The Neurobiology of "Food Addiction" and Its Implications for Obesity Treatment and Policy

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Annu. Rev. Nutr. 2016. 36:105–28

First published online as a Review in Advance on June 1, 2016

The *Annual Review of Nutrition* is online at nutr.annualreviews.org

This article's doi: 10.1146/annurev-nutr-071715-050909

Keywords

obesity, food addiction, neuroscience, policy, treatment, stigma

Abstract

There is a growing view that certain foods, particularly those high in refined sugars and fats, are addictive and that some forms of obesity can usefully be treated as a food addiction. This perspective is supported by a growing body of neuroscience research demonstrating that the chronic consumption of energy-dense foods causes changes in the brain's reward pathway that are central to the development and maintenance of drug addiction. Obese and overweight individuals also display patterns of eating behavior that resemble the ways in which addicted individuals consume drugs. We critically review the evidence that some forms of obesity or overeating could be considered a food addiction and argue that the use of food addiction as a diagnostic category is premature. We also examine some of the potential positive and negative clinical, social, and public policy implications of describing obesity as a food addiction that require further investigation.

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INTRODUCTION

Similarities between the overconsumption of foods high in refined sugar and fat and the use of addictive drugs have led some scientists and clinicians to suggest that obesity may be a form of "food addiction" (43, 62, 155). The view that overeating and obesity may be the result of a food addiction is gaining increasing attention in the mainstream media (e.g., 32, 76). The food addiction view is supported by preclinical and clinical neuroscience research demonstrating that energy-dense, hyperpalatable foods and drugs of abuse evoke similar neural responses in the brain (10, 133, 157).

The view of obesity as a food addiction has significant social, clinical, and public health policy implications (59, 62, 94). In 2013, 1.9 billion adults were classified as overweight and another 600 million as obese (166). Excess weight accounts for over 2.8 million deaths per year, largely due to diabetes, heart disease, and cancer, and is the fifth leading cause of premature death (166). More people now die from being overweight than underweight. Our current public health policies and treatment approaches are not meeting this growing problem.

Proponents of the food addiction model of obesity argue that recognition (8, 59, 62) of the neurobiological and cognitive changes that drive the addictive consumption of hyperpalatable foods will produce more targeted and effective psychological and medical treatments of obesity (8, 99). Proponents contend that such a model will lead to greater recognition of obesity as a medical disease that can be treated, increasing treatment seeking and reducing stigma and discrimination

toward overweight individuals (59, 67, 133). They also argue that it will increase support for public health policies that aim to reduce the availability and consumption of obesogenic foods, such as increasing taxation and regulating the sale, advertising, and availability of these foods (4, 59, 62). Similar policies have substantially reduced the prevalence of cigarette smoking, but the food industry has strongly resisted their application to the prevention of obesity (27).

Prima facie the neurobiology of overeating provides a plausible account of excessive consumption (95). In this article, we critically review the similarities between the behavioral patterns of overeating and addictive drug consumption, neuropharmacological and neuroanatomical evidence from animal models of overeating and addiction, and insights from human neuroimaging and neurocognitive studies that support the claim that some forms of chronic overeating and obesity comprise a food addiction. We then examine the potential positive and negative implications of food addiction for social, policy, and clinical approaches to treating and preventing obesity.

BEHAVIORAL SIMILARITIES BETWEEN DRUG ABUSERS AND OBESE INDIVIDUALS

The suggestion that obesity may be a form of food addiction was initially based on phenotypic similarities between patterns of overeating in obese individuals and addictive drug use. These can be seen in a number of similarities between the eating behavior of obese individuals and diagnostic criteria for substance dependence in the fourth and fifth editions of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV and DSM-5) (43, 79). Both patterns of behavior show signs of tolerance; withdrawal; substances taken in larger amounts or for longer than intended; unsuccessful efforts to control use; a large amount of time spent obtaining, using, or recovering from use of the substance; a neglect of social, occupational, or recreational activities; and continued use despite a "recurrent physical or psychological problem [. . .] caused or exacerbated by the substance" (79).

Gearhardt and colleagues adapted the DSM-IV criteria for substance dependence to create the Yale Food Addiction Scale (YFAS), a tool for diagnosing food addiction (60). Comparisons have also been made between maladaptive eating styles, such as binge eating disorder (BED), and the impaired impulse control and compulsivity of substance-dependent individuals (63, 133).

