scan and once after, thereby providing hunger_before and hunger_after scores. The frequency and attractiveness questions were each asked for the 120 foods presented randomly after scanning. The Dutch eating behavior questionnaire (to assess restraint, van Strien et al., 1986), the healthy eating questionnaire (Hearty, McCarthy, Kearney, & Gibney, 2007), the brief trait self-control (Tangney, Baumeister, & Boone, 2004), and the decentering questionnaire (Papies, van Winckel, & Keesman, 2016) were all assessed after the scan.

Table C1: Individual difference measurements used in the experiment.

Questionnaire	Trials	Question	Scales
Hunger	1	How hungry are you now?	1 (not at all) ---- 7 (very hungry)
	Open-ended	When was your last full meal?	
	Open-ended	What did you eat?	
Frequency	1-120	How often do you eat the food shown in the picture?	X --- Not recognized 0 ---- Never 1 ---- Rarely 2 ---- Sometimes 3 ---- Often
Attractiveness	1-120	How attractive do you find the food shown in the picture?	1 (not at all) ---7 (highly attractive)
The Dutch eating behavior questionnaire	1	If you have put on weight, do you eat less then you usually do?	1 ---- Never 2 ---- Seldom 3 ---- Sometimes 4 ---- Often 5 ---- always
	2	Do you try to eat less at mealtimes than you would like to eat?	
	3	How often do you refuse food or drink offered because you are concerned about your weight?	
	4	Do you watch exactly what you eat?	
	5	Do you deliberately eat foods that are slimming?	
	6	When you have eaten too much, do you eat less than usual the following days?	
	7	Do you deliberately eat less in order to become healthier?	
	8	How often do you try not to eat between meals because you are watching your weight?	
	9	How often in the evening do you try not to eat because you are watching your weight?	
	10	Do you take into account your weight with what you eat?	
Healthy eating	1	I try to keep the amount of fat I eat to a healthy amount	1---- Most of the time 2 ---- Quite often 3 ---- Now & again 4 ---- Hardly ever 5 ---- Don' know
	2	I don't need to change my diet as it is healthy enough.	
	3	I make conscious efforts to try and eat a healthy diet	
Brief trait self-control	1	I am good at resisting temptation.	1 (not at all) ---- 5 (very much)
	2	I have a hard time breaking bad habits. *(recode)	
	3	I am lazy. *(recode)	
	4	I say inappropriate things. *(recode)	
	5	I do certain things that are bad for me, if they are fun. *(recode)	
	6	I refuse things that are bad for me.	
	7	I wish I had more self-discipline. *(recode)	
	8	People would say that I have iron self-discipline.	
	9	Pleasure and fun sometimes keep me from getting work done. *(recode)	
	10	I have trouble concentrating. *(recode)	
	11	I am able to work effectively toward long-term goals.	
	12	Sometimes I can't stop myself from doing	

		something, even if I know it is wrong. *(recode)	
	13	I often act without thinking through all the alternatives. *(recode)	
Decentering questionnaire	1	I notice that food elicits certain reactions in me.	1 (Never) ---- 7 (Always)
	2	I notice what I think about food.	
	3	I notice how I react to food.	
	4	When I have thoughts about food, I notice these thoughts come and go.	
	5	I consider my thoughts about food as transient events in my mind.	
	6	The thoughts I have about food are very intense. *(recode)	
	7	I get lost in my thoughts about food. *(recode)	
	8	The thoughts I have about food seem very real. *(recode)	
	9	Food affects me strongly. *(recode)	
	10	I can distance myself from my thoughts about food.	
	11	I am able to separate myself from my thoughts about food.	
	Open-ended	Which thoughts did you have during the first task when you were asked to adopt your perspective to pictures?	
	Open-ended	How did you experience your thoughts during the first task when you were asked to adopt your perspective to pictures?	

Appendix D

Training instructions

The complete instructions follow for each of the two training groups: Normal Viewing perspective vs. Observe perspective. All instructions were presented by a computer outside the scanner, just prior to the scan. Dashed lines indicate the slide breaks between pages of instructions. The instructions include both the text and food images that participants received. The instructions for each training perspective fall into four sections: (1) learning the color warmth task (the active baseline during training), (2) learning the assigned perspective, (3) learning how to make the training judgments, and (4) practicing all the tasks performed in the training session together.

Training instructions for the Normal Viewing perspective

Thank you for participating in our experiment. There's something that we need to discuss first that is very important. We bring it up now so that you can think about it and remember its importance when you're in the scanner.

It is very important to not move your head at all in the scanner. If you move your head even a small amount, we may not be able to use your data. For this reason, it is very important to get comfortable initially when you first lie down in the scanner, and to spend time working on this until you are comfortable.

Once you're comfortable in the scanner, please do not move your head until the experiment is over.

Out of every 10 scans, 1 person moves their head too much. So this is a problem that we have to worry about. We don't want you to be one of the people whose data we can't use. If you have any questions or concerns about this, please bring them up with us now, or when you're in the scanner.

When you're ready to go on, please press the right-most button on the button box in front of you.

We are now ready to begin the main instructions. Later, when you're in the fMRI scanner, you will perform two tasks: a color warmth task, and a normal viewing task. In the next few minutes, before we go into the scanner, we will go over these two tasks and perform some practice.

We will first work on the color warmth task and then on the normal viewing task. Once you've become familiar with both, we'll do a little practice performing them together.

When you're ready to go on, please press the right-most button on the button box in front of you.

First we'll go over the color warmth task. You will perform the color warmth task multiple times, as it alternates with the norm viewing task. Whenever it's time to perform the color warm task, you'll first receive the following instruction:

Please judge the average color warmth.

Soon thereafter, you'll see 5 abstract pictures each presented for a few seconds. As each abstract picture is presented, please assess the warmth of the colors in it. That's all you need to do as each picture is presented.

Press the right-most button on the button box to go on.

Once the fifth abstract picture has been presented, you'll be asked to judge color warmth:

What was the average color warmth of the previous 5 pictures?

1 2 3 4

very cold very warm

To make your response, press one of the four buttons on the button box that you're holding. Here, 1, the left-most button, means "very cold", whereas 4, the right-most button, means "very warm." The middle two buttons are for indicating 2 or 3, which represent intermediate warmth.

Once you've determined the average color warmth of the previous 5 pictures, press the button that best describes your judgment.

Do you have any questions? When you're ready for some practice, please press the right-most button.

Do you have any questions?

We are now ready to learn about the norm viewing task. When you're ready for learning about the normal viewing task, please press the right-most button.

Now we will go over the normal viewing task. In this task, we will teach you to adopt a particular perspective on viewing pictures of food.

Once you have learned this perspective, we will ask you to use it in the experiment that will follow in the scanner.

We will refer to this as the *normal viewing* perspective. We will ask you to adopt the normal viewing perspective while viewing pictures of food that will be presented to you on the computer screen.

Please press the right-most button to continue.

Here's how the normal viewing perspective works. Consider this cinnamon roll. Imagine encountering it in the world. Maybe consider a situation where you would eat it. What would it be like to encounter this food? Simply imagine encountering the food.

Please press the right-most button to continue.

As you imagine encountering this food, view it as you normally would. For example, you might imagine looking the food over, examining how it looks. You might find the food attractive, or not so attractive. You might experience wanting to eat the food. Simply view the food as you normally would if you were to encounter it in the world somewhere.

Please press the right-most button to continue.

As you imagine encountering this food, view it as you normally would. For example, you might imagine looking the food over, examining how it looks. You might find the food attractive, or not so attractive. You might experience wanting to eat the food. Simply view the food as you normally would if you were to encounter it in the world somewhere.

Please press the right-most button to continue.

As you imagine encountering this food, imagine interacting with it. Perhaps you might imagine what it would be like to pick up the food and eat it. Perhaps you imagine enjoying the food as you eat it. Perhaps you feel like eating more of it. As you view the food, imagine interactions that you might typically have with this food.

Please press the right-most button to continue.

In summary, here are the key points for performing the normal viewing perspective:

-Imagine encountering the food in the world.

-View the food as you would normally.

-Imagine interacting with the food.

While you are adopting this perspective, it can sometimes be helpful to imagine being in another situation elsewhere, other than in this room. Try, for example, being somewhere else where you would encounter the food. Then, imagine viewing the food in that situation and interacting with it.

If you have any questions about the normal viewing perspective at this point, please discuss them with the experimenter. Otherwise, we will next practice performing the normal viewing perspective briefly.

Please press the right-most button to continue.

On each of the next two slides, a food picture will appear, with a brief summary of the normal viewing perspective above the picture. As you see a food picture appear, please practice adopting the normal viewing perspective on it.

Please press the right-most button to continue.

-Imagine encountering the food in the world.

-View the food as you would normally.

-Imagine interacting with the food.

Please press the right-most button to continue.

-Imagine encountering the food in the world.

-View the food as you would normally.

-Imagine interacting with the food.

Please press the right-most button to continue.

If you have any questions about the normal viewing perspective, or are having any difficulties adopting it, please discuss them with the experimenter now.

Otherwise, we will now practice the normal viewing perspective on two more pictures.

Please press the right-most button to continue.

Adopt the normal viewing perspective on the food below.

Please press the right-most button to continue.

Adopt the normal viewing perspective on the food below.

Please press the right-most button to continue.

You just learned about the normal viewing perspective and how to adopt it. In a moment, we would like you to adopt the normal viewing perspective as you view sets of food pictures.

As described earlier, you'll be alternating the normal viewing task with the color warmth task. Whenever it's time to perform the normal viewing task, you'll first receive the following instruction:

Please adopt the normal viewing perspective.

You'll then see 5 food pictures each presented for a few seconds. Please adopt the normal viewing perspective on each picture as you just learned to do. Again, here are the key points for adopting the normal viewing perspective:

-Imagine encountering the food in the world.

-View the food as you would normally.

-Imagine interacting with the food.

As you see each of the 5 food pictures, please adopt the normal viewing perspective on it.

Please press the right-most button when you're ready for the next slide.

Once the fifth picture has been presented, you'll be asked to rate how well you were able to adopt the normal viewing perspective:

How well were you able to adopt the normal viewing perspective

for the previous 5 pictures?

1 2 3 4

not at all very well

To make your response, press one of the four buttons on the button box that you're holding. Again, similar to the color warmth task, 1 is the left-most button, and 4 is the right-most button. 2 and 3 are the buttons in the middle, with 2 being the left-middle button, and 3 being the right middle button. Pressing the 1 button indicates that you were not able to perform the normal viewing perspective at all on the 5 previous pictures, whereas pressing the 4 button indicates that you were able to perform it very well. Pressing 2 or 3 indicates that you were somewhat able to perform the normal viewing perspective at an intermediate level, with 3 indicating greater success than 2.

Once you've determined how well you were able to adopt the normal viewing perspective on the 5 previous pictures, press the button that best describes your judgment.

When you're ready for some practice, please press the right-most button.

You have learned about the normal viewing task and the color warmth task, and practiced them separately. In the scanner, however, the normal viewing task will alternate with the color warmth task:

Normal viewing task

Color warmth task

Normal viewing task

Color warmth task

Normal viewing task

Color warmth task

.

.

.

In the scanner, you'll continue alternating between the two tasks for about 8 minutes. Then, we'll take a short break and then perform the alternating tasks again for another 8 minutes, and then again after another short break.

Next we'll practice performing the two tasks together in an alternating manner. Please press the right-most button when you're ready for a short practice for the two alternating tasks.

We're now ready to perform the experiment.

Do you have any questions about either of the two tasks, or how to perform the experiment? If so, please ask the experimenter now.

Again, here are the key points for adopting the normal viewing perspective:

-Imagine encountering the food in the world.

-View the food as you would normally.

-Imagine interacting with the food.

If you are ready, we will go to the scanner room now and perform these two tasks in the scanner.

Please remember not to move your head at all during the experiment, and to remain as still as you can.

Training instructions for the Observe perspective

Thank you for participating in our experiment. There's something that we need to discuss first that is very important. We bring it up now so that you can think about it and remember its importance when you're in the scanner.

It is very important to not move your head at all in the scanner. If you move your head even a small amount, we may not be able to use your data. For this reason, it is very important to get comfortable initially when you first lie down in the scanner, and to spend time working on this until you are comfortable.

Once you're comfortable in the scanner, please do not move your head until the experiment is over.

Out of every 10 scans, 1 person moves their head too much. So this is a problem that we have to worry about. We don't want you to be one of the people whose data we can't use. If you have any questions or concerns about this, please bring them up with us now, or when you're in the scanner.

When you're ready to go on, please press the right-most button on the button box in front of you.

We are now ready to begin the main instructions. Later, when you're in the fMRI scanner, you will perform two tasks: a color warmth task, and an observe task. In the next few minutes, before we go into the scanner, we will go over these two tasks and perform some practice.

We will first work on the color warmth task and then on the observe task. Once you've become familiar with both, we'll do a little practice performing them together.

When you're ready to go on, please press the right-most button on the button box in front of you.

First we'll go over the color warmth task. You will perform the color warmth task multiple times, as it alternates with the observe task. Whenever it's time to perform the color warm task, you'll first receive the following instruction:

Please judge the average color warmth.

Soon thereafter, you'll see 5 abstract pictures each presented for a few seconds. As each abstract picture is presented, please assess the warmth of the colors in it. That's all you need to do as each picture is presented.

Press the right-most button on the button box to go on.

Once the fifth abstract picture has been presented, you'll be asked to judge color warmth:

What was the average color warmth of the previous 5 pictures?

1 2 3 4

very cold very warm

To make your response, press one of the four buttons on the button box that you're holding. Here, 1, the left-most button, means "very cold", whereas 4, the right-most button, means "very warm." The middle two buttons are for indicating 2 or 3, which represent intermediate warmth.

Once you've determined the average color warmth of the previous 5 pictures, press the button that best describes your judgment.

Do you have any questions? When you're ready for some practice, please press the right-most button.

Do you have any questions?

We are now ready to learn about the observe task. When you're ready for learning about the observe task, please press the right-most button.

Now we will go over the observe task. In this task, we will teach you to adopt a particular perspective on observing your thoughts.

Once you have learned this perspective, we will ask you to use it in the experiment that will follow in the scanner.

We will refer to this as the *observe* perspective. We will ask you to adopt the observe perspective while viewing pictures of food that will be presented to you on the computer screen.

Please press the right-most button to continue.

Here's how the observe perspective works. Consider this cinnamon roll. You might immediately have some thoughts about it. Maybe you briefly imagine what you could do with it, how it would feel or taste, or a situation where you would eat it. Maybe you spontaneously think about how the food would make you feel, and whether you would like or dislike it. You might feel some emotion about it, for example feeling attracted to it. You could also find that your body responds in some way to it, for example, by feeling a little excited. So, at many levels of experience – in your thoughts, in your emotions, and in your body – you might spontaneously have all kinds of responses to seeing the cinnamon roll.

Please press the right-most button to continue.

When adopting the observe perspective, your task is to simply observe all these responses as they arise and dissipate. You don't really have to do anything about these responses. Simply observe them as they come and go. Try to do this with any response that you have. Maybe you think about eating the food, about what the food would taste like, or about whether you like it or not – simply observe how all these responses come up and then go away.

As you perform the observe task, try to remain aware that all the responses you experience are simply constructions of your mind, which appear and then disappear. See them as just fleeting mental states that your mind is producing in the current moment – while you are sitting in this room, on this chair, looking at the pictures. Notice how your mind produces these responses to the picture, and just observe them as they arise and dissipate.

Please press the right-most button to continue.

As you perform the observe task, don't try to avoid, suppress or control your responses. Simply remain aware of how your mind produces them, and observe them as they arise and dissipate.

Please press the right-most button to continue.

In summary, here are the key points for adopting the observe perspective:

-Observe your thoughts, emotions, and bodily responses to the picture arise and dissipate.

-See these responses as fleeting mental states.

-Just observe them as they come and go.

While you are adopting the observe perspective, it can sometimes be helpful to remain aware of the situation in which you currently are. Try, for example, to feel your body rest on the chair, and feel how your feet are resting on the ground. Then, observe all your thoughts and responses as fleeting mental states, as they pass through your mind in this moment.

If you have any questions about the observe perspective at this point, please discuss them with the experimenter. Otherwise, we will now practice performing the observe perspective briefly.

Please press the right-most button to continue.

On each of the next two slides, a food picture will appear, with a brief summary of the "observe" perspective above the picture. As you see the food picture appear, please practice adopting the observe perspective on it.

Please press the right-most button to continue.

-Observe your thoughts, emotions, and bodily responses to the picture arise and dissipate.

-See these responses as fleeting mental states.

-Just observe them as they come and go.

Please press the right-most button to continue.

-Observe your thoughts, emotions, and bodily responses to the picture arise and dissipate.

-See these responses as fleeting mental states.

-Just observe them as they come and go.

Please press the right-most button to continue.

If you have any questions about the observe perspective, or are having any difficulties adopting it, please discuss them with the experimenter now.

Otherwise, we will now practice the observe perspective on two more pictures.

Please press the right-most button to continue.

Adopt the observe perspective on the food below.

Please press the right-most button to continue.

Adopt the observe perspective on the food below.

Please press the right-most button to continue.

You just learned about the observe perspective and how to adopt it. In a moment, we would like you to adopt the observe perspective as you view sets of food pictures.

As described earlier, you'll be alternating the observe task with the color warmth task. Whenever it's time to perform the observe task, you'll first receive the following instruction:

Please adopt the observe perspective.

You'll then see 5 food pictures each presented for a few seconds. Please adopt the observe perspective on each picture as you just learned to do. Again, here are the key points for adopting the observe perspective:

-Observe your thoughts, emotions, and bodily responses to the picture arise and dissipate.

-See these responses as fleeting mental states.

-Just observe them as they come and go.

As you see each of the 5 food pictures, please adopt the observe perspective on it.

Please press the right-most button when you're ready for the next slide.

Once the fifth picture has been presented, you'll be asked to rate how well you were able to adopt the observe perspective:

How well were you able to adopt the observe perspective for the previous 5 pictures?

1 2 3 4

not at all very well

To make your response, press one of the four buttons on the button box that you're holding. Again, similar to the color warmth task, 1 is the left-most button, and 4 is the right-most button. 2 and 3 are the buttons in the middle, with 2 being the left-middle button, and 3 being the right middle button. Pressing the 1 button indicates that you were not able to perform the observe perspective at all on the 5 previous pictures, whereas pressing the 4 button indicates that you were able to perform it very well. Pressing 2 or 3 indicates that you were somewhat able to perform the observe perspective at an intermediate level, with 3 indicating greater success than 2.

Once you've determined how well you were able to adopt the observe perspective on the 5 previous pictures, press the button that best describes your judgment.

When you're ready for some practice, please press the right-most button.

You have learned about the observe task and the color warmth task, and practiced them separately. In the scanner, however, the observe task will alternate with the color warmth task:

Observe task

Color warmth task

Observe task

Color warmth task

Observe task

Color warmth task

.

.

.

In the scanner, you'll continue alternating between the two tasks for about 8 minutes. Then, we'll take a short break and then perform the alternating tasks again for another 8 minutes, and then again after another short break.

Next we'll practice performing the two tasks together in an alternating manner. Please press the right-most button when you're ready for a short practice for the two alternating tasks.

We're now ready to perform the experiment.

Do you have any questions about either of the two tasks, or how to perform the experiment? If so, please ask the experimenter now.

Again, here are the key points for adopting the observe perspective:

-Observe your thoughts, emotions, and bodily responses to the picture arise and dissipate.

-See these responses as fleeting mental states.

-Just observe them as they come and go.

If you are ready, we will go to the scanner room now and perform these two tasks in the scanner.

Please remember not to move your head at all during the experiment, and to remain as still as you can.

Appendix E

Masks (and sub-masks) used for binomial tests

All 17 masks were created using the Draw dataset plugin in AFNI. Unless otherwise noted, all masks were created using the CA_ML_18_MNIA atlas in AFNI. When a mask contains sub-masks, the sub-masks were combined to create a composite mask of all the sub-masks listed. Seventeen total masks were created for the binomial tests, one for each of the brain areas assessed (i.e., the 17 rows across Figures 6-9, Figures 10-13, and Figures 14-17).

