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A systematic review on food-related bias and brain response in obese people

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Abstract. Eating is an essential part in daily life; unhealthy eating habits can increase the risk of obesity and may ultimately trigger various diseases. This review investigated the brain activation patterns, food choice preferences, reward system dysfunction, and impulsive behavior in obese people in response to food cues. This study found that obese individuals showed significant differences in the activation of brain regions in response to food stimuli, particularly in the regions associated with reward, compared to healthy, normal-weight people. In addition, obese individuals were more likely to choose palatable foods high in calories, fat, and sugar, which may be related to abnormalities in the reward system. At the same time, obese individuals showed a higher propensity for impulsive behavior (more willing to choose to consume palatable food that brings happiness at that moment but ignores the long-term health problem). These findings provide a new perspective for understanding the neural mechanisms of obesity and provide a theoretical basis for developing effective interventions.

Keywords: obesity, Neuromechanism, reward system, impulsivity, fMRI

1. Introduction

Overweight and obesity are major health problems worldwide in present days, and how to treat the problems of overweight and obese people caused by excessive eating has become one of the public health problems in the world [1-3]. Previous neuroimaging studies have revealed that compared with normal-weight participants, obese participants showed lower sensitivity to reward in the striatum and higher reactivity in the somatosensory, gustatory and rewards-evaluation areas in anticipation and consumption of delicious foods [4-6]. In addition, studies have shown that obesity can trigger changes in brain connectivity, which may affect eating motivation, thus leading to weight gain [2]. Besides, some studies have confirmed that the reward-related brain response to high-calorie food images significantly reduced in normal-weight individuals after a meal, but when obese individuals exposed to palatable food images, there was increased activation in brain regions related to the reward system, such as the insula, amygdala, orbitofrontal cortex, and striatum, even when after a meal and self-reported satiated [1-2, 7]. This suggested that, in obese people, changes in appetite drive and reward perception induce overeating independent of physiological satiety [1, 4, 8].

In addition, impulsivity is also an important concept closely related to overeating and overweight [9]. In terms of behavior, overweight and obese individuals showed more impulsivity, had worse response inhibition abilities in motor impulse tasks, and had longer stop signal response times [10]. Experiments by Rook & Fisher [11] have shown that among the normal-weight population, impulsivity might associate with higher food intake and also appears to be linked with unhealthy food choices. Guerrier et al [12] found that more impulsive and hungry people consumed higher-calorie food products than others; impulsive shoppers were inclined to choose food based only on the taste instead of considering the long-term health condition, and also associated with a greater tendency to overeating [13].

An increasing number of studies have used neuroimaging techniques to understand the underlying neural mechanisms of obesity. However, to date, no review has included resting-state fMRI, reward dysfunction, and impulsiveness. Thus, the current literature review sought to synthesize the fMRI findings (resting fMRI, reward dysfunction, and impulsiveness) on neuro-mechanisms in obesity and overweight individuals, which could provide a better understanding of the neurobehavioral mechanisms and new insights to help develop personalized treatment.

2. Method

2.1. Search strategy

Three electronic databases were searched (Web of Science and PubMed) with the following keywords: "obesity*fMRI," "food choice*obesity," "obesity*brain function," "obesity*brain imaging," "food bias*obesity," "obesity*reward dysfunction," "obesity*impulsive". Only works in English and Chinese were published from January 2020 to December 2023. All the chosen articles are listed in Table 1.

2.2. Exclusion criteria

Studies with limitations were excluded in this research, such as articles not available in full-text, articles involved barbaric surgery, articles including anorexia nervosa and bulimia nervosa, articles related to child and adolescent obesity, and animal experiment studies.

3. Results

After the removal of duplicates, the initial search produced 5,882 citations (Web of Science: 3428; PubMed: 2,454); 5,869 were excluded, leaving 13 citations to be examined in more detail. All studies will be investigating in resting-fMRI, reward system, and impulsive.