Addictive patterns of eating are associated with obesity, but the overlap between the two is incomplete. Not all persons who are obese meet the criteria for food addiction, and not all individuals who meet the criteria for food addiction are overweight (107). The same is true for BED (138). These observations demonstrate that excess body mass index (BMI) is an inadequate marker of compulsive or addictive-like overeating. A larger correlation exists between BED and food addiction (43, 63). Further research on the development of these disorders is needed to establish if they represent separate diagnoses or are part of the same processes. The validity of the YFAS does not establish that food addiction is a coherent concept. Research is needed to identify neural processes that are similarly involved in both food and drug addiction.

ANIMAL MODELS OF FOOD ADDICTION

Studies in animal models of overeating and obesity have identified many of the brain regions and neurochemical mechanisms associated with the overconsumption of food that mirror those seen in animal models of drug addiction. Rodents fed a cafeteria diet—foods high in both sugar and fat—will develop an addiction-like pattern of behavior that includes binge eating, compulsive food seeking and withdrawal (10, 83). These animals will also overconsume hyperpalatable food in the face of aversive electrical foot shock (10), much like animals exposed to the chronic use of addictive drugs (85).

Dopaminergic Reward Pathways Influence Feeding

Drugs of abuse and hyperpalatable foods both act on the brain's dopaminergic reward pathway, a circuit composed of dopamine (DA) cells that project primarily from the ventral tegmental area (VTA) to the nucleus accumbens (NAc) and into limbic and cortical regions, such as the amygdala, orbitofrontal cortex (OFC), and anterior cingulate cortex (ACC) (114, 136) (see **Figure 1**). The reward pathway is involved in the processes of reward, salience, motivation, decision making, and inhibitory control (158); these processes are central in the development of addiction and excessive food intake.

Repeated drug exposure decreases striatal dopamine D2 receptor (D2R) levels and accumbal DA signaling, which reduces sensitivity to natural rewards (for a review, see 85). This is thought to contribute to an anhedonic state that is linked to a reward-deficiency syndrome (17). Vulnerable individuals engage in drug-seeking behaviors in part to activate these downregulated circuits (148). Rodents fed a highly palatable diet also show diminished striatal D2R expression (83) and reduced DA signaling in the NAc (64). These rats also required a higher level of electrical brain reward stimulation to continue running on a wheel, reflecting brain reward dysfunction (83). Importantly, these changes persisted after the return to a normal diet, and they correlated with increased weight (84).

DA is essential to appropriate feeding in mice: DA-deficient mice are inactive, do not eat, and die within four weeks of birth (140, 141). Treatment with levodopa, a precursor to DA, increases food and water consumption (141), and viral gene therapy that increases striatal DA concentrations restores food intake and a preference for sucrose or high-fat foods (140). Interestingly, calorie-rich foods appear to affect the brain reward system independently of taste, as the dopaminergic response to sucrose is greater than the response to sucralose in mice that cannot detect sweet tastes (46). Reduced striatal D2R availability is associated with decreased metabolism in the OFC and ACC. These areas of the brain are involved in motivation, inhibitory control, emotional regulation, and decision making. Disruption of these regions contributes to the loss of control in both addiction and obesity (101).

Another core feature of addictive behavior is that acute exposure to drug-associated cues or stressors can provoke craving and relapse. As drug use progresses, the initial increase in DA following drug use becomes associated with the stimuli and events that accompany drug use, such as the drug-using environment (78). Repeated exposure to food rewards similarly results in learning in which the DA response transfers to conditioned stimuli, such as the smell of food (16).