In the 17 sections to follow, each of the 17 masks is documented, listing the sub-mask(s) from the CA_ML_18_MNIA that went into it (or occasionally, masks from the TT_Daemon atlas)

1. L insula
    L Insula Lobe: 29
2. R insula
    R Insula lobe: 30
3. Piriform cortex and uncus
    L Olfactory cortex: 21
    R Olfactory cortex: 22
    L Uncus (TT_Daemon atlas): 225
    R Uncus (TT_Daemon atlas): 25
4. Amygdala
    L Amygdala: 41
    R Amygdala: 42

5. Orbital-frontal cortex (OFC)

L Superior Orbital Gyrus: 5
R Superior Orbital Gyrus: 6
L Middle Orbital Gyrus: 9
R Middle Orbital Gyrus: 10
L Mid Orbital Gyrus: 25
R Mid Orbital Gyrus: 26

6. Cortical midline (TT_Daemon atlas)

L Brodmann 8: 288
R Brodmann 8: 88
L Brodmann 9: 289
R Brodmann 9: 89
L Brodmann 10: 290
R Brodmann 10: 90
L Brodmann 23: 300
R Brodmann 23: 100
L Brodmann 24: 301
R Brodmann 24: 101
L Brodmann 31: 307
R Brodmann 31: 107
L Brodmann 32: 308
R Brodmann 32: 108

The integrated map was set to 0 outside from x=21 and x=-21, such that the map covers $-20 \leq x \leq +20$.

7. L inferior frontal gyrus

    L inferior frontal gyrus (p. Opercularis) : 11

    L inferior frontal gyrus (p. Triangularis) : 13

8. R inferior frontal gyrus

    R inferior frontal gyrus (p. Opercularis) : 12

    R inferior frontal gyrus (p. Triangularis) : 14

9. L lateral middle temporal gyrus

    L Middle Temporal Gyrus:85

10. L Occipital and medial temporal

    L superior Occipital Gyrus: 49

    L middle Occipital Gyrus: 51

    L inferior Occipital Gyrus: 53

    L Fusiform Gyrus: 55

    L ParaHippocampal Gyrus: 39

    L Hippocampus: 37

11. R Occipital and medial temporal

    R superior Occipital Gyrus: 50

    R middle Occipital Gyrus: 52

    R inferior Occipital Gyrus: 54

    R Fusiform Gyrus: 56

    R ParaHippocampal Gyrus: 40

    R Hippocampus: 38

12. Precuneus and Angular gyrus

    L Precuneus: 67

    R Precuneus: 68

    L Angular Gyrus: 65

    R Angular gyrus: 66

13. Supplemental motor area

    L SMA: 19

    R SMA: 20

14. Pre-central and Post-central gyrus

    L Precentral Gyrus: 1

    R Precentral Gyrus: 2

    L Postcentral Gyrus: 57

    R Postcentral Gyrus: 58

15. Cerebellum

    L Cerebellum (Crus 1): 91

    R Cerebellum (Crus 1): 92

    L Cerebellum (Crus 2): 93

    R Cerebellum (Crus 2): 94

    L Cerebellum (III): 95

    R Cerebellum (III): 96

    L Cerebellum (IV-V): 97

    R Cerebellum (IV-V): 98

    L Cerebellum (VI): 99

    R Cerebellum (VI): 100

    L Cerebellum (VII): 101

R Cerebellum (VII): 102

L Cerebellum (VIII): 103

R Cerebellum (VIII): 104

L Cerebellum (IX): 105

R Cerebellum (IX): 106

L Cerebellum (X): 107

R Cerebellum (X): 108

Cerebellar Vermis (1/2): 109

Cerebellar Vermis (3): 110

Cerebellar Vermis (4/5): 111

Cerebellar Vermis (6): 112

Cerebellar Vermis (7): 113

Cerebellar Vermis (8): 114

Cerebellar Vermis (9): 115

16. Thalamus

L Thalamus: 77

R Thalamus: 78

17. Striatum

L Caudate Nucleus: 71

R Caudate Nucleus: 72

L Putamen: 73

R Putamen: 74

L Pallidum: 75

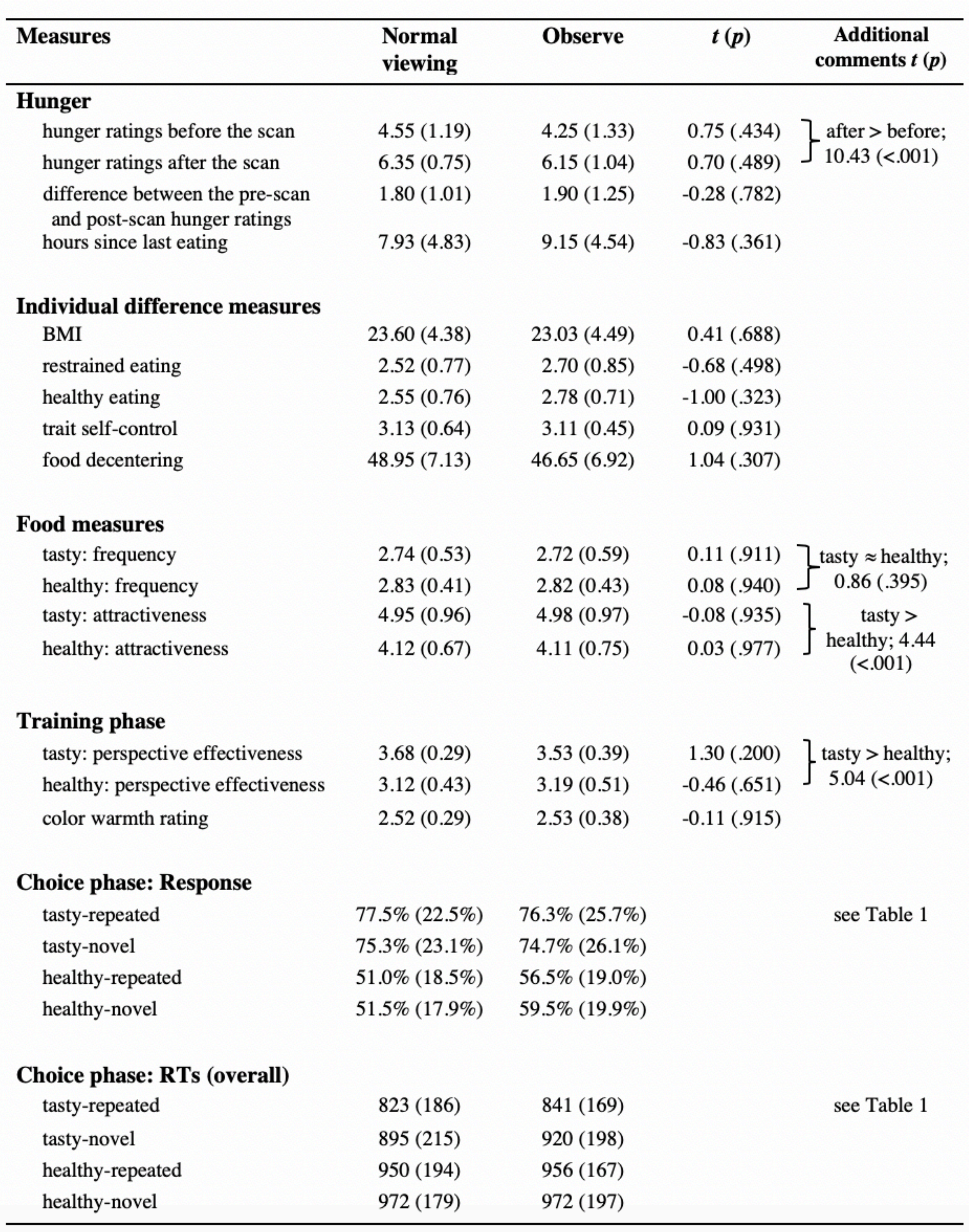
R Pallidum: 76

Appendix F

Preliminary behavioral results

Table F1 presents preliminary behavioral results for hunger ratings before and after the scan, the individual difference measures, frequency and attractiveness ratings for food images, perspective effectiveness for the training phase, and the food response and reaction time (RTs) for the choice phase. Values shown for the normal viewing and observe conditions represent the mean (standard deviation) for each group. The *t* (*p*) column represents the *t* value (*p* value) for *t* tests performed when comparing two groups in a row. Because Table 1 in the main text presents significance tests for choice responses and RTs, Table F1 does not repeat them here. The additional comments in the final column provide significance tests that are of additional interest between rows.

Table F1. Preliminary behavioral results



Measures	**Normal viewing**	**Observe**	***t* (*p*)**	**Additional comments *t* (*p*)**
Hunger				
hunger ratings before the scan	4.55 (1.19)	4.25 (1.33)	0.75 (.434)	after > before; 10.43 (<.001)
hunger ratings after the scan	6.35 (0.75)	6.15 (1.04)	0.70 (.489)	
difference between the pre-scan and post-scan hunger ratings	1.80 (1.01)	1.90 (1.25)	-0.28 (.782)	
hours since last eating	7.93 (4.83)	9.15 (4.54)	-0.83 (.361)	
Individual difference measures				
BMI	23.60 (4.38)	23.03 (4.49)	0.41 (.688)	
restrained eating	2.52 (0.77)	2.70 (0.85)	-0.68 (.498)	
healthy eating	2.55 (0.76)	2.78 (0.71)	-1.00 (.323)	
trait self-control	3.13 (0.64)	3.11 (0.45)	0.09 (.931)	
food decentering	48.95 (7.13)	46.65 (6.92)	1.04 (.307)	
Food measures				
tasty: frequency	2.74 (0.53)	2.72 (0.59)	0.11 (.911)	tasty ≈ healthy; 0.86 (.395)
healthy: frequency	2.83 (0.41)	2.82 (0.43)	0.08 (.940)	
tasty: attractiveness	4.95 (0.96)	4.98 (0.97)	-0.08 (.935)	tasty > healthy; 4.44 (<.001)
healthy: attractiveness	4.12 (0.67)	4.11 (0.75)	0.03 (.977)	
Training phase				
tasty: perspective effectiveness	3.68 (0.29)	3.53 (0.39)	1.30 (.200)	tasty > healthy; 5.04 (<.001)
healthy: perspective effectiveness	3.12 (0.43)	3.19 (0.51)	-0.46 (.651)	
color warmth rating	2.52 (0.29)	2.53 (0.38)	-0.11 (.915)	
Choice phase: Response				
tasty-repeated	77.5% (22.5%)	76.3% (25.7%)		see Table 1
tasty-novel	75.3% (23.1%)	74.7% (26.1%)		
healthy-repeated	51.0% (18.5%)	56.5% (19.0%)		
healthy-novel	51.5% (17.9%)	59.5% (19.9%)		
Choice phase: RTs (overall)				
tasty-repeated	823 (186)	841 (169)		see Table 1
tasty-novel	895 (215)	920 (198)		
healthy-repeated	950 (194)	956 (167)		
healthy-novel	972 (179)	972 (197)		

Appendix G

Clusters significantly active above (or below) the active baseline for the training phase and for the choice phase

Table E1 presents clusters significantly active above (or below) the active baseline during the training phase, for each training group (normal vs. observe perspective), and for each food type (tasty vs. healthy). Tables E2 and E3 present the significantly active clusters during the choice phase, for repeated foods and novel foods, respectively. Activations were obtained using an independent voxel threshold of $p < .005$ and a cluster threshold set at alpha = .05, determined to be 20.3 voxels for the training phase and 20.4 voxels for the choice phase. For each table, clusters for the normal viewing perspective are shown first, followed by clusters for the observe perspective. Within each perspective, clusters for tasty foods are shown first, followed by clusters for healthy foods. Within each food type, positive clusters (significantly active above the active baseline) are presented before negative clusters (significantly active below the active baseline).

The clusters shown in these tables were subsequently submitted to conjunction analyses, as described in the text, with the results presented in Figures 6 to 17 and Tables 2 to 7. Because only positive clusters bear on our hypotheses, only positive clusters were assessed in these later analyses.

Table G1. During the training phase, clusters significantly active above (or below) the active baseline for each training group (normal vs. observe perspective) and food type (tasty vs. healthy).

Brain region	**Brodmann Area**	**Cluster volume**	**Max intensity voxel (MNI coordinates)**			
			t	**X**	**Y**	**Z**
NORMAL PERSPECTIVE						
Tasty foods (positive clusters)						
L occipital and medial temporal	19, 18, 36, 37	3498	9.24	-39	-90	-6
inferior occipital gyrus	20, 13					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
uncus						
insula						
thalamus						
R occipital and medial temporal	19, 18, 36, 37	1833	7.98	39	-48	-21
inferior occipital gyrus	20					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
uncus						
thalamus						
B vmOFC (cortical midline)	11, 10	1059	7.28	-6	42	-12
R cerebellum		134	4.97	15	-45	-48
R cerebellum		98	5.14	15	-87	-36
R cerebellum		90	4.56	42	-75	-3
L cerebellum		33	4.81	-3	-57	-12
B cerebellum		29	4.17	0	-72	-21
L cerebellum		24	5.19	-18	-39	-45
L OFC	11	129	6.04	-30	36	-15
IFG	47					
L lateral middle temporal gyrus	21	104	4.82	-57	-12	-21
L pre-central and post-central gyrus	2, 4	72	4.27	-51	-27	39
R precuneus	7	61	4.91	27	-72	36
R SMA	6	38	4.32	6	3	66
L thalamus		28	4.45	-6	-15	3
R insula	13	28	4.70	39	-3	6
L SPL		26	4.25	-33	-54	60
R IFG	47	23	3.96	36	33	-18
L SMA	6	22	3.66	-6	6	60

Tasty foods (negative clusters)						
B lingual gyrus	17, 18	401	-6.70	6	-90	-6
R IPL	40	327	-5.64	48	-54	48
R precuneus	7	216	-4.91	9	-72	42
R middle frontal gyrus (vlPFC)	10	201	-5.53	39	61	3
R middle temporal gyrus	21	91	-4.81	60	-27	-18
R middle frontal gyrus/ superior frontal gyrus	6, 8	85	-3.92	27	12	48
R middle frontal gyrus (dlPFC)	46	70	-4.36	51	33	24
L cerebellum		51	-4.00	-42	-72	-48
R middle orbital gyrus/ superior orbital gyrus	11	50	-5.09	18	48	-15
OFC						
L IPL / angular gyrus/ SMG	40	40	-5.52	-27	-57	39
L postcentral gyrus	40, 42	31	-4.20	-54	-24	12
L cerebellum		23	-3.71	-9	-81	-27
L cerebellum		21	-3.56	-27	-63	-30
L PCC (cortical midline)		21	-3.69	0	-33	24
Healthy foods (positive clusters)						
L occipital and medial temporal	19, 18, 36, 37	2668	8.94	-39	-90	-6
inferior occipital gyrus	20, 13					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
uncus						
insula						
thalamus						
lentiform nucleus						
putamen						
R occipital and medial temporal	19, 18, 36, 37	1625	7.64	42	-87	-9
inferior occipital gyrus	20, 13					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
uncus						
thalamus						
B vmOFC	11	632	5.96	-6	42	-15
L OFC	11	175	5.77	-33	36	-15
IFG	47					
R cerebellum		126	5.52	18	-42	-45
R cerebellum		120	4.98	21	-72	-24
R cerebellum		49	4.97	15	-87	-36
L lateral middle temporal gyrus	21	74	4.33	-54	-15	-3

L pre-central and post-central gyrus	4, 2	71	4.56	-51	-30	39
R precuneus	19	51	4.66	30	-72	27
R insula	13	34	4.49	39	-3	6
R dmPFC (cortical midline)	10	33	3.95	12	54	18
R IFG	47	25	3.86	36	33	-12
L middle frontal gyrus	6	23	3.78	-39	6	51
B ACC (cortical midline)		22	4.00	3	18	24
Healthy foods (negative clusters)						
B lingual gyrus	18	380	-5.46	-3	-90	-9
R SPL / precuneus	7	185	-5.16	6	-69	57
R postcentral gyrus	40	142	-4.35	57	-39	54
L postcentral gyrus	40	100	-4.79	-54	-30	21
R vlPFC	10	99	-4.29	42	48	-3
R middle frontal gyrus/ STG	8, 6	68	-4.30	27	12	48
R MTG	21	28	-3.65	69	-27	-12
R post-central gyrus/ STG	40, 42	24	-3.84	63	-21	12
OBSERVE PERSPECTIVE						
Tasty foods (positive clusters)						
B occipital and medial temporal	19, 18, 36, 37	10600	12.30	45	-84	-6
inferior occipital gyrus	20, 13, 11, 47					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
uncus						
insula						
OFC						
IFG						
thalamus						
lentiform nucleus						
putamen						
substantia nigra						
L cortical midline	10, 9, 24, 11, 32	2364	7.98	-6	63	24
SMA	6					
R lateral middle temporal gyrus	22	177	5.66	48	-39	3
L precentral gyrus	6	162	6.00	-39	6	54
middle frontal gyrus						
L pre-central gyrus and post-central gyrus	2, 4	88	4.71	-60	-12	33
R pre-central and post-central gyrus	3, 4	75	4.72	39	-27	57
R cerebellum		53	4.61	36	-60	-57
L middle cingulate cortex (cortical midline)	24	52	6.68	-3	-12	39
L cerebellum		46	4.77	-27	-81	-36
R medial frontal gyrus	6	40	4.58	6	-30	63

R ITG	21	33	4.10	51	3	-39
R precuneus	7	22	3.89	24	-54	60
SPL						
Tasty foods (negative clusters)						
R IPL/ precuneus/ SPL	40, 19, 7	485	-6.46	42	-54	42
R precuneus/ SPL	7	478	-8.81	9	-69	54
R vlPFC (middle frontal gyrus)	10	408	-5.52	36	63	3
R middle frontal gyrus/ superior frontal gyrus	6, 8	264	-7.38	30	12	63
L cerebellum		138	-5.04	-36	-66	-39
L IPL/ angular gyrus	40	97	-4.69	-42	-51	42
R ITG	20	42	-5.17	60	-33	-21
R lingual gyrus	18	49	-5.24	9	-87	-9
L cuneus	18	36	-4.57	-9	-99	9
R cuneus	18	32	-4.47	15	-96	12
L post-central gyrus	3	24	-4.33	-48	-24	60
L post-central gyrus		23	-4.13	-54	-21	21
B posterior cingulate	23	23	-3.82	0	-30	21
R vmPFC	10	21	-4.05	30	45	3
Healthy foods (positive clusters)						
L occipital and medial temporal	19, 18, 36, 37	4183	9.11	-39	-90	-6
inferior occipital gyrus	20, 13, 11, 47					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
uncus						
insula						
OFC						
IFG						
thalamus						
lentiform nucleus						
putamen						
substantia nigra						
R occipital and medial temporal	19, 18, 36, 37	2553	10.61	45	-84	-6
inferior occipital gyrus	20					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
thalamus						
lentiform nucleus						
putamen						

substantia nigra						
L cortical midline	9, 10, 11	1426	7.68	-9	57	33
SMA	6					
R insula	13	526	9.40	42	6	-9
OFC	11					
IFG	47					
L lateral middle temporal gyrus	21	221	5.55	-51	-27	-3
L lateral middle temporal gyrus	21	29	4.18	-51	3	-33
R middle cingulate cortex (cortical midline)	32, 24	134	5.05	9	15	39
L cerebellum		49	4.63	-33	-60	-54
R cerebellum		44	4.06	45	-48	-48
R cerebellum		41	4.93	15	-42	-45
R cerebellum		38	4.36	3	-54	-39
L cerebellum		21	3.90	-27	-84	-36
L middle frontal gyrus	8	82	4.72	-36	21	57
L thalamus		75	6.32	-3	-18	3
R lateral middle temporal gyrus	22	73	4.31	60	-42	6
L pre-central and post-central gyrus	4, 3	50	4.29	-60	-21	36
R pre-central and post-central gyrus	4, 3	40	4.65	69	-12	27
L middle cingulate cortex (cortical midline)	24	37	5.77	-3	-12	39
R uncus		32	4.18	30	-3	-30
L ITG	38	26	4.22	-45	6	-42
Healthy foods (negative clusters)						
R precuneus/ SPL	7	454	-7.26	6	-69	54
R IPL/ angular gyrus	40	383	-5.48	42	-54	42
R superior frontal gyrus/ medial frontal gyrus	6	262	-6.50	21	12	54
L postcentral gyrus		69	-4.10	-51	-21	18
R middle frontal gyrus (dlPFC)	9	65	-4.27	54	30	33
R middle frontal gyrus (vlPFC)	10	57	-4.27	42	60	-3
L angular gyrus	39	55	-4.22	-33	-57	33
L cerebellum		53	-4.18	-36	-78	-51
R lingual gyrus	18	42	-4.27	12	-81	-9
R cuneus	18	40	-4.36	15	-96	9
L ITG	20	36	-5.33	60	-33	-21
L precentral gyrus	6	35	-5.20	-36	-15	63
L cuneus	18	30	-4.38	-9	-99	9
R middle cingulate cortex	31	27	-4.87	12	-39	39
R superior orbital gyrus/ middle orbital gyrus	11	26	-4.36	18	48	-15
R middle frontal gyrus/ superior frontal gyrus	6	25	-4.24	-24	3	60
L middle frontal gyrus		24	-4.01	-24	3	42

Note. Activations were obtained using an independent voxel threshold of *p*<.005 and a cluster threshold of 20.3 voxels. Clusters having 20.3 voxels or larger are significant at *p*<.05. L = left, R = right, B = bilateral, ACC = anterior cingulate cortex, d = dorsal, IFG = inferior frontal gyrus, IPL = inferior parietal lobule, ITG = inferior temporal gyrus, l = lateral, m = medial, MTG = middle temporal gyrus, OFC = orbitofrontal cortex, PCC = posterior cingulate cortex, PFC = prefrontal cortex, SMA = supplementary motor area, SMG = supraMarginal gyrus, SPL = superior parietal lobule, STG = superior temporal gyrus, v = ventral.