3.1. Studies investigating resting-fMRI

Avery et al. [14] revealed that obese participants' hunger state was negatively correlated with ventral striatum functional connectivity, meaning that the greater their post-meal hunger decreases, the larger the increased function connectivity between the mid-insula and the ventral striatum. Another study found that the obese group showed increased functional connectivity between the bilateral anterior cingulate cortex and precuneus, while functional connectivity of the frontal gyrus was decreased [15]. In addition, another research showed that resting state activity plays a key role in how the hippocampus/amygdala respond to high-calorie food cues, with BMI influencing this relationship [16]. Thus, resting state activity in these regions may affect individual's response of to food cues.

3.2. Studies investigating reward system

Five studies investigated reward sensitivity and revealed that obese people have higher activation in the reward system. These studies confirmed that obese people have a higher activation in the reward system when looking at pictures of food than normal-weight people, especially in high-energy food cues [4-5].

Frankfort et al. [5] found that activation of the reward system increases in normal weight individuals when viewing pictures of food; however, obese people have higher reward system activation when imagining the food taste. Obesity individuals seem to show a higher reward sensitivity to food, even in satiated conditions [4-5]. Several studies also proved that when obese people see pictures of tasty foods, the regions of the brain associated with reward, such as the insula, amygdala, orbitofrontal cortex, and striatum become more active. The activation even continues after eating [2, 7, 17]. These findings further support Schachter's externality theory [18], which stated that obese individuals are more influenced by external cues when eating, like the appearance and smell, rather than the internal signals of hunger and fullness as seen in those with a normal weight.

In addition, Filbey et al. [19] found that high-calorie foods cues trigger heightened activity in the reward system of individuals with high BMI. This hyper-responsivity increases with a greater number of binge-eating symptoms, similar to addiction behavior symptoms. This may explain why some people develop excessive cravings for high-calorie foods and may further lead to overeating and weight gain. Verharen, Adan & Vanderschuren [20] argued that this change in value-based decision-making could lead to substance addiction and overeating when the expected rewards outweigh the costs associated with substance use and food consumption over a long period. Due to reduced function in the prefrontal cortex, the control center for motivated behavior, obese individuals seem to have difficulty in making decisions [2].

3.3. Studies investigating impulsive

Impulsivity refers to impairments in cognitive control constructs, often defined as individuals taking swift acts without prior consideration, and they may rarely or never consider the negative impact of the consequences [21]. In the context of obesity, impulsivity may contribute to a stronger drive for food rewards and difficulties with organization and planning, which may lead to less consideration for future health and hinder weight loss [22].

One of the main characteristics of impulsivity is the tendency to seek immediate gratification and to ignore long-term negative consequences [23]. Liu et al. [10] and Stoeckel et al. [24] discovered that overweight people were more impulsive and less likely to choose delayed rewards. The higher the BMI, the less likely it is to choose delayed rewards, which is related to deficits in executive function regions of the brain [24]. In addition, in difficult and easy decision-making conditions, overweight people had lower activation in executive function brain areas such as the anterior cingulate gyrus, the frontal pole, and the inferior frontal gyrus [10]. Some studies have found that obese people may pay more attention to food vs. non-food pictures, and the bias toward food is related to the orbitofrontal cortex activation. Thus, the attentional bias to food cues, in addition to impulsivity, would cause an increase in craving for food, irrespective of internal feelings of hunger or satiety [25].

Although growing studies have indicated that impulsivity is an essential behavior process that could lead to obesity, impulsivity is a multidimensional construct that involves independent patterns of decision-making that may associated with obesity.