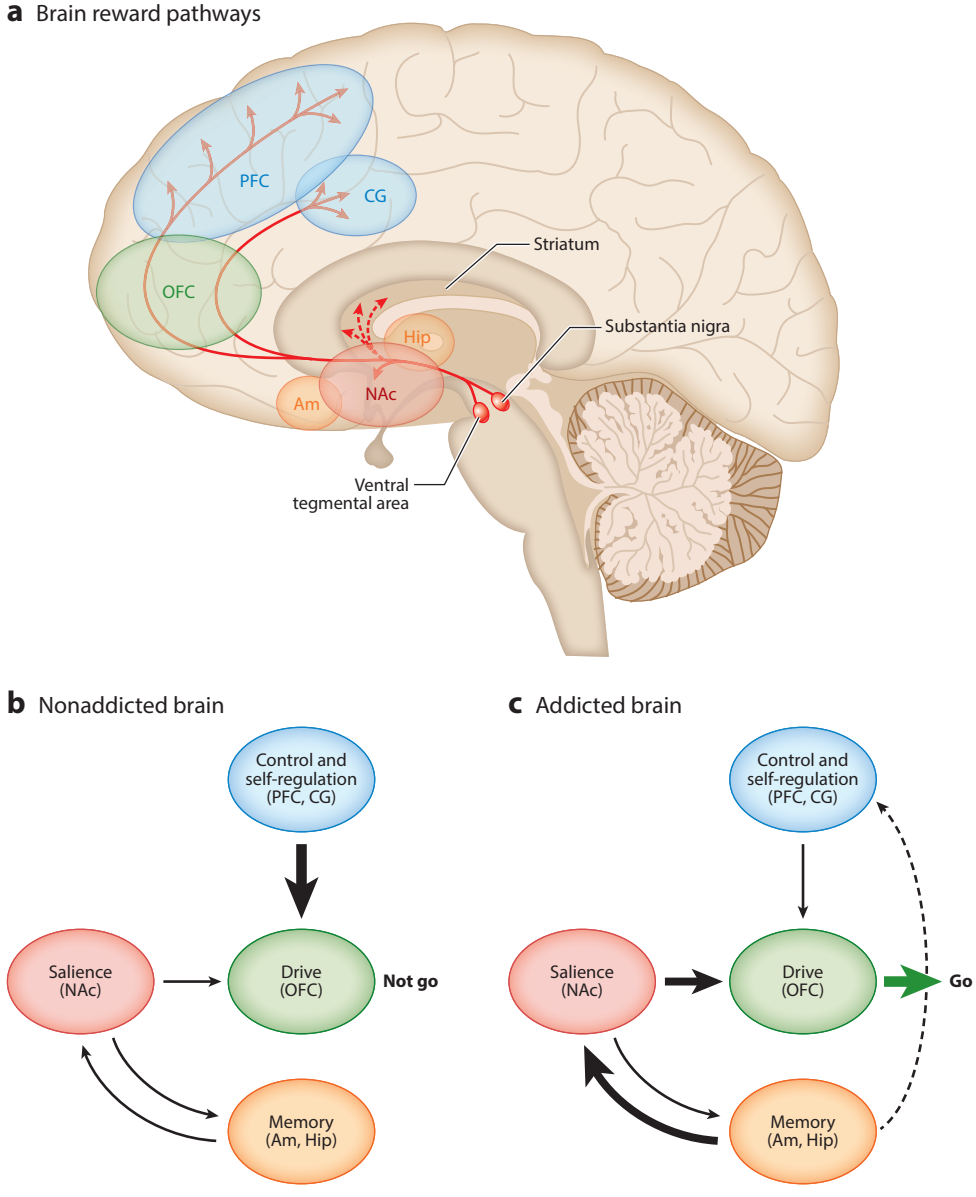
Figure 1

Model of brain circuits implicated in drug addiction and obesity. (*a*) The structures of the brain involved in addiction and obesity. The nucleus accumbens (NAc) is thought to play an important role in identifying activities that are rewarding or salient (the feature of a thing that makes it stand out from all others). The orbitofrontal cortex (OFC) is involved in decision making and determining the expected rewards/punishments of an action. The amygdala (Am) and hippocampus (Hip) are involved in forming memories of the stimulus/reward relationship; inhibitory control and emotional regulation are provided by the prefrontal cortex (PFC) and the anterior cingulate gyrus (CG). Addictive drugs and food, particularly in obese individuals, are believed to cause neurons from the ventral tegmental area to release the neurotransmitter dopamine in the NAc. These regions regulate activity in the frontal cortical regions. This pathway is referred to as the mesolimbic reward pathway (marked with *red arrows*). (*b*,*c*) Schematics showing the reward pathways in the (*b*) nonaddicted and the (*c*) so-called addicted brain. In a person suffering from addiction, the reward pathway is disrupted such that the PFC and CG are no longer controlling factors, and compulsive behavior is driven by the enhanced activation of the reward/saliency and memory/conditioning regions of the brain. As such, when an individual is exposed to the reinforcing stimulant (a drug or food, for example), the system goes into overdrive. Figure adapted with permission from Reference 12a.