Table G2. During the choice phase for repeated foods only, clusters significantly active above (or below) the active baseline for each training group (normal vs. observe perspective) and food type (tasty vs. healthy).

Brain region	Brodmann Area	Cluster volume	Max intensity voxel (MNI coordinates)			
			t	X	Y	Z
NORMAL PERSPECTIVE						
Tasty repeated foods (positive clusters)						
L occipital and medial temporal	19, 18, 36, 37	2198	10.13	-39	-90	-3
inferior occipital gyrus	20, 13, 7					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
insula						
precuneus						
uncus						
R occipital and medial temporal	19, 18, 36, 37	2061	10.40	39	-87	0
inferior occipital gyrus	20, 13, 7					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
insula						
precuneus						
uncus						
L lingual gyrus	19	200	5.63	-15	-48	3
L pre-central and post-central gyrus	6	166	4.30	-60	-18	42
B cingulate gyrus (cortical midline)	32	150	5.20	-3	18	45
L OFC	11	111	5.50	-24	33	-12
L dlPFC	9	92	3.66	-36	12	24
L ACC (cortical midline)	32	87	4.84	-6	27	27
R OFC	11	58	4.14	30	33	-15
L calcarine gyrus / lingual gyrus	18, 19	48	4.18	-6	-69	12
L dIFG	46, 10	29	4.06	-39	39	9
R amygdala/ hippocampus		26	3.96	21	-3	-15
L ACC (cortical midline)	33	26	4.62	-3	9	27
Tasty repeated foods (negative clusters)						
R SMG/ STG	40, 22	136	-5.19	60	-51	24
R IPL	40	78	-4.91	57	-39	51
R precuneus	7	66	-4.48	9	-60	57
R middle cingulate cortex / paracentral lobule	31	60	-4.52	6	-33	48
R middle frontal gyrus	8	54	-4.28	33	27	48

R lateral MTG	21	48	-4.69	63	-9	-6
L PCC	29	48	-4.95	-18	-45	12
L parahippocampal gyrus	30	47	-5.19	-30	-54	3
L pSTG	39	45	-3.93	-45	-57	21
L pMTG	21	42	-4.40	-60	-48	6
R parahippocampal gyrus	19	36	-4.68	36	-51	0
L precuneus	7	29	-3.63	-3	-54	45
L thalamus		26	-4.56	-6	-33	15
R caudate		35	-4.86	24	-45	15
R caudate		23	-4.13	18	18	18
L caudate		28	-4.19	-15	-21	21
L IPL	40	22	-3.57	-48	-48	42

Healthy repeated foods (positive clusters)

B occipital and medial temporal	19, 18, 36, 37	8817	10.94	-39	-90	-3
inferior occipital gyrus	20, 13, 7, 47, 11					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
insula						
precuneus						
uncus						
OFC						
B medial frontal gurus (cortical midline)	8	1663	8.90	0	18	51
L dlPFC	8, 9	752	6.73	-42	42	9
R dlPFC	46, 9	336	6.53	48	27	27
L thalamus		198	5.88	-3	-12	0
L cerebellum		67	4.02	-27	-66	-51
L cerebellum		31	4.56	-6	-75	-21
R middle frontal gyrus	6	65	4.49	39	0	63
L superior frontal gyrus/ middle frontal gyrus	10	62	4.15	-27	51	18
R post-central gyrus	2	32	4.04	39	-27	42
L medial frontal gyrus (cortical midline)	10	41	4.47	-3	60	9
L anterior ITG/ MTG	20, 38	23	4.32	-39	0	-42

Healthy repeated foods (negative clusters)

R caudate		129	-5.25	6	21	3
R caudate		34	-4.75	24	-45	15
L parahippocampal gyrus (medial temporal)	30	74	-6.12	-30	-54	3
R STG	22	65	-5.35	33	-51	9
R IPL	40	45	-4.24	57	-33	39
R middle frontal gyrus	8	44	-4.52	27	24	48
R lateral MTG	21	36	-4.55	66	-6	-9
R medial frontal gyrus	10	32	-3.54	15	48	15

B thalamus		29	-4.86	0	-24	15
L MTG/ STG/ SMG	39	28	-4.47	-42	-60	24
L precuneus	7	26	-4.19	0	-57	42
L lateral MTG/ STG	22	23	-5.09	-66	-48	3
L caudate		21	-4.21	-15	-24	21

OBSERVE PERSPECTIVE

Tasty repeated foods (positive clusters)

R occipital and medial temporal	19, 18, 20, 37	1513	9.33	45	-84	-6
inferior occipital gyrus	36					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
L occipital and medial temporal	19, 18, 20, 37	1381	8.70	-39	-87	-3
inferior occipital gyrus	36					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
L insula	13	310	5.93	-39	-6	9
OFC	11					
IFG	47					
L medial frontal gyrus (cortical midline)	8	219	4.75	-3	18	51
L precuneus / SPL	7	154	6.15	-24	-63	45
L uncus	28	120	6.47	-27	-9	-36
R precuneus / SPL	7	104	5.64	27	-66	33
L hippocampus/ parahippocampal gyrus	27	53	4.73	-21	-36	0
L pre-central and post-central gyrus	4, 3	52	4.68	-63	-15	33
R IFG (insula)	47	47	4.52	45	12	-6
L dlPFC (middle frontal gyrus)	9	45	3.95	-48	12	33
R IFG (insula)	47	30	3.91	30	27	-6
B PCC / middle cingulate cortex (cortical midline)	31	27	4.43	0	-33	33
L superior frontal gyrus	6	26	4.75	-12	27	63
R OFC	11	24	4.33	24	33	-15
R uncus/ amygdala/ parahippocampal gyrus	34, 28	22	5.40	21	0	-24

Tasty repeated foods (negative clusters)

R post-central gyrus/ precuneus		293	-5.44	12	-57	66
R lingual gyrus	18	134	-5.69	9	-81	-6
R IPL/ post-central gyrus	40, 2	126	-4.48	54	-27	30
R precuneus	31	83	-5.07	21	-57	18
R precuneus	19	54	-6.16	42	-81	36
L precuneus	31	76	-5.31	-18	-63	21

R post-central gyrus	3	64	-4.19	45	-33	66
R caudate		52	-4.84	21	18	18
L lingual gyrus	30	51	-5.32	-33	-54	3
R middle frontal gyrus	6	49	-5.11	24	-6	66
L caudate nucleus		48	-4.22	-18	-6	27
R middle cingulate cortex	31	41	-4.31	15	-33	39
R caudate nucleus		27	-4.40	24	33	9
R medial frontal gyrus	6	26	-4.17	3	-9	60
R pre-central gyrus	6	23	-3.90	48	-15	57
R lateral MTG	21	23	-4.07	63	-12	-12
L cuneus	18	23	-4.33	-9	-99	15
R cuneus	18	22	-4.39	15	-90	15
L cuneus	19	22	-3.65	-3	-93	27
R parahippocampal gyrus	36	22	-5.35	42	-36	-6
Healthy repeated foods (positive clusters)						
L occipital and medial temporal	19, 18, 20, 37	1772	8.62	-39	-87	-3
inferior occipital gyrus	36					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
R occipital and medial temporal	19, 18, 20, 37	1710	9.42	45	-84	-6
inferior occipital gyrus	36					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
uncus						
B SMA (cortical midline)	6	545	5.61	6	21	45
middle cingulate gyrus	32					
medial frontal gyrus	6					
ACC	6					
L insula	13	483	7.81	-39	-6	6
OFC	11					
IFG	47					
L dlPFC (middle frontal gyrus)	8, 9	315	5.46	-48	12	36
R OFC	11	153	5.26	24	33	-15
R dlPFC (middle frontal gyrus)	9	113	4.58	51	12	33
L pre-central and post-central gyrus	4, 2	70	4.76	-63	-15	33
L uncus	36	63	5.93	-27	-3	-36
R IFG	46	57	4.24	48	36	15
R ACC/ middle cingulate cortex (cortical midline)	24	43	4.89	6	3	27
L parahippocampal gyrus/ lingual gyrus	30	40	5.30	-21	-39	-3
L cuneus	23	38	3.89	-15	-72	6

R precuneus/ SPL	7, 19	37	4.39	27	-51	51
R insula	13	32	5.03	39	-3	0
R cerebellum		29	3.71	3	-60	-39
R cerebellum		25	3.53	45	-60	-45
R cuneus	30	27	3.46	15	-69	6
B PCC (cortical midline)	31	23	4.75	0	-33	33
R thalamus		23	4.75	21	-30	-3
Healthy repeated foods (negative clusters)						
B precuneus	7	324	-5.82	-6	-54	54
R post-central gyrus/ IPL	40	174	-4.63	57	-27	21
R precuneus/ angular gyrus	19, 39	138	-6.26	42	-81	36
R lateral MTG	21	104	-4.98	60	-3	-18
B ACC/ caudate	32	98	-4.35	9	21	0
R PCC	30	95	-4.79	21	-57	18
R lingual gyrus	18	94	-5.52	6	-81	-12
L caudate		90	-4.49	-18	12	21
L precuneus	31	84	-7.40	-18	-63	21
L parahippocampal gyrus	19	55	-5.43	-33	-54	3
R middle cingulate cortex	31	52	-4.37	18	-27	39
R thalamus		51	-4.41	3	-18	15
R cuneus	18, 19	48	-5.16	15	-93	18
L precuneus/ angular gyrus	19, 39	42	-4.95	-36	-81	39
R medial frontal gyrus	10	37	-3.86	9	42	-9
L STG	41	33	-4.31	-54	-30	9
R medial frontal gyrus/ ACC	10	31	-3.86	3	51	9
R SMG	40	29	-4.16	54	-48	30
R post-central gyrus	2, 5	27	-3.85	27	-45	66
L STG	22	25	-4.16	-27	-48	18
R caudate		22	-4.07	18	-21	21
R caudate		21	-4.42	18	12	21
L middle frontal gyrus	9	21	-3.91	-30	27	33

Note. Activations were obtained using an independent voxel threshold of p<.005 and a cluster threshold of 20.3 voxels. Clusters having 20.3 voxels or larger are significant at p<.05. L = left, R = right, B = bilateral, ACC = anterior cingulate cortex, d = dorsal, IFG = inferior frontal gyrus, IPL = inferior parietal lobule, ITG = inferior temporal gyrus, l = lateral, m = medial, MTG = middle temporal gyrus, OFC = orbitofrontal cortex, p = posterior, PCC = posterior cingulate cortex, PFC = prefrontal cortex, SMA = supplementary motor area, SMG = supraMarginal gyrus, SPL = superior parietal lobule, STG = superior temporal gyrus, v = ventral.

Table G3. During the choice phase for novel foods only, clusters significantly active above (or below) the active baseline for each training group (normal vs. observe perspective) and food type (tasty vs. healthy).

Brain region	Brodmann Area	Cluster volume	Max intensity voxel (MNI coordinates)			
			t	X	Y	Z
NORMAL PERSPECTIVE						
Tasty novel foods (positive clusters)						
B occipital and medial temporal	18, 19, 20, 37	8190	12.39	-45	-66	-6
inferior occipital gyrus	36, 47, 13,11					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
uncus						
amygdala						
insula						
IFG						
OFC						
L ACC (cortical midline)	32	844	6.50	-9	27	27
R dlPFC	9, 45	300	5.61	54	6	24
L pre-central gyrus	4, 6	254	5.56	-45	-12	60
R cerebellum		234	5.30	9	-78	-45
R cerebellum		31	5.24	24	-39	-45
L dlPFC	46	152	5.32	-42	39	9
R post-central gyrus	2, 3	86	4.78	39	-27	42
R OFC	11	61	5.79	27	30	-15
R Substantia Nigra		32	4.07	9	-21	-15
R pre-central and post-central gyrus	4, 3, 2	30	4.17	66	-15	36
Tasty novel foods (negative clusters)						
R MTG/ parahippocampal gyrus	19	760	-6.61	36	-51	0
B precuneus	7	405	-6.06	0	-60	42
R IPL/ SMG	40	402	-5.13	54	-51	51
L IPL/ SMG	40	286	-5.40	-48	-48	42
R lateral MTG	21	210	-5.60	69	-27	-3
R middle frontal gyrus	8	163	-5.13	24	24	45
L lateral MTG	21	67	-4.26	-51	-6	-15
R vlPFC (middle frontal gyrus)	10	63	-4.25	39	60	0
L caudate		46	-4.89	0	15	9
L middle frontal gyrus		36	-4.18	-24	33	6
L cerebellum		26	-3.99	-30	-87	-33
L vlPFC	10	25	-5.37	-42	57	0

Healthy novel foods (positive clusters)

B occipital and medial temporal	18, 19, 20, 37	10571	12.78	36	-87	0
inferior occipital gyrus	36, 47, 13,11					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
uncus						
amygdala						
insula						
IFG						
OFC						
thalamus						
B cortical midline	8,6, 9, 32, 24	1459	9.08	-3	18	48
R dlPFC	9, 44, 46	525	7.33	36	9	27
R post-central gyrus/ IPL	2, 40	97	5.20	48	-33	45
L PCC (cortical midline)	23, 31	40	5.48	-3	-30	30
L cerebellum		38	6.32	-21	-36	-45
R pre-central and post-central gyrus	4, 3	31	3.74	66	-15	39
R pre-central and post-central gyrus	4, 6	25	4.08	57	-12	54
L lentiform nucleus		31	4.05	-24	0	12
R lentiform nucleus		21	4.29	15	9	0

Healthy novel foods (negative clusters)

R precuneus/ IPL/ angular gyrus	39, 19, 40	298	-5.59	45	-75	36
B precuneus	7, 31	233	-6.16	-3	-54	42
L caudate/ ACC	10	216	-5.22	-18	0	27
R middle frontal gyrus	8	163	-6.17	27	24	48
R lateral MTG/ ITG	21, 20	134	-6.40	63	-15	-12
L parahippocampal gyrus/ MTG	19	83	-6.93	-33	-48	0
R caudate		47	-5.42	18	3	24
R caudate		42	-5.86	24	-45	15
L MTG/ STG/ SMG	39	69	-5.18	-42	-57	21
L lateral MTG/STG	22	67	-4.93	-66	-48	3
R middle frontal gyrus (vPFC)	10	56	-4.21	39	60	-3
L IPL	40	45	-4.64	-54	-51	45
B thalamus		39	-5.20	0	-24	15
R middle cingulate cortex	31	38	-4.50	12	-33	39
R vmPFC	10	34	-4.81	9	51	3
L calcarine gyrus/ cuneus	31	29	-5.01	-18	-60	21
L precuneus	19	23	-5.20	-33	-81	42

OBSERVE PERSPECTIVE

Tasty novel foods (positive clusters)

L occipital and medial temporal	18, 19, 20, 37	3034	10.35	-45	-66	-6
inferior occipital gyrus	36, 47, 13					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
uncus						
amygdala						
insula						
IFG						
R occipital and medial temporal	18, 19, 20, 37	2555	10.63	45	-84	-6
inferior occipital gyrus	36, 47, 13					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
uncus						
amygdala						
insula						
IFG						
thalamus						
B cortical midline	8, 32	412	5.10	0	18	58
L dlPFC	9, 46	351	6.70	-42	9	27
L pre-central and post-central gyrus	1, 2, 3, 4	214	6.82	-63	-15	33
R dlPFC (middle frontal gyrus)	9	197	6.53	51	12	33
R OFC	11	128	7.24	24	33	-15
L OFC	11	94	6.84	-33	33	-12
R dlPFC (IFG)	46	65	5.10	48	36	15
B ACC/ middle cingulate cortex	24	54	5.45	0	3	30
L calcarine gyrus (cuneus)	18	41	3.89	-15	-72	9
B cerebellum		43	5.84	3	-57	-39
L cerebellum		39	3.81	-15	-72	-51
L cerebellum		28	5.48	-9	-75	-42
R cerebellum		39	5.07	12	-72	-48
R cerebellum		26	5.77	21	-42	-45
L thalamus		26	4.13	-6	-18	3

Tasty novel foods (negative clusters)

B precuneus	7	1261	-7.10	-3	-66	45
R precuneus/ SMG / angular gyrus/ IPL	39, 40	515	-6.39	45	-75	39
R lateral MTG / ITG	20, 21	423	-6.45	63	-12	-12
L precuneus / angular gyrus	19, 39	261	-6.34	-36	-81	39
R vlPFC (middle frontal gyrus)	10	147	-5.16	42	60	-3
L lateral MTG	21	111	-4.68	-66	-30	-3

R dlPFC (middle frontal gyrus)	8	108	-4.53	48	18	51
L vPFC (middle frontal gyrus)	10	91	-5.09	-39	60	0
L caudate		90	-4.82	-18	-6	27
R lingual gyrus	19	82	-5.08	6	-81	-12
L parahippocampal gyrus / MTG	19	60	-6.29	-33	-48	3
L dlPFC (middle frontal gyrus)	8, 9	52	-4.56	-39	30	45
R caudate		49	-4.56	18	6	24
B thalamus		47	-4.61	6	-33	6
R MTG / parahippocampal gyrus	19	46	-5.48	36	-51	0
R post-central gyrus	5	31	-4.40	27	-42	63
R middle occipital gyrus / calcarine gyrus	19	29	-4.45	30	-72	3
L medial IFG	47	25	-4.10	-18	27	-3
R superior frontal gyrus	6	24	-4.15	18	-9	72
L lateral ITG	20	21	-5.71	-57	-21	-27
Healthy novel foods (positive clusters)						
R occipital and medial temporal	18, 19, 20, 37	2216	10.03	45	-84	-6
inferior occipital gyrus	36, 47, 13					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
uncus						
insula						
IFG						
L occipital and medial temporal	18, 19, 20, 37	2113	9.71	-45	-66	-9
inferior occipital gyrus	36, 11					
middle occipital gyrus						
fusiform gyrus						
parahippocampal gyrus						
hippocampus						
amygdala						
OFC						
B cortical midline	8, 32	639	5.51	0	18	54
L insula	13	521	8.36	-36	-6	12
IFG	47					
R OFC	11	272	6.37	27	33	-15
L dlPFC (IFG / middle frontal gyrus)	9, 46	259	6.89	-42	9	30
L uncus	36	187	7.24	-30	-6	-36
R dlPFC (IFG / middle frontal gyrus)	9	180	5.31	42	6	30
L pre-central and post-central gyrus	1, 2, 3, 4	96	5.12	-63	-14	39
L dlPFC (middle frontal gyrus)	46	95	5.09	-45	33	21
B ACC	24, 33	66	5.88	-3	9	24
L thalamus		66	5.26	-18	-30	-3
R dLPFC (IFG)	46	59	5.35	48	36	15
L cerebellum		52	4.34	-24	-75	-48