4. Discussion & limitation

This literature review generalized the different brain responses to food cues stimuli and functional connectivity in both resting fMRI and task fMRI between obese people and healthy normal-weight individuals and the reward dysfunction and impulsiveness among obese participants. It also reveals the mechanisms of dysfunction of homeostasis signals in obese people. In the presence of satiety, homeostasis signals (such as hunger) in obese people may still be maintained. It is important to note that the insula region plays a key role in processing internal signals related to food, such as hunger and fullness [26] so reduced insula cortical functional connectivity may reflect dysfunctional satiety signals, especially in areas associated with reward, such as the ventral striatum and prefrontal cortex. This may lead to decreased pleasure and satisfaction from eating. When food cues stimulate obese people, there is a strong association between impulsive behavior and reward dysfunction. Obese people tend to show higher impulsivity and attentional bias towards food, which can lead to increased food cravings and ignore intrinsic feelings of hunger or fullness.

Studies have revealed obesity has a correlation with the changes in the reward system. Increased activation of reward centers in response to food cues and a higher sensitivity to rewards may contribute to overeating and weight gain. These studies on the brain reward system provide insights into the complexity of obesity causes and their relationship with dietary behavior. Therefore, understanding how neural mechanisms induce obesity can help those struggling with weight management develop a series of targeted interventions and treatments.

Obese people often exhibit impulsive tendencies, making decisions based on immediate gratification without considering the long-term consequences in health, which may explain the link between obesity and impulsivity. Impulsivity is also associated with deficits in executive function, the cognitive processes that control and manage behavior, emotions, and thoughts. Overweight people tend to have less activation in executive function areas of the brain when making decisions, suggesting they may have trouble suppressing impulsive responses [24]. This relationship between impulsivity and executive function could explain why obese people struggle to control their eating habits and lose weight.

This study has several limitations. Firstly, due to individual physiological differences, we did not include bio-physiological and genetic factors. Besides, it did not include child and adolescent obesity since this might have more uncertain factors, even though they could be factors toward adult obesity. Thirdly, as Carbine et al. [27] mentioned, N2 amplitude, which is more sensitive to differentiate obese individuals' brain responses to different food types, might be considered in future studies. In addition, more different types of food cues (such as real taste and smell) could be a stimulus in future experimental studies, which could provide more evidence to understand obesity and help develop more precise treatments for the obesity population.

5. Conclusion

In conclusion, this study reveals the neural mechanisms of obesity-related reward dysfunction and impulsivity by comparing brain responses and functional connectivity in resting and task-state fMRI in obese and healthy normal-weight individuals. These studies provide an essential theoretical basis for further research on the prevention and treatment of obesity and help to develop more targeted intervention strategies for these neural mechanisms to help obese people achieve weight control and physical and mental health. Obesity has become a public health problem worldwide; therefore, understanding the neural mechanisms of obesity is critical to developing effective interventions and treatment.

Table 1. PubMed and Web of Science electronic search for food choice in obese people and fMRI