These conditioned stimuli can induce cravings that correlate with the magnitude of striatal DA release and activation of the amygdala, ACC, NAc, and OFC (136). Cravings and other behaviors associated with drug or food intake can be elicited after exposure to these conditioned stimuli, rewards, or stressors.

The Endocrine System and Reward

Peptides responsible for the regulation of homeostatic functions, such as food consumption, also influence the reinforcing effects of drugs (157). The hypothalamus is the brain region primarily responsible for regulating food intake and is structurally and functionally connected with the brain's



motivational circuitry (51), emphasizing neurochemical similarities between food consumption and addiction. Hypothalamic mechanisms can act on dopaminergic pathways, thereby influencing reward-related processes, such as drug use. For example, activation of hypothalamic agouti-related neuropeptide (AgRP) neurons, which sense negative energy balance and increase food intake, also increase the motivation to eat and food-seeking behavior in the absence of food (89). Similarly, direct activation of AgRP neurons in mice promotes food seeking and excessive eating (7). AgRP neurons can also influence non-food-related reward behaviors, such as cocaine sensitivity (47).

Ghrelin is a hormone that produces hunger, protecting us from the negative consequences of energy depletion (e.g., increased blood glucose during starvation) (22). Ghrelin acts on AgRP neurons in the hypothalamus and DA neurons in the VTA to increase food intake, to increase the motivation to obtain food, and to regulate blood glucose (5). Appetite-suppressing hormones (e.g., insulin, leptin, and glucagon-like peptide 1) oppose the metabolic actions of ghrelin; their levels increase in response to signals of food consumption and appear to attenuate the brain reward system, reducing the motivation for food rewards (92). These studies demonstrate that the metabolic state has a profound influence on the reward system by linking homeostatic mechanisms in the hypothalamus with reward pathways in the midbrain and cortex (51).

Other Neurotransmitter Systems Involved in Addictive Behaviors

Whereas DA underpins the motivation for, or wanting of, food or drugs, the liking of both food and addictive drugs is mediated by the cannabinoid and opioid systems (156). Sugar (and possibly other hyperpalatable foods) directly increases endogenous opioid levels (156). Opioid agonists increase the intake of palatable foods, whereas opioid antagonists reduce intake (136). These effects have been observed in normal-weight and obese individuals (136). Opioid antagonists also reduce drug and behavioral addictions (119). The endocannabinoid system increases food consumption by modulating excitatory and inhibitory inputs to the VTA and NAc, indirectly activating mesolimbic DA transmission (38). Endocannabinoid systems also transiently regulate the actions of mediators in the hypothalamus that regulate appetite (38).

The serotonergic system has long been a target for central-acting drugs to produce weight loss. The serotonergic system is involved in the regulation of cognitive processes, notably impulse control, and plays a significant modulatory role in regulating DA neuronal activity (75). Animal models have demonstrated decreased dopaminergic and serotonergic transmission in the NAc during drug withdrawal (85). Serotonin $(5\text{-HT})_{2C}$ receptor agonists (e.g., Lorcaserin) impact the hypothalamus and mesocorticolimbic DA system to influence the metabolic and hedonic aspects of feeding (75). Selective mutations of the *5-HT$_{2C}$* receptor gene in mice leads to hyperphagia and middle-aged obesity (118). 5-HT_{2C} receptor agonists have also been shown to alter neural systems and behaviors associated with drug abuse and addiction (75).

EVIDENCE FROM HUMAN NEUROIMAGING STUDIES

Human neuroimaging studies support many of the findings in animal models of obesity and drug addiction. Studies have shown increased DA release in the NAc in response to several substances of abuse (e.g., stimulants, nicotine, alcohol, and marijuana) (153). Similarly, consumption of highly palatable foods causes striatal DA release in humans, the magnitude of which correlates with self-rated meal pleasantness (136). Deficits in dopaminergic pathways have also been observed among obese individuals, including decreased striatal D2R availability (156). As in animal models, decreased striatal D2R in humans is associated with reductions in baseline activity in regions responsible for inhibitory control (e.g., ACC) and decision making (e.g., OFC) (157).

Structural and functional neuroimaging studies have shown that obese individuals have deficits in frontal-striatal systems that overlap with those seen in cocaine users (132). Gray matter density in the frontal and striatal areas related to reward and self-regulation is significantly lower in obese human adults compared to healthy controls (120). A meta-analysis of functional activation studies found extensive overlap in response to palatable food images in obese individuals and the reward regions activated by drug cues in drug-addicted individuals (143).