L cerebellum		21	4.04	-6	-75	-39
B cerebellum		51	5.79	0	-54	-39
L cuneus	18	43	3.77	-15	-72	6
R amygdala		36	6.10	21	0	-21
R thalamus		39	5.00	21	-33	0
L PCC	31	32	4.55	0	-33	33
R cuneus	18	27	3.89	18	-72	6
R cerebellum		21	6.61	24	-36	-42
Healthy novel foods (negative clusters)						
B precuneus/ PCC	31, 7	1400	-8.24	18	-54	21
R precuneus/ IPL/ Angualar gyrus/ SMG	19, 39	509	-8.12	45	-75	39
L caudate		227	-5.32	-27	24	21
R lateral MTG/ ITG	21, 20	223	-5.49	57	-6	-18
L precuneus/ angular gyrus	19	163	-7.21	-36	-81	39
R vPFC (middle frontal gyrus)	10	123	-4.67	33	66	3
R dPFC (middle frontal gyrus)	8	122	-5.14	24	30	42
L MTG/ parahippocampal gyrus	19	106	-7.16	-33	-48	3
R caudate		81	-5.82	18	12	21
R lingual gyrus	18	78	-5.12	9	-78	-9
L dPFC (middle frontal gyrus)	8, 9	60	-5.16	-27	27	42
L lateral MTG	21	57	-4.46	-60	-51	0
R middle cingulate cortex	31	55	-4.40	15	-33	39
R MTG/ parahippocampal gyrus	19	52	-6.11	36	-51	0
R cuneus	18	45	-5.44	15	-93	18
R medial IFG / middle frontal gyrus	10	41	-4.21	30	30	15
L caudate		34	-4.30	-24	-54	12
R parahippocampal gyrus/ MTG	36	30	-5.18	39	-36	-9
L lateral MTG	21	29	-4.07	-60	-6	-9
R post-central gyrus	5	26	-4.16	27	-45	69
L dPFC (superior frontal gyrus)	10	25	-4.25	-24	63	6
R vmPFC (medial frontal gyrus)	10	24	-3.72	9	39	-6
L STG		24	-4.38	-36	-27	0
R middle occipital gyrus / calcarine gyrus	19	22	-4.45	33	-66	9

Note. Activations were obtained using an independent voxel threshold of p<.005 and a cluster threshold of 20.3 voxels. Clusters having 20.3 voxels or larger are significant at p<.05. L = left, R = right, B = bilateral, ACC = anterior cingulate cortex, d = dorsal, IFG = inferior frontal gyrus, IPL = inferior parietal lobule, ITG = inferior temporal gyrus, l = lateral, m = medial, MTG = middle temporal gyrus, OFC = orbitofrontal cortex, PCC = posterior cingulate cortex, PFC = prefrontal cortex, SMA = supplementary motor area, SMG = supraMarginal gyrus, SPL = superior parietal lobule, STG = superior temporal gyrus, v = ventral.

Table 1. Results for mixed-effect regressions on the behavioral data from the scan session for choice (logistic, *z*) and RTs (linear, *t*).

	Model 1			Model 2					Model 3	
	Estimate	**SE**	***z* / *t***	**Estimate**	**SE**	***z* / *t***	**R^2**	**AIC**	**ΔR^2**	**AIC**
Choice responses (logistic)										
training group	-.167	.138	-1.213							
food type	.604	.069	8.726	.672	.137	4.907	52	3,331	-4	3,515
repetition	.026	.066	.399							
frequency	.826	.061	13.509	.867	.134	6.492	51	3,347	-4	3,654
attractiveness	.797	.034	23.264	.915	.076	12.072	54	3,386	-15	4,138
hunger before	.312	.118	2.644	.323	.12	2.692	52	3,455	-1	3,459
BMI	-.015	.039	-.389							
restrained eating	.325	.201	1.621							
healthy eating	-.369	.219	-1.685							
Choice RTs										
training group	-4.866	27.151	-.179							
food type	-39.325	6.286	-6.256	-39.387	8.816	-4.468	36	67,195	-2	67,276
repetition	-23.421	6.136	-3.817	-23.472	6.316	-3.716	34	67,242	0	67,255
frequency	-9.596	5.273	-1.820							
attractiveness	-18.865	2.844	-6.634	-19.234	4.899	-3.926	38	67,184	-4	67,285
hunger before	-25.327	23.396	-1.083							
BMI	3.019	7.805	.387							
restrained eating	-3.735	39.612	-.776							
healthy eating	-7.380	43.169	-.171							
food type X repetition	-13.300	6.136	-2.167	-13.342	6.166	-2.164	37	67,201	-2	67,246

Note. The logistic regression on choice computed the z statistic to assess the significance of the estimated coefficients; the linear regression on RTs computed the t statistic. Model 1 predicted choice or RT with the three experimental variables (training, food type, repetition) including all their two- and three-way interactions, continuous control variables for attractiveness, frequency, hunger before, BMI, restrained dating, and healthy eating (no interactions), and random intercepts for participants and foods. Results are shown for all main effects, regardless of significance, and for all significant interactions (z or $t > |1.96|$). Model 2 tested all significant main effects and interactions maximally (Barr et al., 2013), adding relevant random slopes for the tested main effect or interaction to the model (such that Model 2 differed for each main effect or interaction tested). Model 3 assessed each significant main effect or interaction in Model 2 by dropping it (and only it) from the model, along with any relevant slopes (for interactions, main effect slopes remained). All regressions were performed on standardized measures, except for the dependent variables (values of 0 and 1 for choice; original values for the RTs). For training, normal viewing was scored +1 and observe training was scored -1. For food type, tasty foods were scored +1 and healthy foods were scored -1. For repetition, repeated foods were scored +1 and novel foods were scored -1. An Estimate is the estimate of a standardized regression coefficient in the respective model, with SE and *z* or *t*, being the standard error and *z* or *t* value of the estimate. R^2 is the total variance explained by Model 2, and ΔR^2 is the amount of variance explained by the main effect or interaction dropped in Model 3. AIC is the value of the Akaike Information Criterion for Models 2 and 3.

Table 2. In the training phase, voxel counts from two conjunction analyses for the Normal viewing and Observe perspectives, each contrasting Tasty vs. Healthy foods.

Training phase	**Normal viewing**						**Observe**					
Brain region	**Tasty unique**	**Healthy unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**	**Tasty unique**	**Healthy unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**
L insula	19	6	>>	0.0073	61	86	37	9	>>	0.0000	133	179
R insula	15	3	>>	0.0038	20	38	25	12	>>	0.0235	69	106
Piriform cortex and uncus	53	15	>>	0.0000	75	143	98	30	>>	0.0000	111	239
Amygdala	26	15	>>	0.0586	30	71	37	12	>>	0.0002	73	122
Orbital-frontal cortex	124	11	>>	0.0000	117	252	176	12	>>	0.0000	127	315
Cortical midline	192	16	>>	0.0000	229	437	302	28	>>	0.0000	401	731
L inferior frontal gyrus	0	6	><	0.0156	0	6	99	44	>>	0.0000	233	376
R inferior frontal gyrus	0	0	>=	1.0000	0	0	39	9	>>	0.0000	109	157
L lateral middle temporal gyrus	96	35	>>	0.0000	134	265	234	24	>>	0.0000	275	533
L occipital and medial temporal	292	41	>>	0.0000	1,199	1,532	242	38	>>	0.0000	1,368	1,648
R occipital and medial temporal	143	90	>>	0.0003	766	999	365	30	>>	0.0000	965	1,360
Angular gyrus and precuneus	73	7	>>	0.0000	112	192	86	1	>>	0.0000	67	154
Supplemental motor area	58	0	>>	0.0000	0	58	95	24	>>	0.0000	216	335
Pre-central and post-central gyrus	15	13	>>	0.4253	22	50	318	6	>>	0.0000	120	444
Cerebellum	473	106	>>	0.0000	766	1,345	586	111	>>	0.0000	1,345	2,042
Thalamus	18	2	>>	0.0002	10	30	41	11	>>	0.0000	33	85
Basal ganglia	1	4	><	0.1875	0	5	92	24	>>	0.0000	10	126
Total	1,598	370	>>	0.0000	3,541	5,509	2,872	425	>>	0.0000	5,655	8,952

Note. For each perspective during the training phase (Normal viewing, Observe), a conjunction analysis was performed on the clusters significantly active above baseline for Tasty vs. Healthy foods. For each brain region on the left, the numbers of unique voxels contained within it for Tasty vs. Healthy foods are shown in the columns for Tasty unique and Healthy unique (Appendix E presents the specific masks used). Shared voxels between Tasty and Healthy foods, as well as the total voxels across them, are also shown. A binomial test was conducted on the Tasty unique vs. Healthy unique voxels in each brain region for each conjunction analysis. The probability of obtaining a given pair of voxel counts in the observed direction is presented (Unique binomial *p*). In the Pred / Obs column, the first symbol indicates the predicted direction of the Tasty vs. Healthy unique voxel counts, and the second indicates the observed direction. As described in the main text, we view each *p* value as representing the strength of an asymmetric distribution between two unique sets of voxels, rather than as testing the null hypothesis.

Table 3. For repeated trials during the choice phase, voxel counts from two conjunction analyses for the Normal viewing and Observe perspectives, each contrasting Tasty vs. Healthy foods.

Choice: Repeated trials	**Normal viewing**						**Observe**					
Brain region	**Tasty unique**	**Healthy unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**	**Tasty unique**	**Healthy unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**
L insula	1	135	> <	0.0000	82	218	17	60	> <	0.0000	83	160
R insula	3	160	> <	0.0000	11	174	5	29	> <	0.0000	21	55
Piriform cortex and uncus	3	121	> <	0.0000	67	191	43	23	> >	0.0093	58	124
Amygdala	10	40	> <	0.0000	26	76	1	2	> <	0.5000	2	5
Orbital-frontal cortex	1	50	> <	0.0000	37	88	6	13	> <	0.0835	36	55
Cortical midline	3	404	> <	0.0000	119	526	15	103	> <	0.0000	61	179
L inferior frontal gyrus	0	381	> <	0.0000	107	488	0	207	> <	0.0000	37	244
R inferior frontal gyrus	0	226	> <	0.0000	0	226	0	130	> <	0.0000	0	130
L lateral middle temporal gyrus	1	4	> <	0.1875	17	22	0	5	> <	0.0313	10	15
L occipital and medial temporal	29	320	> <	0.0000	1,062	1,411	79	132	> <	0.0002	861	1,072
R occipital and medial temporal	9	306	> <	0.0000	897	1,212	64	91	> <	0.0182	753	908
Angular gyrus and precuneus	5	51	> <	0.0000	18	74	0	19	> <	0.0000	20	39
Supplemental motor area	0	296	> <	0.0000	63	359	12	100	> <	0.0000	37	149
Pre-central and post-central gyrus	8	263	> <	0.0000	71	342	15	70	> <	0.0000	43	128
Cerebellum	17	776	> <	0.0000	954	1,747	74	101	> <	0.0245	641	816
Thalamus	2	118	> <	0.0000	4	124	0	1	> <	0.5000	0	1
Basal ganglia	0	129	> <	0.0000	0	129	0	1	> <	0.5000	0	1
Total	92	3,780	> <	0.0000	3,535	7,407	331	1,087	> <	0.0000	2,663	4,081

Note. For repeated trials during the choice phase, a conjunction analysis was performed for each perspective (Normal viewing, Observe) on the clusters significantly active above baseline for Tasty vs. Healthy foods. For each brain region on the left, the numbers of unique voxels contained within it for Tasty vs. Healthy foods are shown in the columns for Tasty unique and Healthy unique (Appendix E presents the specific masks used). Shared voxels between Tasty and Healthy foods, as well as the total voxels across them, are also shown. A binomial test was conducted on the Tasty unique vs. Healthy unique voxels in each brain region for each conjunction analysis. The probability of obtaining a given pair of voxel counts in the observed direction is presented (Unique binomial *p*). In the Pred / Obs column, the first symbol indicates the predicted direction of the Tasty vs. Healthy unique voxel counts, and the second indicates the observed direction. As described in the main text, we view each *p* value as representing the strength of an asymmetric distribution between two unique sets of voxels, rather than as testing the null hypothesis.

Table 4. In the training phase, voxel counts from two conjunction analyses for Tasty foods and Healthy foods, each contrasting Normal viewing vs. Observe training.

Training phase	**Tasty foods**						**Healthy foods**					
Brain region	**Normal unique**	**Observe unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**	**Normal unique**	**Observe unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**
L insula	2	92	<<	0.0000	78	172	4	79	<<	0.0000	63	146
R insula	9	68	<<	0.0000	26	103	5	63	<<	0.0000	18	86
Piriform cortex and uncus	21	102	<<	0.0000	107	230	25	76	<<	0.0000	65	166
Amygdala	6	60	<<	0.0000	50	116	2	42	<<	0.0000	43	87
Orbital-frontal cortex	62	124	<<	0.0000	179	365	55	66	<<	0.1817	73	194
Cortical midline	87	369	<<	0.0000	334	790	93	277	<<	0.0000	152	522
L inferior frontal gyrus	0	332	<<	0.0000	0	332	0	271	<<	0.0000	6	277
R inferior frontal gyrus	0	148	<<	0.0000	0	148	0	118	<<	0.0000	0	118
L lateral middle temporal gyrus	61	340	<<	0.0000	169	570	92	222	<<	0.0000	77	391
L occipital and medial temporal	239	358	<<	0.0000	1,252	1,849	204	370	<<	0.0000	1,036	1,610
R occipital and medial temporal	56	477	<<	0.0000	853	1,386	137	276	<<	0.0000	719	1,132
Angular gyrus and precuneus	106	74	<>	0.0103	79	259	81	30	<>	0.0000	38	149
Supplemental motor area	5	258	<<	0.0000	53	316	0	240	<<	0.0000	0	240
Pre-central and post-central gyrus	25	426	<<	0.0000	12	463	31	122	<<	0.0000	4	157
Cerebellum	299	991	<<	0.0000	940	2,230	218	802	<<	0.0000	654	1,674
Thalamus	11	57	<<	0.0000	17	85	6	38	<<	0.0000	6	50
Basal ganglia	1	102	<<	0.0000	0	103	3	33	<<	0.0000	1	37
Total	990	4,378	<<	0.0000	4,149	9,517	956	3,125	<<	0.0000	2,955	7,036

Note. For each food type during the training phase (Tasty, Healthy), a conjunction analysis was performed on the clusters significantly active above baseline for the Normal viewing vs. Observe perspectives. For each brain region on the left, the numbers of unique voxels contained within it for the Normal viewing vs. Observe perspectives are shown in the columns for Normal unique and Observe unique (Appendix E presents the specific masks used). Shared voxels between the Normal viewing and Observe perspectives, as well as the total voxels across them, are also shown. A binomial test was conducted on the Normal unique vs. Observe unique voxels in each brain region for each conjunction analysis. The probability of obtaining a given pair of voxel counts in the observed direction is presented (Unique binomial *p*). In the Pred / Obs column, the first symbol indicates the predicted direction of the Normal vs. Observe unique voxel counts, and the second indicates the observed direction. As described in the main text, we view each *p* value as representing the strength of an asymmetric distribution between two unique sets of voxels, rather than as testing the null hypothesis.

Table 5. For repeated trials during the choice phase, voxel counts from two conjunction analyses for Tasty foods and Healthy foods, each contrasting the Normal viewing vs. Observe perspectives.

Choice: Repeated trials	**Tasty foods**						**Healthy foods**					
Brain region	**Normal unique**	**Observe unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**	**Normal unique**	**Observe unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**
L insula	29	46	>>	0.0320	54	129	88	14	>>	0.0000	129	231
R insula	11	23	><	0.0288	3	37	123	2	>>	0.0000	48	173
Piriform cortex and uncus	34	65	><	0.0012	36	135	121	14	>>	0.0000	67	202
Amygdala	36	3	>>	0.0000	0	39	62	0	>>	0.0000	4	66
Orbital-frontal cortex	10	14	><	0.2706	28	52	47	9	>>	0.0000	40	96
Cortical midline	87	41	>>	0.0000	35	163	376	17	>>	0.0000	147	540
L inferior frontal gyrus	97	27	>>	0.0000	10	134	300	56	>>	0.0000	188	544
R inferior frontal gyrus	0	0	>=	1.0000	0	0	144	48	>>	0.0000	82	274
L lateral middle temporal gyrus	10	2	>>	0.0193	8	20	10	4	>>	0.0898	11	25
L occipital and medial temporal	328	177	>>	0.0000	763	1,268	482	93	>>	0.0000	900	1,475
R occipital and medial temporal	215	126	>>	0.0000	691	1,032	425	66	>>	0.0000	778	1,269
Angular gyrus and precuneus	16	13	>>	0.3555	7	36	41	11	>>	0.0000	28	80
Supplemental motor area	49	35	>>	0.0778	14	98	248	26	>>	0.0000	111	385
Pre-central and post-central gyrus	52	31	>>	0.0138	27	110	252	31	>>	0.0000	82	365
Cerebellum	316	60	>>	0.0000	655	1,031	1,036	48	>>	0.0000	694	1,778
Thalamus	6	0	>>	0.0156	0	6	121	0	>>	0.0000	1	122
Basal ganglia	0	0	>=	1.0000	0	0	129	1	>>	0.0000	0	130
Total	1,296	663	>>	0.0000	2,331	4,290	4,005	440	>>	0.0000	3,310	7,755

Note. For repeated trials during the choice phase, a conjunction analysis was performed for each food type (Tasty, Healthy) on the clusters significantly active above baseline for the Normal viewing vs. Observe perspectives. For each brain region on the left, the numbers of unique voxels contained within it for the Normal viewing vs. Observe perspectives are shown in the columns for Normal unique and Observe unique (Appendix E presents the specific masks used). Shared voxels between the Normal viewing and Observe perspectives, as well as the total voxels across them, are also shown. A binomial test was conducted on the Normal unique vs. Observe unique voxels in each brain region for each conjunction analysis. The probability of obtaining a given pair of voxel counts in the observed direction is presented (Unique binomial *p*). In the Pred / Obs column, the first symbol indicates the predicted direction of the Tasty vs. Healthy unique voxel counts, and the second indicates the observed direction. As described in the main text, we view each *p* value as representing the strength of an asymmetric distribution between two unique sets of voxels, rather than as testing the null hypothesis.

Table 6. For the Normal viewing perspective during the choice phase, voxel counts from two conjunction analyses for Tasty foods and Healthy foods, each contrasting Repeated vs. Novel trials.