	Author	Journal	Sample size	Methodology	Main Finding
Studies investigating resting-state fMRI	Avery et al. [14]	J Psychopharmacol	N=70, 52 obese, 18 healthy normal weight	Resting fMRI scans in both fasting and post-meal.	- Decreased hunger related to decreased functional connectivity between mid-insula and dorsal striatum in obese people. - Increased hunger related to increased functional connectivity in the orbitofrontal cortex.
	Chao et al. [15]	Behav Brain Res.	N=50, 20 obese, 30 healthy normal weight	Multimodal MRI techniques.	- Obese patients show an increased functional connectivity in the bilateral anterior cingulate cortex and precuneus and a decreased functional connectivity in the frontal gyrus of the default mode network.
	Li et al. [16]	Addict Biol. 2020	N=118, 37 obese, 37 overweight, 44 healthy normal weight	Resting fMRI and a fMRI task with high- and low-caloric food cues.	- Obesity people show both greater food cue-induced activation and increased response to food cues. - In obese individuals, activation in the left hippocampus/amygdala is positively linked to exposure to high-calorie food-cues. - Overweight people have greater activation in the hippocampus/amygdala compared to those with a healthy-weight, but only significant in resting state.
Studies investigating reward sensitivity	Frankort et al. [5]	Int J Obes	N=29, 14 overweight, 15 healthy normal weight	fMRI in unbiased viewing vs. imagining taste.	- Obese group has greater activation in reward response under the taste imagination statement. - Obese group has less activation in reward activity under an unbiased viewing statement.
	Dimitropoulos et al. [4]	Appetite	N=38, 22 obese, 16 healthy normal weight	fMRI response to visual cues of high- and low-calorie foods vs. non-food pictures before and after eating.	- Obese group has a larger brain response to both high- and low-energy food cues even in post-meal and has greater activation to high-energy food cues in corticolimbic regions, such as lateral OFC, caudate, and anterior cingulate.
	Zhang et al. [28]	Obesity	N=46, 26 obese, 26 healthy normal weight	Resting-state fMRI.	- Obese individuals have increased amplitude in the inferior temporal gyrus, amygdala, left fusiform gyrus, hippocampus, and bilateral caudate, and decreased in the right superior temporal gyrus. - Functional connectivity among the obese group increased between the left caudate and right superior temporal gyrus, amygdala, and left inferior temporal gyrus.
	Filbey et al. [19]	Neuroimage	N=26, all participants were obese with binge eating behavior	Event-related fMRI paradigm: response during exposure to high-calorie taste cue.	- People with high BMI status show a response in the reward system when exposed to high-calorie tastes, and this hyper-response increases with a larger number of binge eating symptoms.

Table 1. (continued).

	Author	Journal	Sample size	Methodology	Main Finding
Studies investigating reward sensitivity continued	Opel et al. [29]	Humman Brain Mapping	N=58, 29 obese, 29 healthy normal weight	fMRI, modified card guessing paradigm.	- Obese people showed more robust neural activation during reward processing even without food-related stimuli.
	Castellanos et al. [30]	Int J Obes	N=36， 18 obese, 18 healthy normal weight	Eye-movement and reaction time to food vs. non-food pictures in both fasted and satiated conditions.	- Obese people pay more attention to pictures of food even after eating. - Obese individuals retain incentive salience for food cues despite self-reported reductions in hunger.
Studies investigating impulsive	Liu et al. [10]	Appetite	N=82, 34 obese, 48 healthy normal weight	Inter-temporal Choice Task, fMRI.	- Overweight people are more impulsive than normal-weight people, and a higher BMI is associated with less likely to choose delayed rewards. - During both easy and difficult decision-making.
	Stoeckel et al. [24]	Brain Imaging and Behavior	N=19, all participants were obese	Delay Discounting Task, Choice difficulty (hard > easy trials)	- Impulsivity and poor self-control are associated with a higher delay discounting rate, meaning a greater preference for smaller immediate rewards over larger but delayed rewards. - In more challenging delay discounting situations, greater delay discounting was associated with less activation regulation in presumed executive function brain areas, such as the superior frontal gyrus and inferior parietal lobe.
	Carbine et al. [27]	Neuroimage	N= 54, 19 obese, 18 overweight, 17 healthy normal weight	Go/No-Go, low vs high calorie food.	- Individuals show more inhibitory control when they hold a response to high-calorie foods than low-calorie foods. - The left inferior frontal gyrus and left inferior parietal lobe have higher activity in inhibiting high-energy foods. - Left lateral orbitofrontal cortex was enhanced only in response to high-calorie foods. - BMI status does not affect food-related inhibition control.
	Lawyer et al., [31]	Appetite	N= 296, 56 obese, 78 overweight, 147 healthy normal weight, 10 underweight	Delay Discounting Task, Probability Discounting Task, and Response Inhibition Task.	- BMI status is associated with delay and probability discounting tasks in the general population. - Obese individuals show more impulsive choice patterns on delay discounting and choose more risk-averse choices on probability discounting. - No group difference on the response inhibition task.

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