Both addicted and obese individuals show sensitized responses to cues associated with food consumption, and exposure to these cues plays a significant role in relapse in both disorders (157). Akin to addicted individuals, obese individuals display increased functional connectivity in the dorsal striatum that correlates with the strength of food craving and predicts weight regain after weight-loss interventions (36). Obese individuals, however, exhibit less activation in reward circuitry than do lean controls during food consumption (156). Additionally, the hypothalamus and prefrontal regions (such as the ACC) are less reactive to satiety in obese individuals (156). Disparities between reward expectation and attainment from actual food consumption may lead to overeating as a compensatory behavior.

Food cues similarly increase DA in the striatum, and the increase is associated with food cravings. Nonobese male subjects were instructed to inhibit their food cravings upon exposure to food cues, and doing so decreased activity in their OFC, amygdala, insula, and striatum (160). A similar pattern was observed among cocaine abusers who were asked to inhibit their cravings when exposed to drug-related cues (161). Human imaging studies have demonstrated an inverse relationship between brain activity in the prefrontal cortex, a region critical to executive control, and BMI (157). Interestingly, successful dieting appears to activate prefrontal regions (e.g., OFC) that are involved in inhibitory control when individuals are eating.

NEUROCOGNITIVE AND PERSONALITY SIMILARITIES BETWEEN ADDICTED AND OBESE PERSONS

Studies have identified a number of neurocognitive deficits in obese individuals that are also found in drug-addicted individuals, such as executive function and cognitive control impairments (156).

Executive Function and Decision Making

Executive functioning encompasses a range of cognitive domains that regulate flexible goal-directed behavior. A systematic review of obese adults' performance on behavioral measures of executive function identified consistent impairments in decision making (55). Overweight adolescents also have reduced cognitive flexibility and poorer decision-making ability in comparison with healthy weight-matched controls (151). The poorer decision making of obese persons means that they are more heavily influenced by immediate rewards and less responsive to future consequences, such as increased weight gain, resulting in poorer food choices. Similar deficits are seen in drug-addicted individuals (14).

Maladaptive eating patterns are associated with a tendency to heavily discount future rewards and focus on immediate gratification, referred to as delay discounting (163). Similar attributes have been found in individuals addicted to cocaine, smoking, opiates, and gambling (2, 124). Heightened delay discounting can increase consumption of both drugs and hyperpalatable foods and reduce attention to long-term health goals, such as weight management and healthy eating.

Impulsivity and Inhibitory Control

Impaired inhibitory control is central to both overeating and drug addiction (13). Obese children and adolescents perform poorly on tasks requiring the inhibition of responses (e.g., the stop-signal,

go/no-go, and Stroop tasks) (111, 151). Reduced inhibitory control in early life may be a risk factor for the onset and maintenance of obesity; it also predicts weight gain one year after a weight-loss intervention (111).

Similar deficits in response inhibition have been reported in adults with a high BMI (113). Lower inhibitory control in adulthood is associated with higher food intake (69) and weight gain (112). Impaired response inhibition may also explain the poor outcomes of many behavioral weight-management programs, which require effective self-control and self-regulation (113). Successful weight loss is associated with improved inhibitory control (90). Heightened impulsivity and increased sensitivity to reward lead to overconsumption and may explain why some individuals find it difficult to abstain from binge eating and chronic drug use. Lifestyle factors such as elevated stress and poor sleep impair inhibitory control, and obese individuals experience higher stress and sleep disturbances that are likely to account for some of the impulsivity deficits ascribed to obesity (150).

Cue Reactivity, Cognitive Biases, and Affective Processing

The ability to identify food sources is essential for human survival in environments in which food is scarce (30). In contemporary society, however, attentional biases to food may increase maladaptive eating in an environment saturated with hyperpalatable food sources and cues. Psychophysiological, neuroimaging, and neurocognitive studies have identified enhanced attentional processing of food and food-related stimuli in obese individuals (74, 115). Eye-tracking paradigms have also shown greater increased food-cue reactivity in obese than in healthy-weight participants under conditions of satiety (30). Exaggerated salience of food information in obese individuals appears to be motivationally rather than homeostatically mediated, suggesting that the focus on food is driven by increased salience, as seen in drug addiction, and not simply metabolic need.