Normal Viewing: Choice	**Tasty foods**						**Healthy foods**					
Brain region	**Repeated unique**	**Novel unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**	**Repeated unique**	**Novel unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**
L insula	5	79	<<	0.0000	78	162	28	31	<<	0.3974	189	248
R insula	0	104	<<	0.0000	14	118	35	19	<>	0.0201	136	190
Piriform cortex and uncus	3	85	<<	0.0000	67	155	43	26	<>	0.0266	145	214
Amygdala	9	24	<<	0.0068	27	60	10	19	<<	0.0680	56	85
Orbital-frontal cortex	1	32	<<	0.0000	37	70	19	17	<>	0.4340	68	104
Cortical midline	22	182	<<	0.0000	100	304	148	47	<>	0.0000	375	570
L inferior frontal gyrus	9	183	<<	0.0000	98	290	44	65	<<	0.0275	444	553
R inferior frontal gyrus	0	191	<<	0.0000	0	191	24	89	<<	0.0000	202	315
L lateral middle temporal gyrus	0	7	<<	0.0078	18	25	3	5	<<	0.3633	18	26
L occipital and medial temporal	9	405	<<	0.0000	1,082	1,496	73	165	<<	0.0000	1,309	1,547
R occipital and medial temporal	7	410	<<	0.0000	899	1,316	69	154	<<	0.0000	1,134	1,357
Angular gyrus and precuneus	6	32	<<	0.0000	17	55	15	12	<>	0.3506	54	81
Supplemental motor area	0	171	<<	0.0000	63	234	48	65	<<	0.0660	311	424
Pre-central and post-central gyrus	4	361	<<	0.0000	75	440	44	187	<<	0.0000	290	521
Cerebellum	17	726	<<	0.0000	954	1,697	210	498	<<	0.0000	1,520	2,228
Thalamus	2	31	<<	0.0000	4	37	47	14	<>	0.0000	75	136
Basal ganglia	0	2	<<	0.2500	0	2	100	28	<>	0.0000	29	157
Total	94	3,025	<<	0.0000	3,533	6,652	960	1,441	<<	0.0000	6,355	8,756

Note. For the Normal viewing perspective during the choice phase, a conjunction analysis was performed for each food type (Tasty, Healthy) on the clusters significantly active above baseline for Repeated vs. Novel trials. For each brain region on the left, the numbers of unique voxels contained within it for Repeated vs. Novel trials are shown in the columns for Repeated unique and Novel unique (Appendix E presents the specific masks used). Shared voxels between Repeated and Novel trials, as well as the total voxels across them, are also shown. A binomial test was conducted on the Repeated unique vs. Novel unique voxels in each brain region for each conjunction analysis. The probability of obtaining a given pair of voxel counts in the observed direction is presented (Unique binomial *p*). In the Pred / Obs column, the first symbol indicates the predicted direction of the Repeated vs. Novel unique voxel counts, and the second indicates the observed direction. As described in the main text, we view each *p* value as representing the strength of an asymmetric distribution between two unique sets of voxels, rather than as testing the null hypothesis.

Table 7. For the Observe perspective during the choice phase, voxel counts from two conjunction analyses for Tasty foods and Healthy foods, each contrasting Repeated vs. Novel trials.

Observe: Choice	**Tasty foods**						**Healthy foods**					
Brain region	**Repeated unique**	**Novel unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**	**Repeated unique**	**Novel unique**	**Pred Obs**	**Unique binomial *p***	**Shared**	**Total**
L insula	14	76	<<	0.0000	86	176	15	42	<<	0.0002	128	185
R insula	15	28	<<	0.0330	11	54	7	30	<<	0.0001	43	80
Piriform cortex and uncus	8	70	<<	0.0000	93	171	7	56	<<	0.0000	74	137
Amygdala	1	50	<<	0.0000	2	53	0	19	<<	0.0000	4	23
Orbital-frontal cortex	2	29	<<	0.0000	40	71	5	29	<<	0.0000	44	78
Cortical midline	23	84	<<	0.0000	53	160	35	80	<<	0.0000	129	244
L inferior frontal gyrus	8	259	<<	0.0000	29	296	58	105	<<	0.0001	186	349
R inferior frontal gyrus	0	187	<<	0.0000	0	187	25	54	<<	0.0007	105	184
L lateral middle temporal gyrus	1	16	<<	0.0001	9	26	2	3	<<	0.5000	13	18
L occipital and medial temporal	12	453	<<	0.0000	928	1,393	17	187	<<	0.0000	976	1,180
R occipital and medial temporal	6	360	<<	0.0000	811	1,177	15	168	<<	0.0000	829	1,012
Angular gyrus and precuneus	1	17	<<	0.0001	19	37	8	17	<<	0.0539	31	56
Supplemental motor area	6	97	<<	0.0000	43	146	23	58	<<	0.0001	114	195
Pre-central and post-central gyrus	4	168	<<	0.0000	54	226	13	63	<<	0.0000	100	176
Cerebellum	15	307	<<	0.0000	700	1,022	29	335	<<	0.0000	713	1,077
Thalamus	0	16	<<	0.0000	0	16	0	3	<<	0.1250	1	4
Basal ganglia	0	1	<<	0.5000	0	1	1	0	<>	0.5000	0	1
Total	116	2,218	<<	0.0000	2,878	5,212	260	1,249	<<	0.0000	3,490	4,999

Note. For the Observe perspective during the choice phase, a conjunction analysis was performed for each food type (Tasty, Healthy) on the clusters significantly active above baseline for Repeated vs. Novel trials. For each brain region on the left, the numbers of unique voxels contained within it are shown in the columns for Repeated unique and Novel unique (Appendix E presents the specific masks used). Shared voxels between Repeated and Novel trials, as well as the total voxels across them, are also shown. A binomial test was conducted on the Repeated unique vs. Novel unique voxels in each brain region for each conjunction analysis. The probability of obtaining a given pair of voxel counts in the observed direction is presented (Unique binomial *p*). In the Pred / Obs column, the first symbol indicates the predicted direction of the Repeated vs. Novel unique voxel counts, and the second indicates the observed direction. As described in the main text, we view each *p* value as representing the strength of an asymmetric distribution between two unique sets of voxels, rather than as testing the null hypothesis.

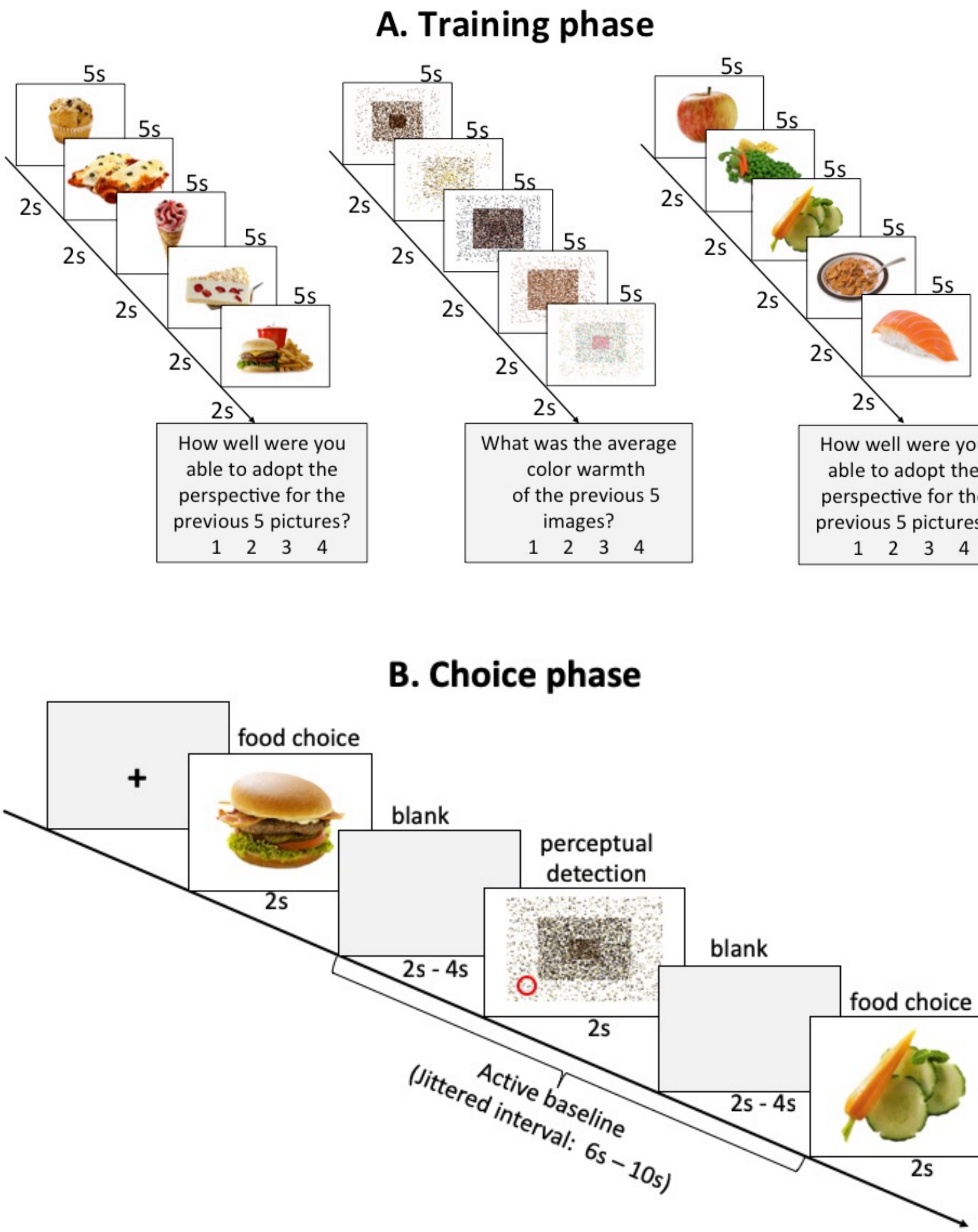


Figure 1. Panel A illustrates the training phase of the experiment. Each of 3 training runs included 4 blocks of 5 food pictures each, alternating with 5 blocks of scrambled object images for the active baseline task (with each of 2 food blocks containing pictures of only tasty foods or only healthy foods). A 2 sec instruction before each block indicated whether it would be a food block or color warmth block. Each food image and scrambled object image was presented for 5 sec, followed by a 2 sec blank screen. Following the fifth food picture in a food block, participants rated how well they were able to perform their assigned perspective on the 5 images (normal viewing or observe). Following the final scrambled image in an active baseline block, participants rated the average color warmth of the 5 images. Thus each of 3 training runs included 10 tasty foods, 10 healthy foods and 20 scrambled object images (for a total of 30 tasty foods, 30 healthy foods, and 60 scrambled object images across 3 runs). Panel B illustrates the choice phase of the experiment. On each food choice trial, a food image was presented for 2 sec, with participants indicating whether or not they would like to eat the food. Between food choice trials, a randomly-jittered active baseline task occurred, varying from 6 to 10 sec. During the active baseline, a scrambled image of an object with a red circle, appeared for 2 sec, and participants had to indicate whether the circle occurred on the left or right. Each of 3 food choice runs included 10 repeated tasty foods, 10 repeated healthy foods, 10 novel tasty foods, and 10 novel healthy foods, randomly ordered within each run (for a total of 30 repeated tasty foods, 30 repeated healthy foods, 30 novel tasty foods, and 30 novel health foods across runs).

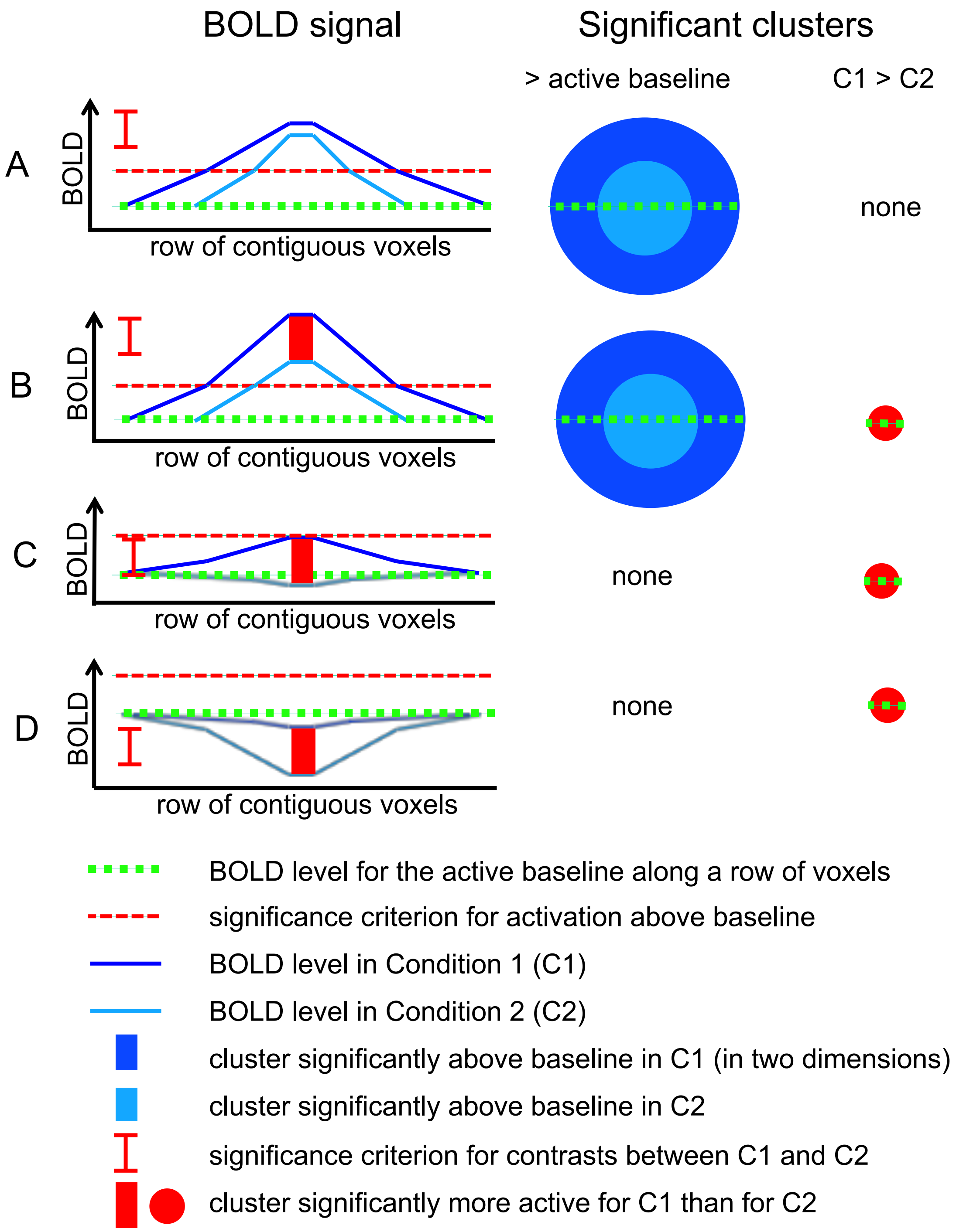


Figure 2. Differences between overlapping clusters significantly active above baseline vs. clusters differing significantly between conditions (C1 and C2). Panel A provides an example of how focusing on contrasts can miss activations above baseline. Panel B provides an example of how a significant contrast can miss additional activations above baseline. Panels C and D provide examples of how clusters can emerge from contrasts, even when the more active condition is not significantly active above baseline, or even lies below baseline, respectively.

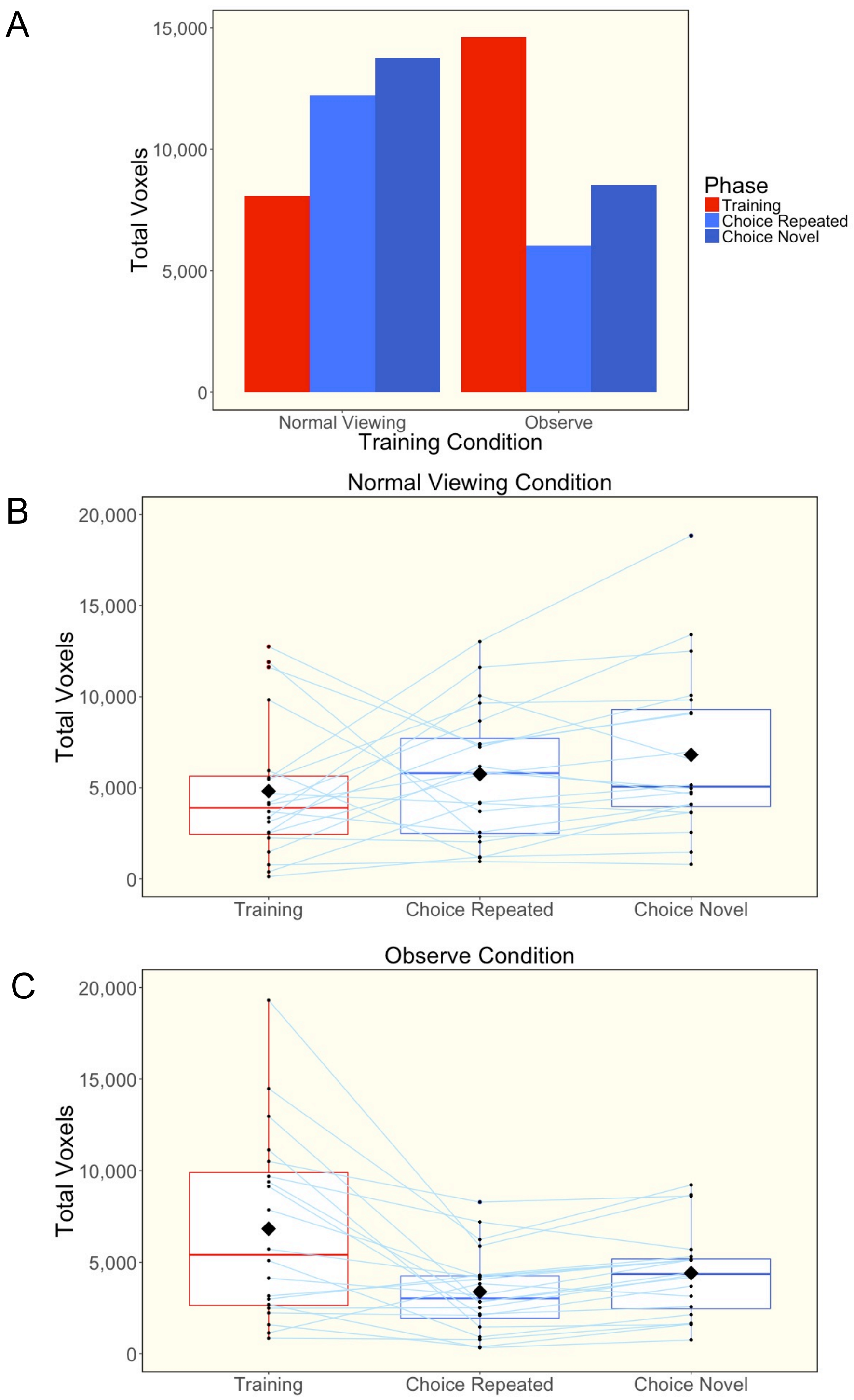


Figure 3. Panel A displays the total number of voxels significantly active above the relevant active baseline in a group-level random effects analysis, where the voxels included were independently significant at *p*<.005 in spatial clusters significant at *p*<.05. The results are plotted as a function of training group (normal viewing vs. observe) and phase (training vs. choice), with choice for repeated and novel choice items broken out separately. Panel B displays the total number of voxels significantly active above the relevant active baseline in individual-level analyses for the 20 participants in the normal viewing condition. A line connects the 3 data points across the 3 phases for each participant. Again the voxels included were again independently significant at *p*<.005 in spatial clusters significant at *p*<.05 (set individually for each participant), and are plotted as a function of training group and choice phase. Panel C displays the analogous results for the 20 participants in the observe condition. The ◆ for each group indicates its mean value.

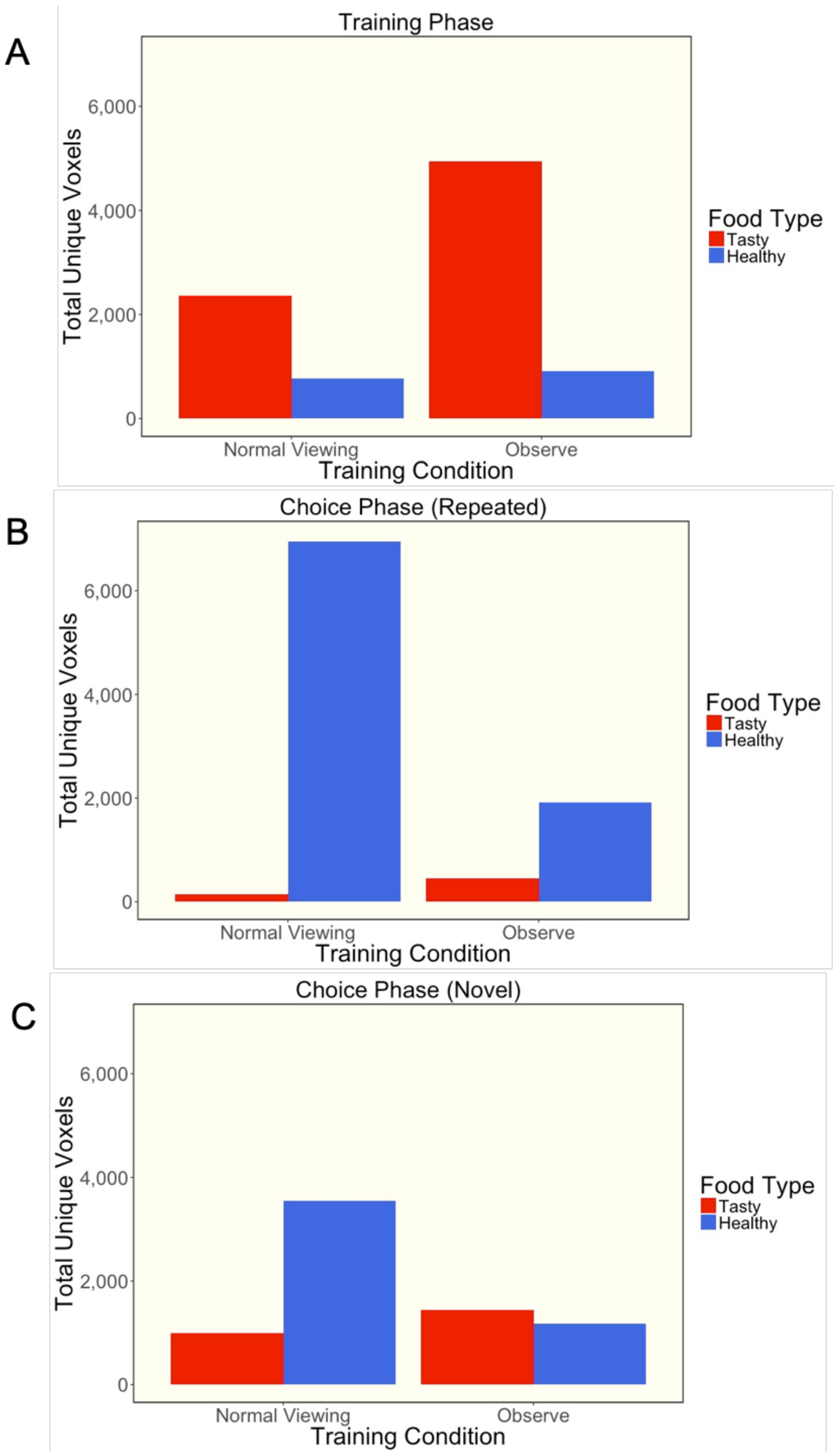


Figure 4. All panels display the total number of unique voxels significantly active above the relevant active baseline in conjunction analyses at the group level (in random effects analyses). All voxels included were independently significant at *p*<.005 in spatial clusters significant at *p*<.05. Panel A, on the left, shows the voxels uniquely activated for tasty vs. healthy foods in a conjunction analyses of all active voxels for the normal viewing condition; on the right are the voxels uniquely active for tasty vs. healthy foods in an analogous conjunction analysis for the observe condition (shared voxels active for both tasty and healthy foods are not shown). Panels B and C analogously show the uniquely active voxels for tasty and healthy foods in the choice phase for repeated and novel foods, respectively.

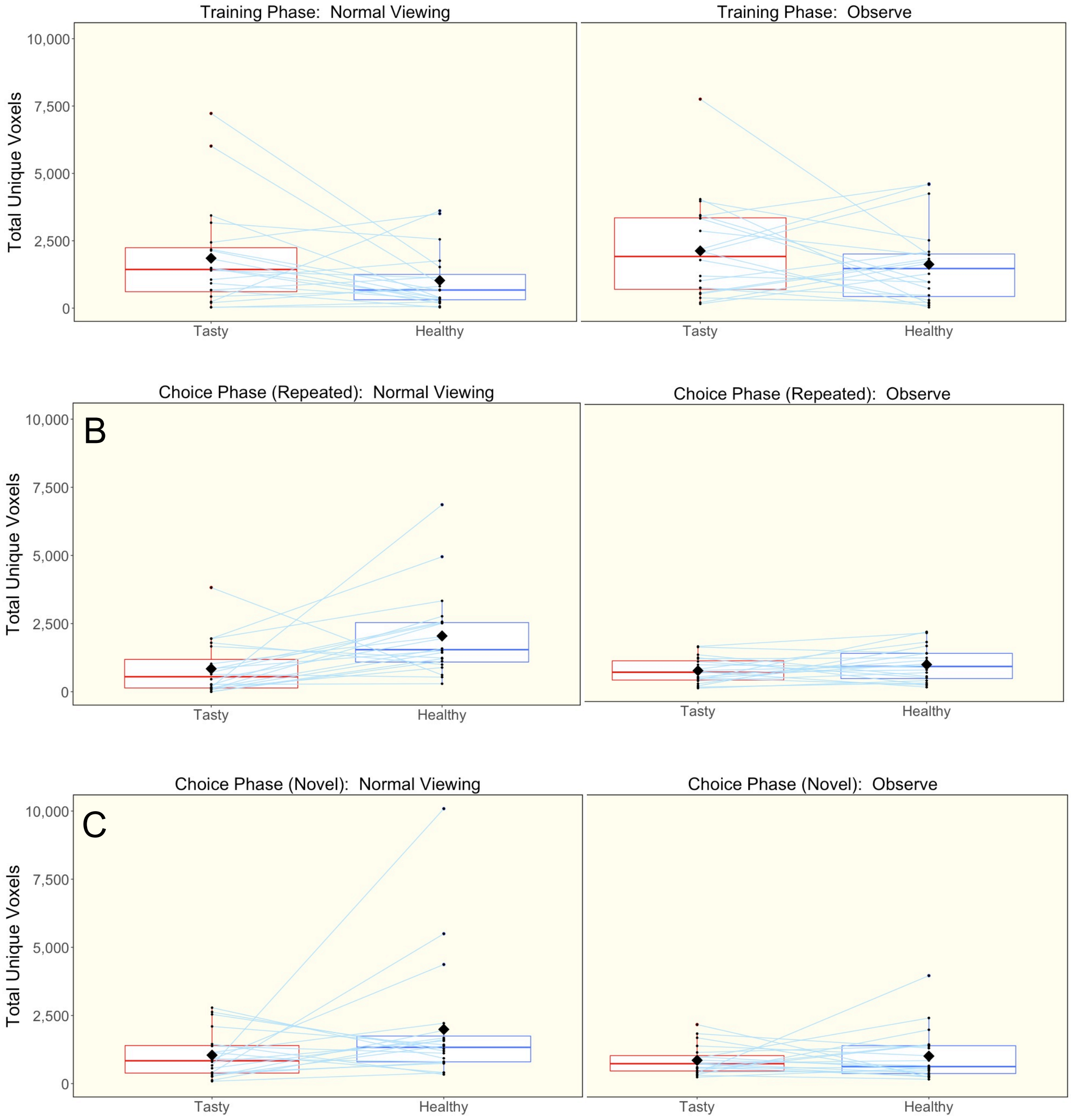


Figure 5. All panels display the total number of unique voxels significantly active above the relevant active baseline in conjunction analyses at the individual level. All voxels included were independently significant at $p<.005$ in spatial clusters significant at $p<.05$ (set individually for each participant). Panel A displays the total number of unique voxels for tasty foods vs. healthy food during the training phase for each of the 20 participants in the normal viewing group (left), and for each of the 20 participants in the observe group (right). Shared voxels active for both tasty and healthy foods are not shown. A line connects the 2 data points across the 2 food types for each participant. Panels B and C analogously show the uniquely active voxels for tasty and healthy foods in the choice phase for repeated and novel foods, respectively, again for the 20 individuals in each training condition. The ◆ for each group indicates its mean value.

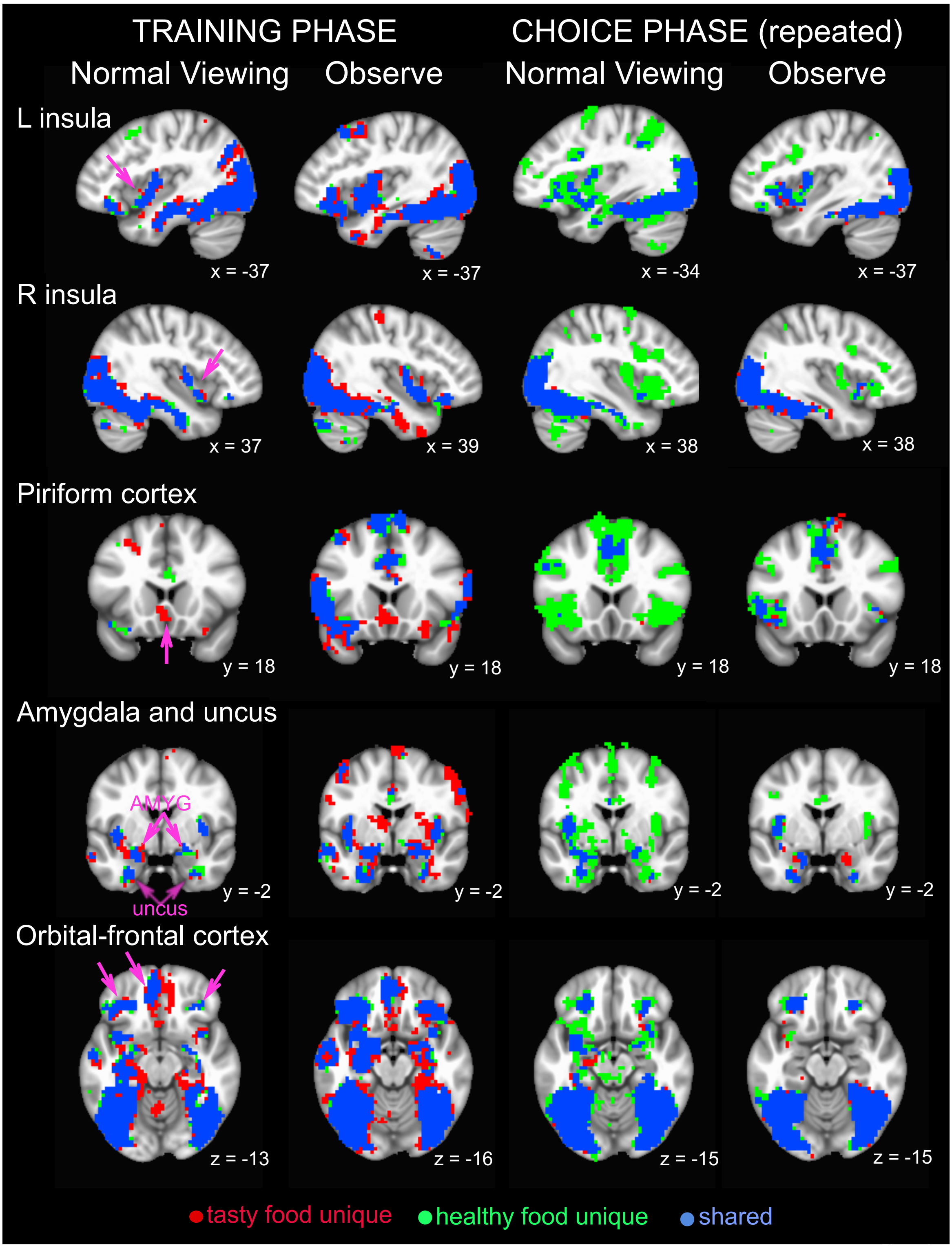


Figure 6. Significant activations above the active baseline in brain areas important for taste (L and R insula), olfaction (perform cortex and uncus), attention (amygdala), and predicted reward (orbital-frontal cortex). Each column presents results from a conjunction analysis between tasty vs. healthy foods. The first two columns show results from the Normal Viewing and Observe conditions during the training phase, whereas the last two columns show results from the choice phase for repeated foods. Unique activations for tasty and healthy foods are shown in red and green, respectively; shared activations for both are shown in blue. Tables 1 and 3 present statistical analyses of these activations.

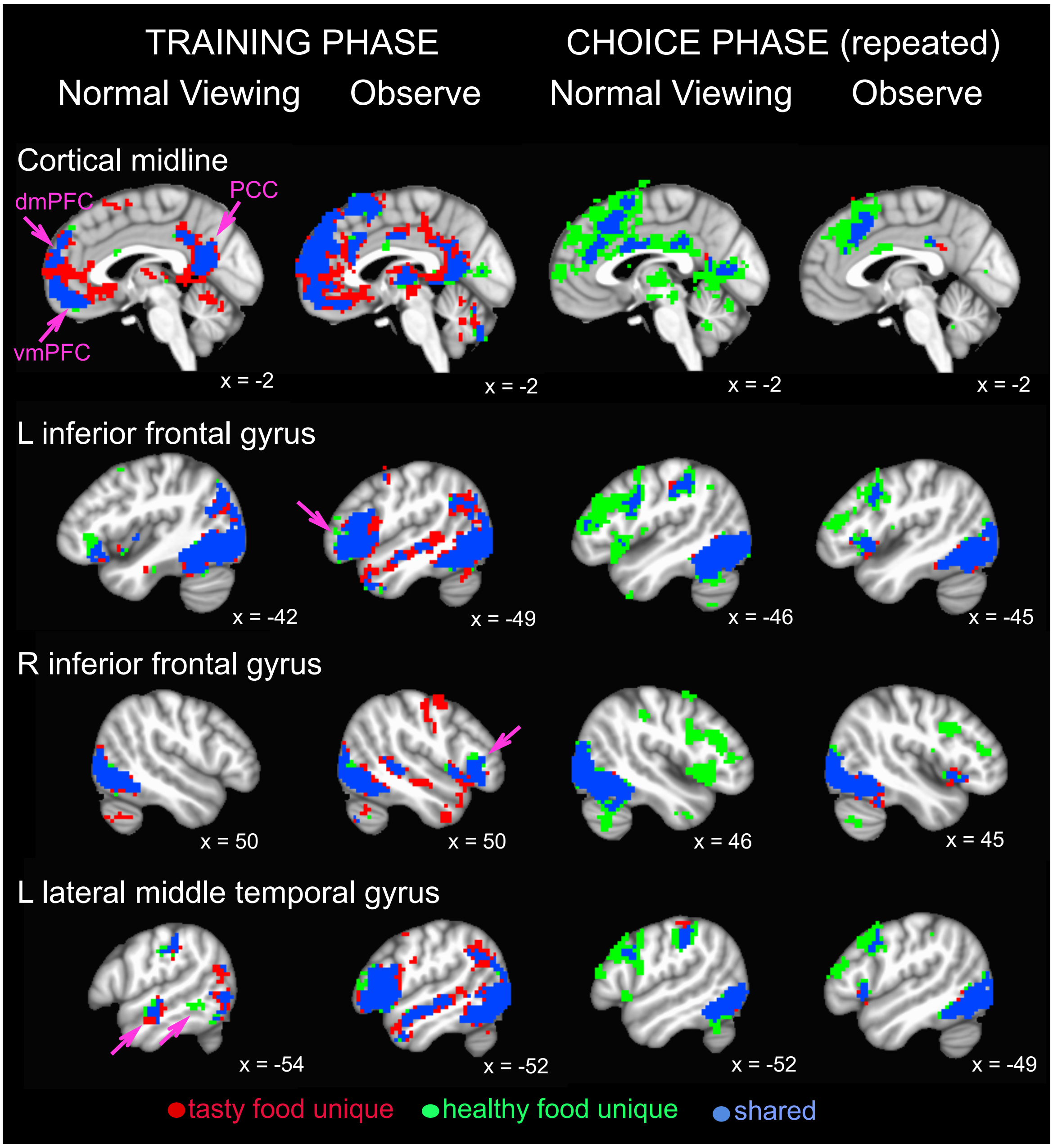


Figure 7. Significant activations above the active baseline in brain areas important for self-relevance and mind wandering (cortical midline), self-regulation (L and R inferior frontal gyrus), and language (L inferior frontal gyrus and L lateral middle temporal gyrus), all potentially relevant for processing foods. Each column presents results from a conjunction analysis between tasty vs. healthy foods. The first two columns show results from the Normal Viewing and Observe conditions during the training phase, whereas the last two columns show results from the choice phase for repeated foods. Unique activations for tasty and healthy foods are shown in red and green, respectively; shared activations for both are shown in blue. Tables 2 and 4 present statistical analyses of these activations.

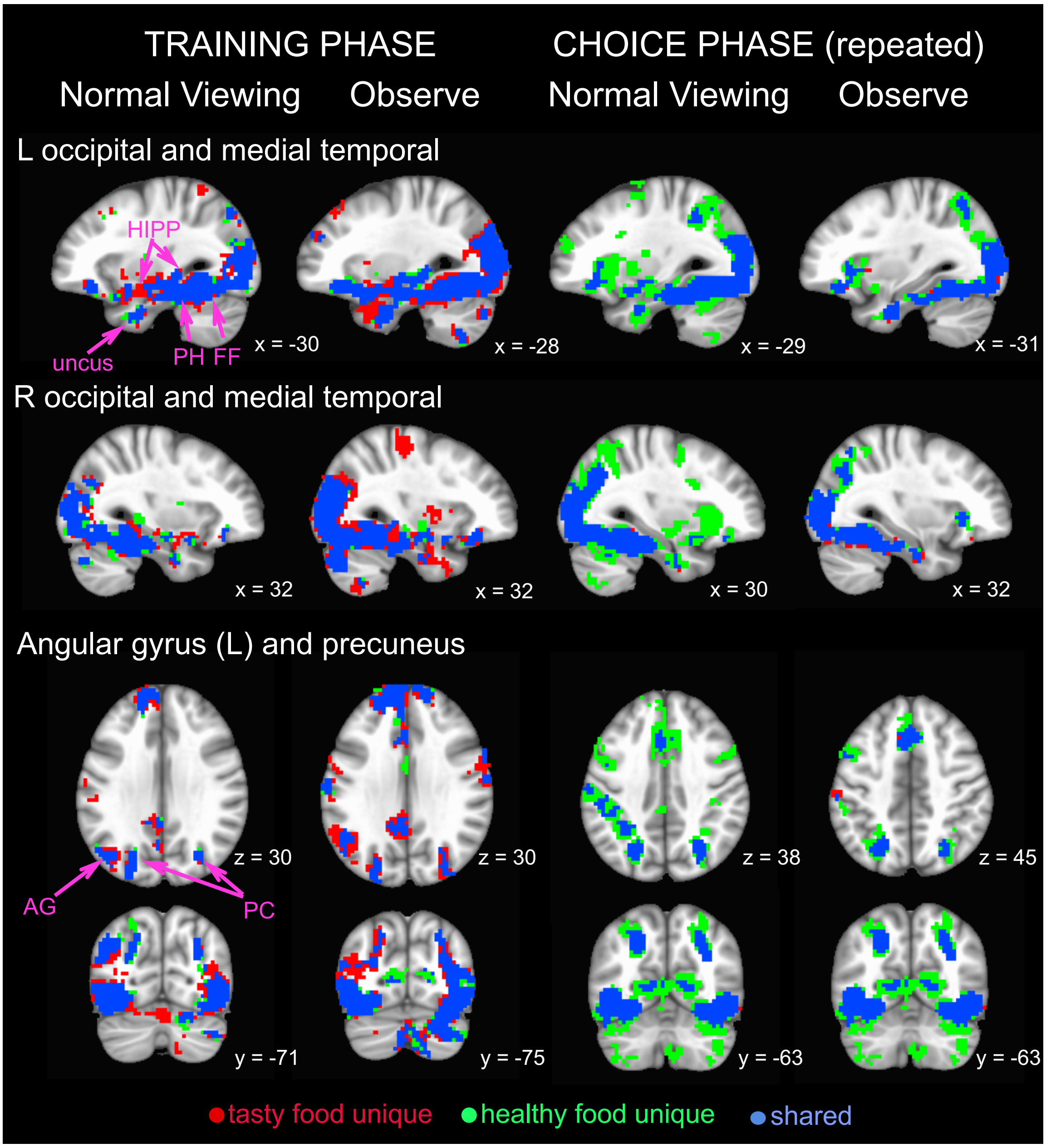


Figure 8. Significant activations above the active baseline in brain areas important for visual processing of foods (occipital cortex, medial temporal cortex, angular gyrus, precuneus). Each column presents results from a conjunction analysis between tasty vs. healthy foods. The first two columns show results from the Normal Viewing and Observe conditions during the training phase, whereas the last two columns show results from the choice phase for repeated foods. Unique activations for tasty and healthy foods are shown in red and green, respectively; shared activations for both are shown in blue. Tables 2 and 4 present statistical analyses of these activations.