The same phenomena are seen in studies in drug-addicted persons. Individuals who are addicted to cocaine, opiates, alcohol, nicotine, cannabis, and caffeine respond strongly to drug-related stimuli (52–54, 57, 167). Given the similarities between obesity and drug addiction, the augmented salience and motivational properties of certain foods may increase cravings and make foods more difficult to resist. Correlations between self-reported food cravings and attentional biases to food stimuli provide preliminary support for this association (116).

A number of personality dimensions have been investigated in disordered eating. Surveys show that persons with higher BMIs score higher on neuroticism and extraversion and lower on conscientiousness (139), personality traits that are shared by drug-addicted individuals (41). Sutin et al. (139) found that participants in the highest 10% on impulsiveness ratings were 11 kg heavier on average than those in the lowest 10%. In a related finding, individuals scoring high on conscientiousness had lower BMIs (33). Conscientiousness is negatively correlated with disordered eating (19), binge eating, and binge drinking (130) and positively correlated with physical activity (128). Increased conscientiousness reflects increased self-control and an ability to pursue higher-order goals (144). Impulsiveness and conscientiousness represent facets of personality that substantially affect healthy lifestyles and eating behaviors in opposite directions.

THE GENETIC BASIS OF ADDICTIVE BEHAVIORS AND OBESITY

Evidence from twin, family, and adoption studies suggest that 40% to 70% of interindividual BMI may be explained by shared genetic factors (45). Candidate gene and linkage studies provided the first evidence of specific obesity-related loci. However, these studies were often limited by small sample size, and findings were often not replicated (82). These approaches have been superseded

by genome-wide association studies that use larger samples to achieve adequate statistical power (45). Genome-wide association studies have identified a number of genes associated with excess weight that are also implicated in decision making. The fat mass and obesity-associated gene (*FTO*) was the first genetic variant reliably associated with obesity (58) and has the largest effect size of all obesity-associated loci (100). *FTO* mRNA is expressed in the hypothalamic nuclei (65), influencing food intake and energy homeostasis (31). Common variants of the key gene locus linked to *FTO* are dose-dependently associated with increases in BMI and impulsive behavior and decreases in prefrontal cortex function (34).

Genetic variants affecting dopamine signaling have been investigated as a risk factor for addictive, impulsive, and compulsive disorders. The *D2R Taq1A* polymorphism has emerged as a potential genetic marker for cognitive phenotypes (e.g., reward sensitivity, reinforcement learning, and impulsivity) related to both substance dependence and overeating (168). Carriers of this allele have reduced dopamine receptor density, dopamine signaling abnormalities, and blunted reward sensitivity and reinforcement learning (17). This may lead individuals to engage in compensatory reward-driven behaviors, such as drug use and overeating, to promote dopamine release (17), consistent with the reward-deficiency syndrome. This finding has been replicated in cocaine (117) and opiate (48) addiction and would appear to corroborate studies linking addiction to decreased striatal D2R availability (154). As with drug addiction, a reduction in D2R availability in obesity has been correlated with the *Taq1A A1* allele (137). Overweight and obese individuals with this allele show hypofunctioning of the dorsal striatum, a dopaminergic region involved in the processing of food reward, after consuming appetizing food (137). Genetic attenuations of dopamine transmission may contribute to unhealthy eating patterns and weight gain. Genes linked to leptin signaling also moderate dopamine function (28), which is linked to impulsivity and obesity (137). The *D2R Taq1A A1* allele and the opioid receptor mu-1 gene have both been associated with BED, suggesting that BED is associated with greater hedonic eating and liking of food (44).

A CRITICAL REVIEW OF THE EVIDENCE FOR A FOOD ADDICTION MODEL OF OBESITY

The evidence reviewed suggests that certain foods, particularly those high in refined sugar and fats, and eating patterns, such as bingeing, may produce changes in the reward neurocircuitry and impairments in decision making that are associated with addictive patterns of eating in some individuals. These are similar to the changes in brain structure and function seen in drug addiction. However, this evidence is essentially descriptive. It is still unknown if these overlapping patterns are mechanistically implicated in both conditions. We believe that there is insufficient evidence to describe some forms of obesity as a food addiction, and its inclusion as a diagnostic category would be premature (see sidebar, Does the Neuroscience Evidence Support the Food Addiction Model?).