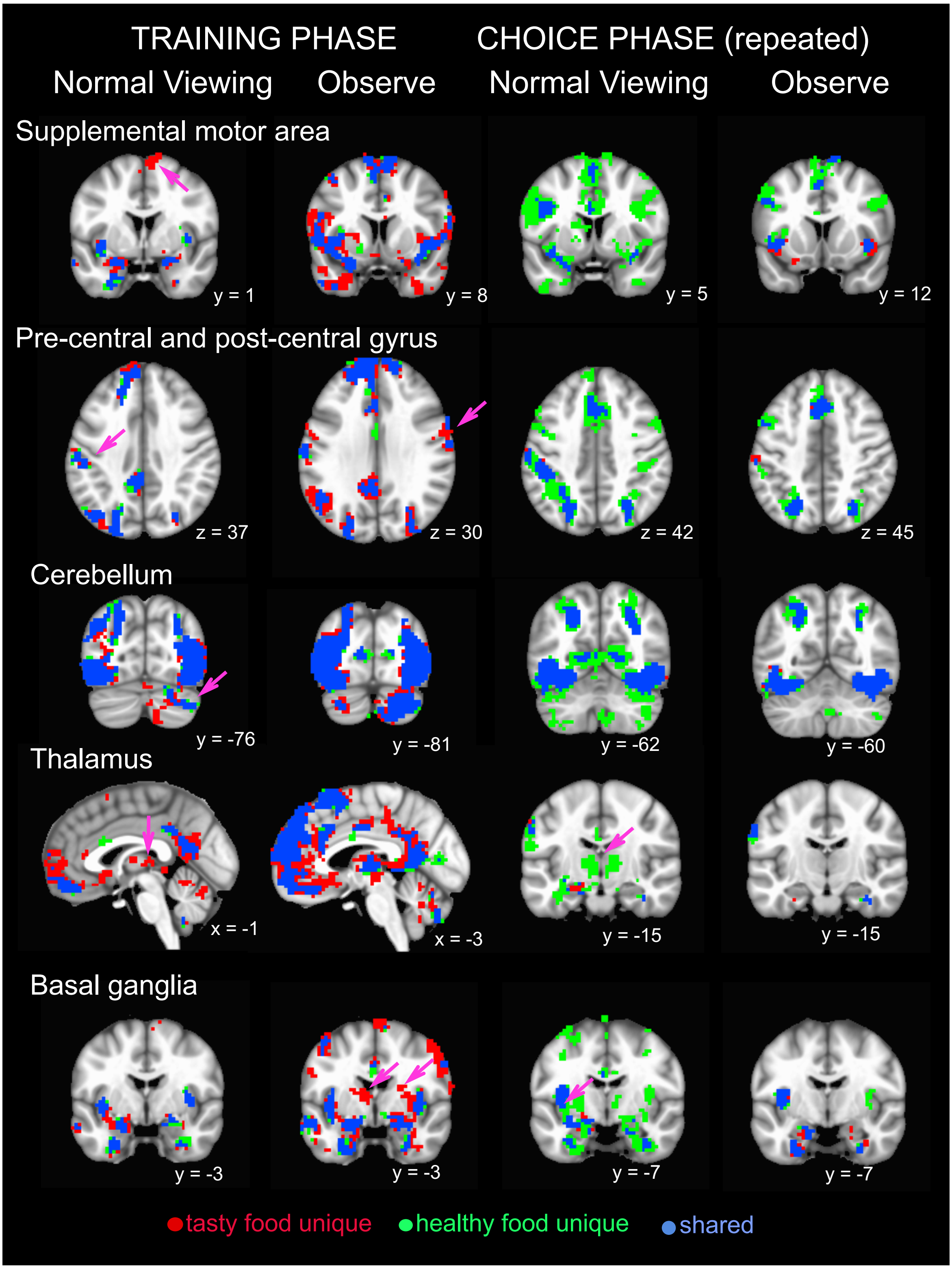


Figure 9. Significant activations above the active baseline in brain areas important for action and embodiment (supplemental motor area, pre-central and post-central gyrus, cerebellum, thalamus, basal ganglia). Each column presents results from a conjunction analysis between tasty vs. healthy foods. The first two columns show results from the Normal Viewing and Observe conditions during the training phase, whereas the last two columns show results from the choice phase for repeated foods. Unique activations for tasty and healthy foods are shown in red and green, respectively; shared activations for both are shown in blue. Tables 2 and 4 present statistical analyses of these activations.

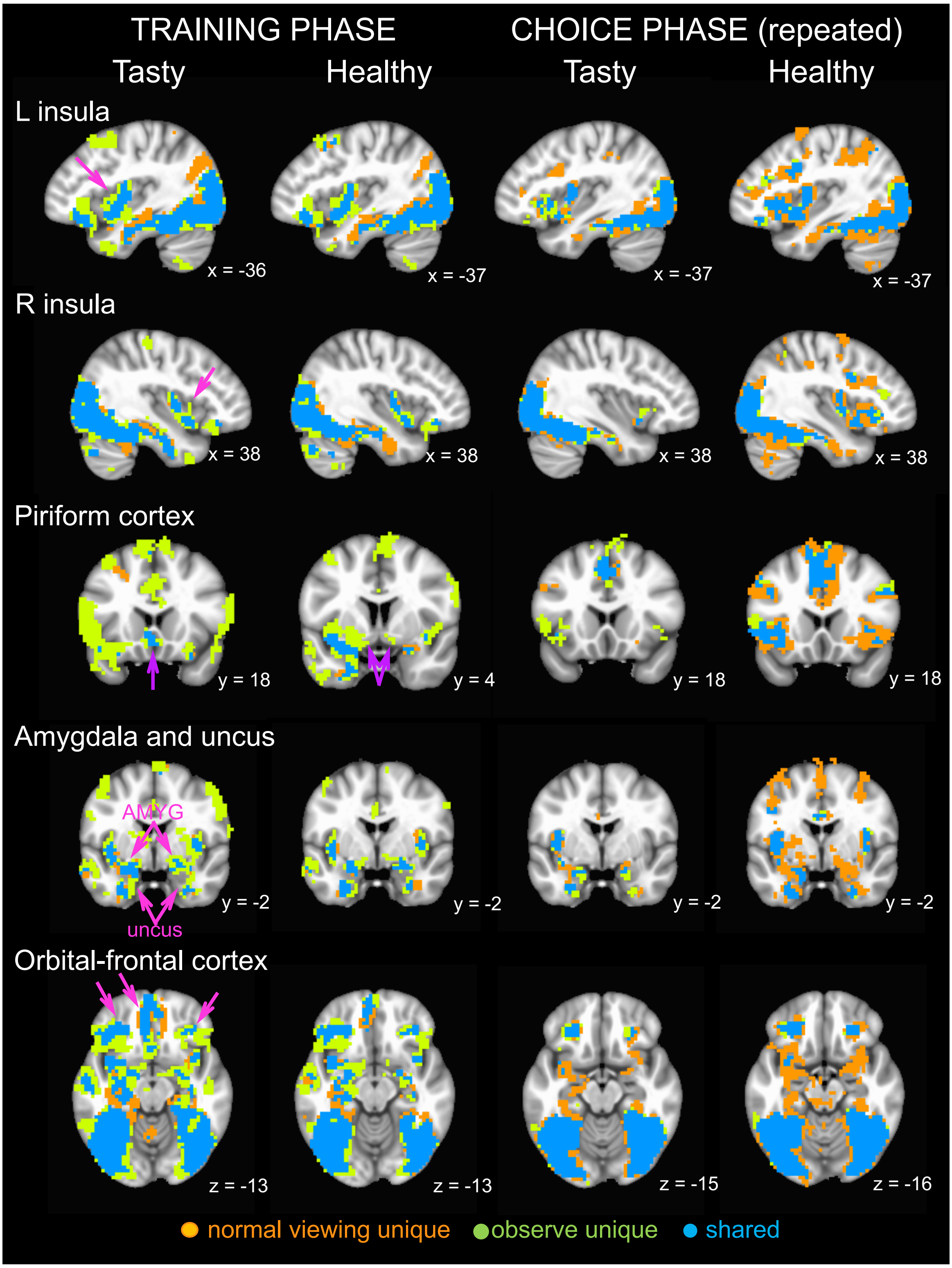


Figure 10. Significant activations above the active baseline in brain areas important for taste (L and R insula), olfaction (perform cortex and uncus), attention (amygdala), and predicted reward (orbital-frontal cortex). Each column presents results from a conjunction analysis between the Normal Viewing and Observe training groups. The first two columns show results for Tasty and Healthy foods during the training phase, whereas the last two columns show results from the choice phase for repeated foods. Unique activations for the Normal Viewing and Observe groups are shown in orange and light green, respectively; shared activations for both are shown in orange. Tables 3 and 5 present statistical analyses of these activations.

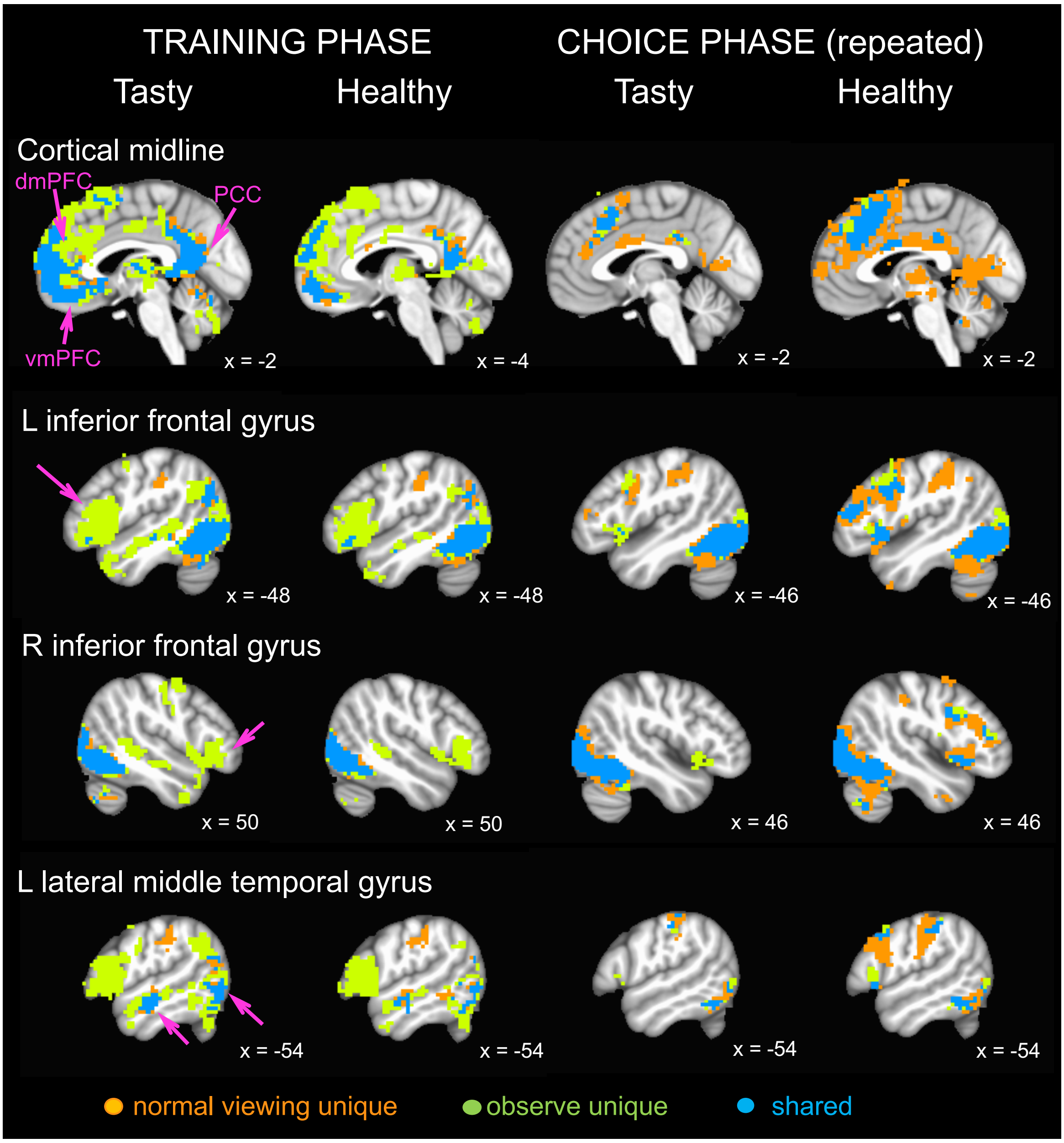


Figure 11. Significant activations above the active baseline in brain areas important for self-relevance and mind wandering (cortical midline), self-regulation (L and R inferior frontal gyrus), and language (L inferior frontal gyrus and L lateral middle temporal gyrus), all potentially relevant for processing foods. Each column presents results from a conjunction analysis between the Normal Viewing and Observe training groups. The first two columns show results for Tasty and Healthy foods during the training phase, whereas the last two columns show results from the choice phase for repeated foods. Unique activations for the Normal Viewing and Observe groups are shown in orange and light green, respectively; shared activations for both are shown in orange. Tables 3 and 5 present statistical analyses of these activations.

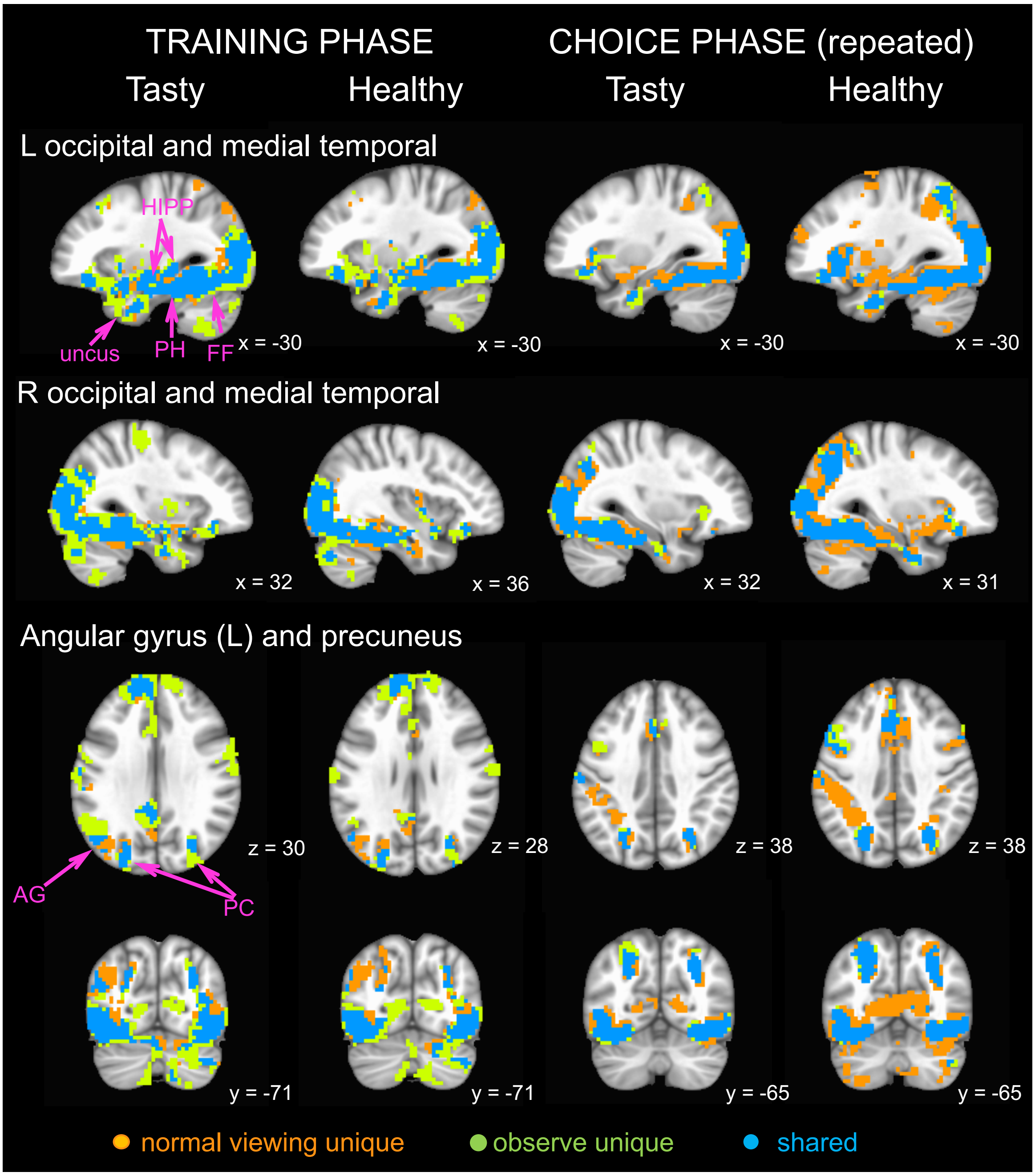


Figure 12. Significant activations above the active baseline in brain areas important for visual processing of foods (occipital cortex, medial temporal cortex, angular gyrus, precuneus). Each column presents results from a conjunction analysis between the Normal Viewing and Observe training groups. The first two columns show results for Tasty and Healthy foods during the training phase, whereas the last two columns show results from the choice phase for repeated foods. Unique activations for the Normal Viewing and Observe groups are shown in orange and light green, respectively; shared activations for both are shown in orange. Tables 3 and 5 present statistical analyses of these activations.

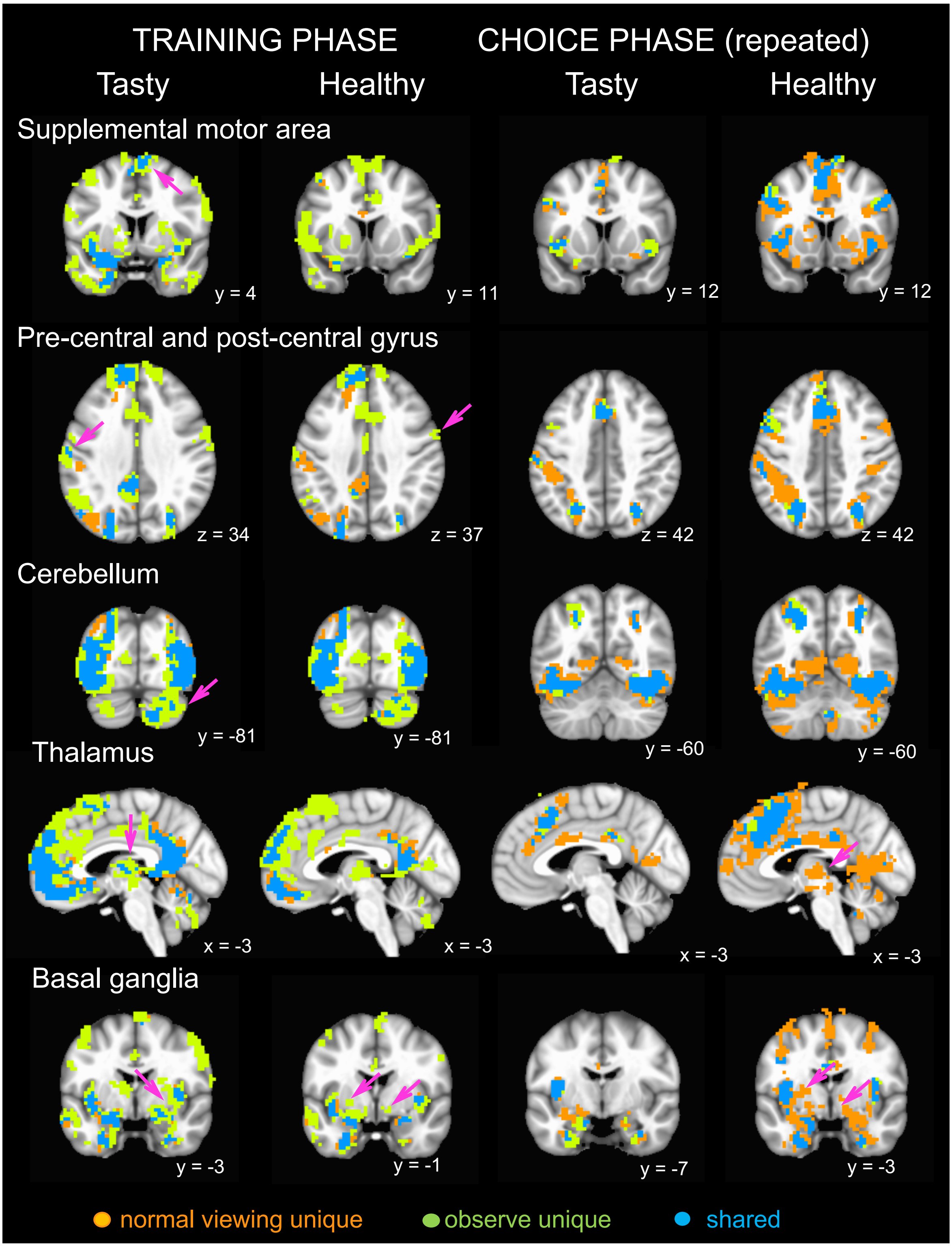


Figure 13. Significant activations above the active baseline in brain areas important for action and embodiment (supplemental motor area, pre-central and post-central gyrus, cerebellum, thalamus, basal ganglia). Each column presents results from a conjunction analysis between the Normal Viewing and Observe training groups. The first two columns show results for Tasty and Healthy foods during the training phase, whereas the last two columns show results from the choice phase for repeated foods. Unique activations for the Normal Viewing and Observe groups are shown in orange and light green, respectively; shared activations for both are shown in orange. Tables 3 and 5 present statistical analyses of these activations.

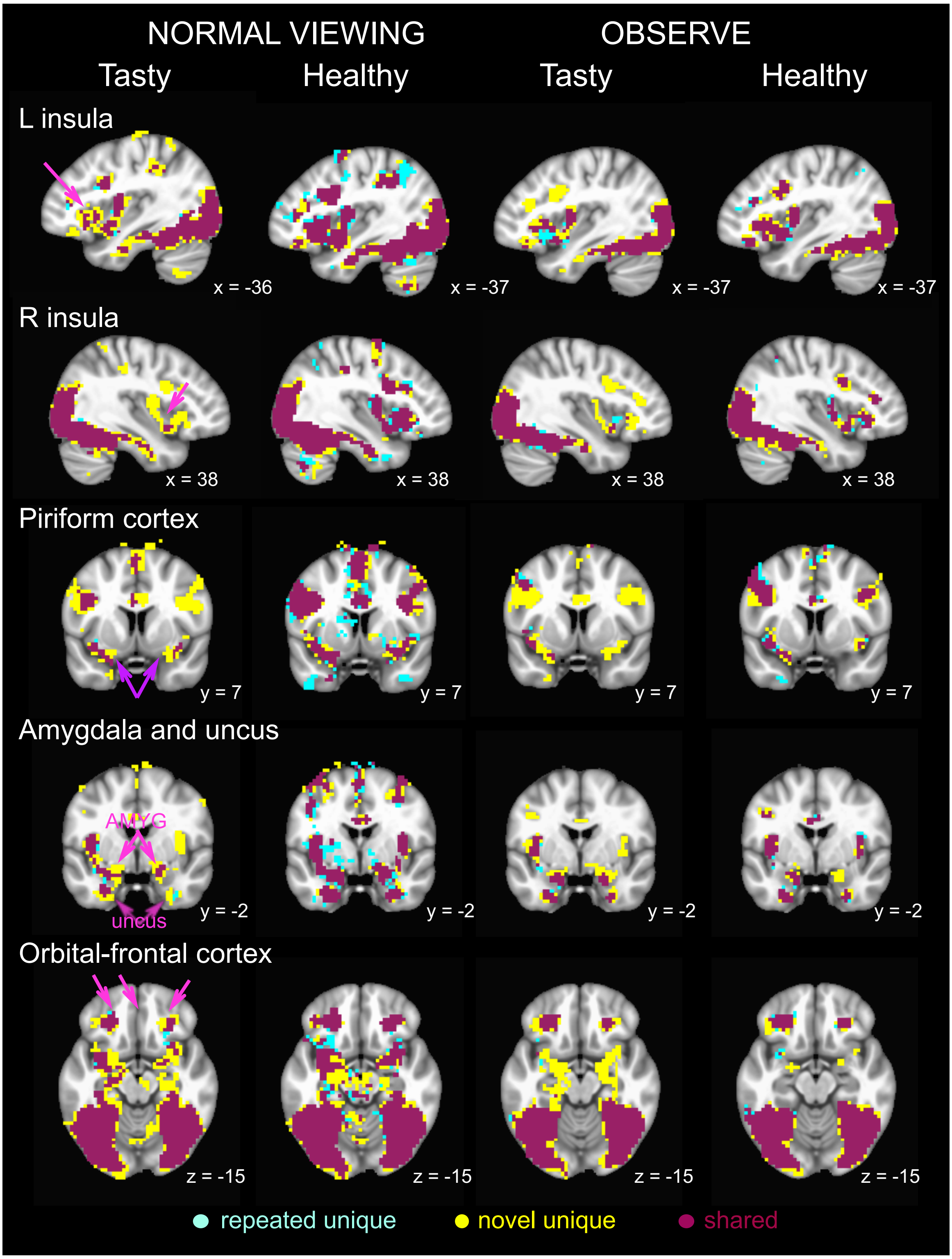


Figure 14. Significant activations above the active baseline in brain areas important for taste (L and R insula), olfaction (perform cortex and uncus), attention (amygdala), and predicted reward (orbital-frontal cortex). Each column presents results from a conjunction analysis between Repeated and Novel foods during the choice phase. The first two columns show results for Tasty and Healthy foods in the Normal Viewing group, whereas the last two columns show results in the Observe group. Unique activations for the Repeated and Novel foods are shown in light blue and yellow, respectively; shared activations for both are shown in purple. Tables 5 and 6 present statistical analyses of these activations.

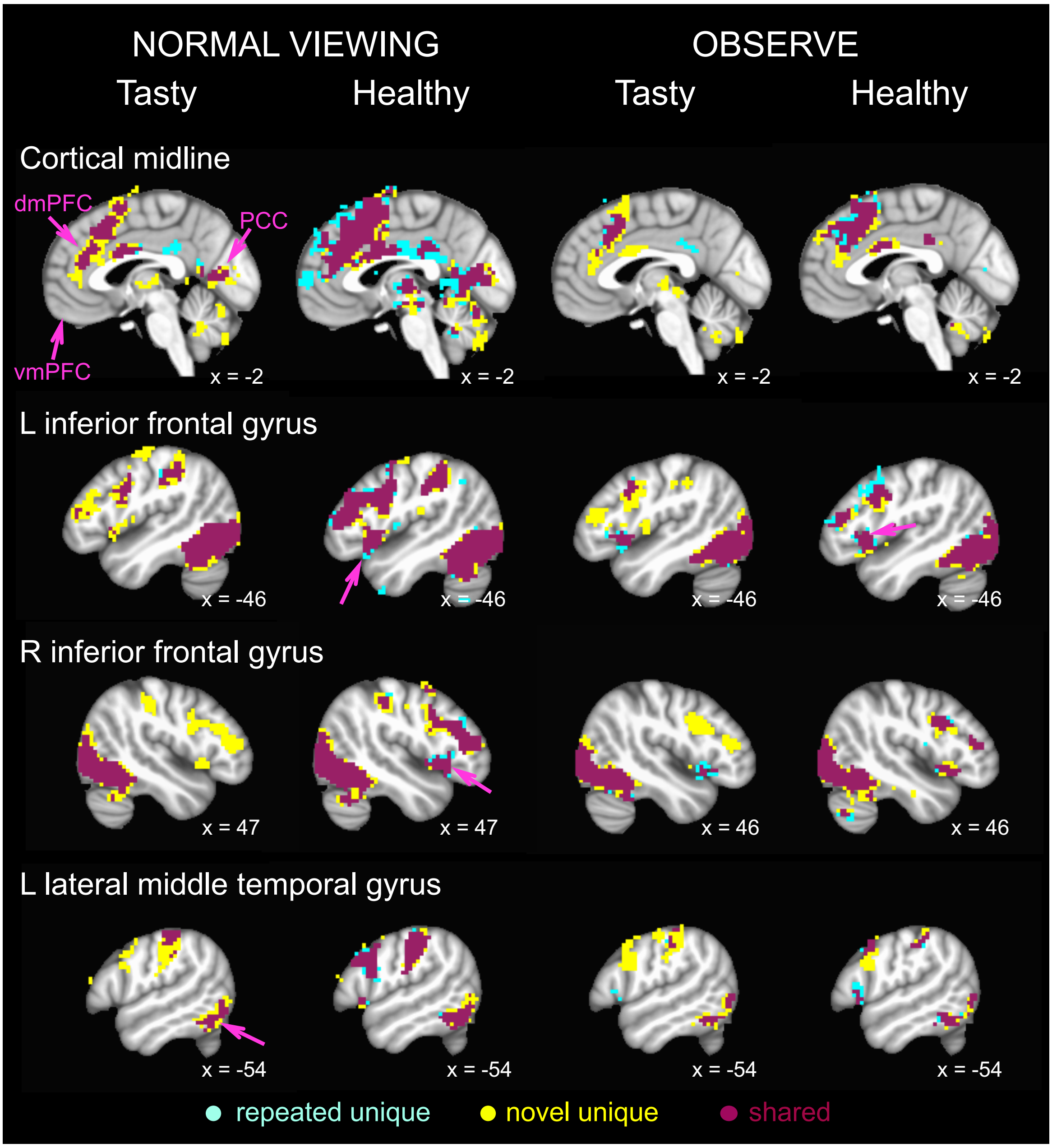


Figure 15. Significant activations above the active baseline in brain areas important for self-relevance and mind wandering (cortical midline), self-regulation (L and R inferior frontal gyrus), and language (L inferior frontal gyrus and L lateral middle temporal gyrus), all potentially relevant for processing foods. Each column presents results from a conjunction analysis between Repeated and Novel foods during the choice phase. The first two columns show results for Tasty and Healthy foods in the Normal Viewing group, whereas the last two columns show results in the Observe group. Unique activations for the Repeated and Novel foods are shown in light blue and yellow, respectively; shared activations for both are shown in purple. Tables 5 and 6 present statistical analyses of these activations.

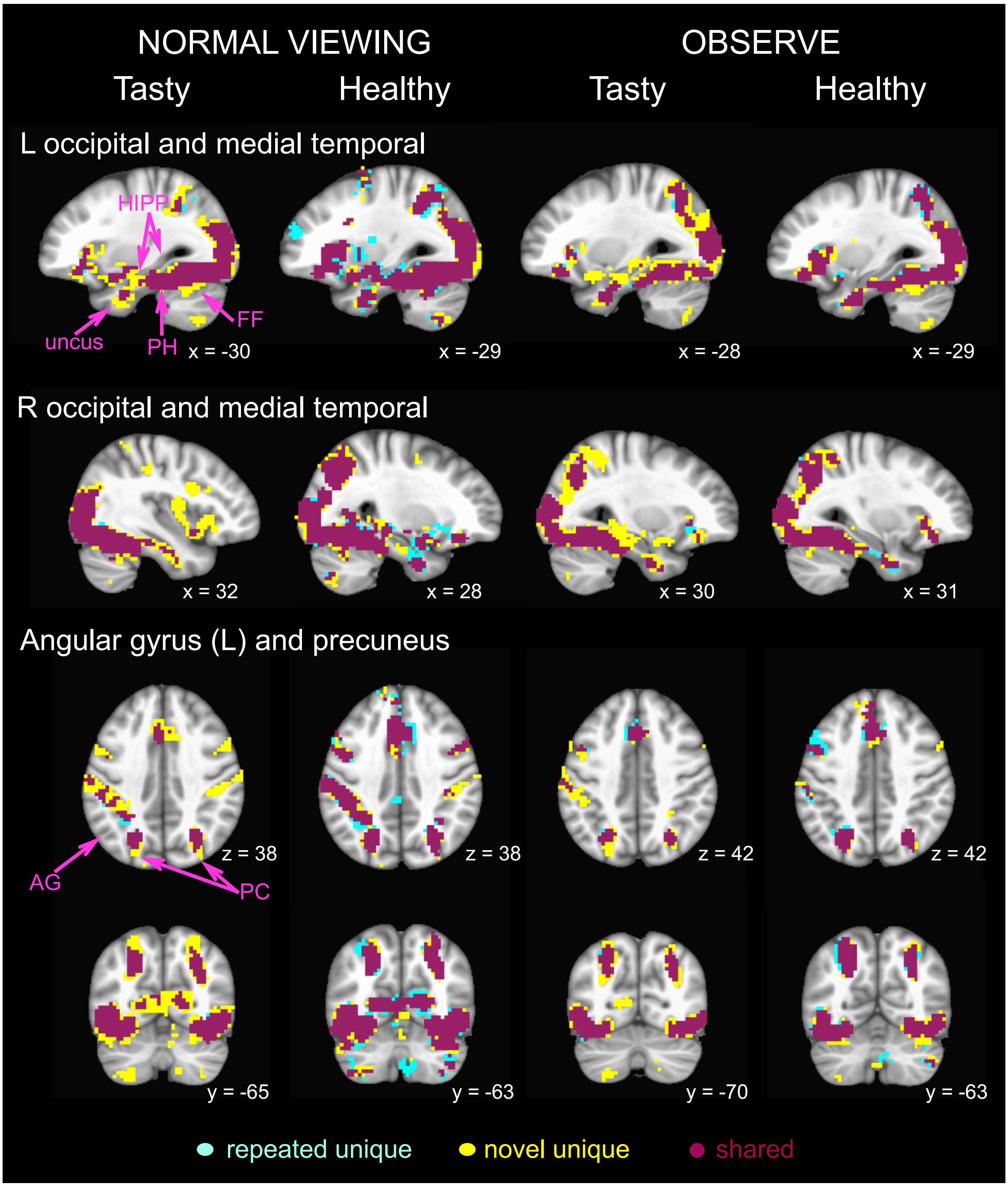


Figure 16. Significant activations above the active baseline in brain areas important for visual processing of foods (occipital cortex, medial temporal cortex, angular gyrus, precuneus). Each column presents results from a conjunction analysis between Repeated and Novel foods during the choice phase. The first two columns show results for Tasty and Healthy foods in the Normal Viewing group, whereas the last two columns show results in the Observe group. Unique activations for the Repeated and Novel foods are shown in light blue and yellow, respectively; shared activations for both are shown in purple. Tables 5 and 6 present statistical analyses of these activations.

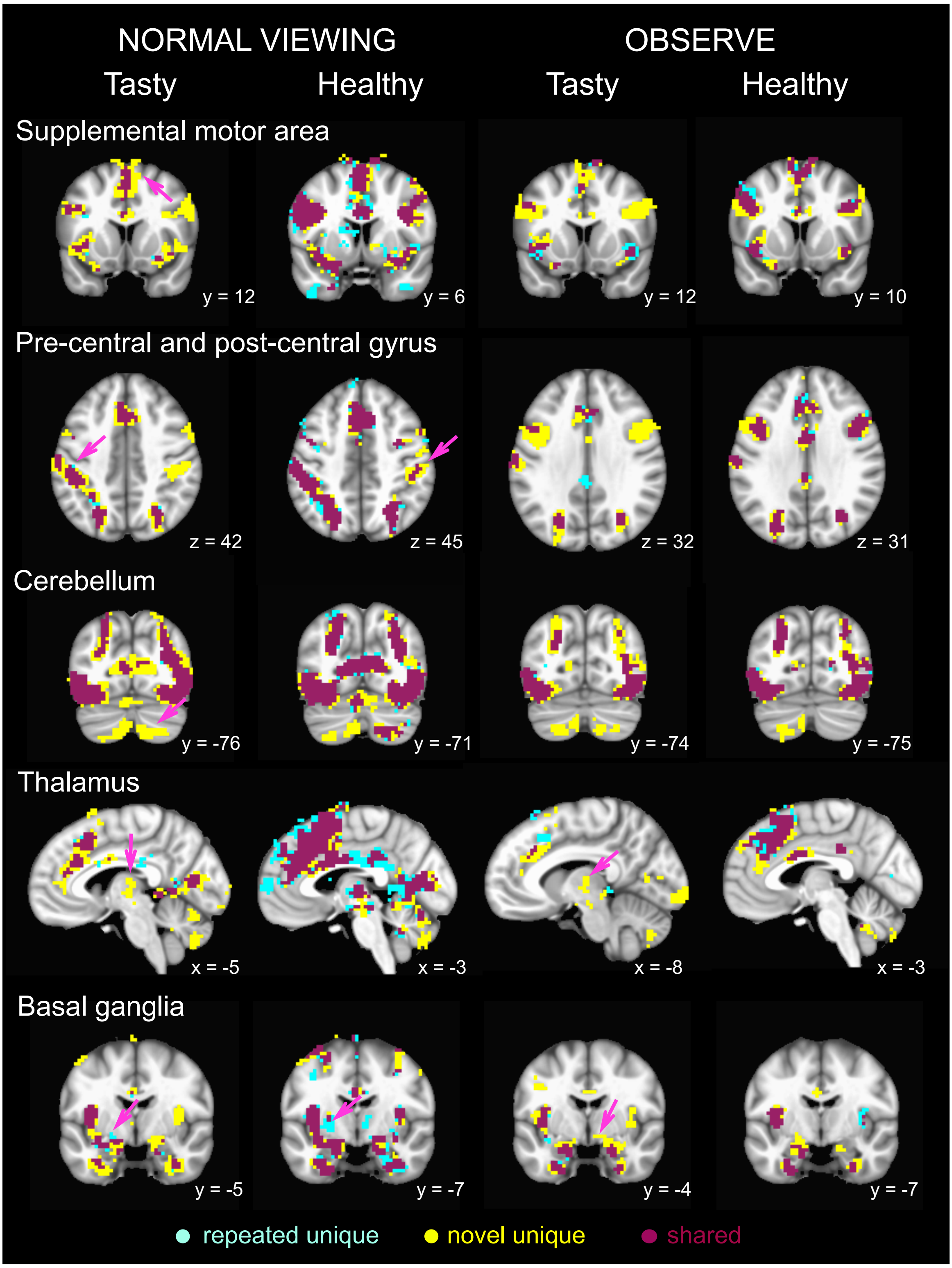


Figure 17. Significant activations above the active baseline in brain areas important for action and embodiment (supplemental motor area, pre-central and post-central gyrus, cerebellum, thalamus, basal ganglia). Each column presents results from a conjunction analysis between Repeated and Novel foods during the choice phase. The first two columns show results for Tasty and Healthy foods in the Normal Viewing group, whereas the last two columns show results in the Observe group. Unique activations for the Repeated and Novel foods are shown in light blue and yellow, respectively; shared activations for both are shown in purple. Tables 5 and 6 present statistical analyses of these activations.