First, food addiction is not synonymous with obesity. Only a small percentage of obese individuals meet the diagnostic criteria for food addiction or a clinically relevant condition such as BED; some normal and underweight individuals also meet these criteria (95, 107). Food addiction is neither necessary nor sufficient for being overweight. At best, the neuroscience of compulsive eating only applies to a subset of individuals, some of whom will not be overweight. This is an important distinction given that the majority of neuroscience research to date has focused on brain changes in obese individuals.

Second, important differences exist between food and addictive drugs. Food, unlike drugs, is essential for survival. We are also exposed to food from birth. However, foods that tend to be associated with overconsumption and that are the subject of neuroscientific research, such as those

DOES THE NEUROSCIENCE EVIDENCE SUPPORT THE FOOD ADDICTION MODEL?

Support for a food addiction model of obesity is based upon neurobiological and behavioral similarities between obesity and addiction. However, a number of methodological caveats weaken the case for food addiction. First, obesity is a complex, heterogeneous condition that can arise as the result of hormonal, thyroid, and genetic conditions or through a sedentary lifestyle. Second, although animal models provide strong evidence for the food addiction model, they employ highly constrained eating regimens that do not accurately reflect the ways in which humans consume food. Third, human cognitive and neuroimaging studies have focused predominantly on comparisons between normal-weight and obese individuals. These differences are best interpreted in relation to BMI and do not provide a satisfactory argument for a food addiction model. Only a small percentage of obese individuals meet the diagnostic criteria for food addiction, whereas some normal-weight and underweight individuals also meet the criteria. Fourth, small sample sizes, publication bias, and a lack of longitudinal evidence make it difficult to elucidate the relationship between observed changes to brain structure and function and overeating and obesity. We believe that it is premature to accept the food addiction model, yet it may prove to be a valuable explanation for subgroups of disordered eaters.

high in refined sugar and fat, are not essential for survival. These foods are the product of fairly recent industrial innovations that have greatly increased their purity and the quantities that we are able to consume. In this regard, refined foods do resemble the industrialization of addictive drugs that yielded cocaine from coca leaf or heroin from poppies. Refined foods, like addictive drugs, may produce powerful changes in the brain reward circuitry that we did not evolve for, leading to overconsumption and weight gain. This does not entail that many or most obese or overweight individuals have become addicted to food, such that they are unable to refuse foods high in sugar and fat due to neurobiological changes in their brain, or that these neurobiological changes play a significant explanatory role in the high rates of obesity or in an individual's difficulty in losing weight.

Third, obesity is a complex multifactorial and heterogeneous condition that can arise from sedentary lifestyles or other hormonal or thyroid conditions (105); there is no equivalent feature of drug addiction. Unlike addictive drugs, the addictive component of food has not yet been clearly defined (62). Distinguishing between normal consumption and compulsive abuse is even more difficult than in drug addiction. Even if food addiction is supported by the neuroscientific evidence, it is unlikely to be relevant to the majority of overweight or obese individuals (146). We agree with Ziauddeen & Fletcher (170) that food addiction most likely applies to a subset of individuals whose pattern of eating closely resembles drug addiction, such as individuals with BED. Even in this subset, a diagnosis of food addiction does not prevent these individuals from making autonomous healthy food choices. Even severely dependent drug-addicted individuals are able to refrain from drug use (77).

Methodological Limitations and Directions for Future Research

A number of methodological limitations or caveats weaken the case that the chronic consumption of refined foods produces changes in brain function that lead to addictive or uncontrolled eating. The most compelling evidence for the concept of food addiction comes from animal models (50, 169, 170), but the applicability of these findings to obese humans is uncertain. Animal studies do demonstrate that it is possible to induce addictive patterns of eating that are similar to patterns of

addictive drug use and involve common neurocircuitry. However, these studies employ highly constrained eating regimens that are of minimal relevance to the way in which humans encounter food (170). As with drug addiction studies, it takes considerable effort and environmental manipulation to get animals such as rodents addicted (1). Rats taught to self-administer opiates under standard conditions of addiction do not display this behavior if housed in more naturalistic conditions (e.g., with litter mates) (3, 134). Rats that have been trained to self-administer drugs will abstain when given a choice of other natural rewards. Studies of animal models of overeating in these limited environments therefore are of limited relevance to the settings in which we consume food.

Neuroimaging studies have identified differences in brain structure and function between normal-weight individuals and overweight or obese individuals. However, most of the neuroimaging and cognitive studies have focused on differences in brain structure and function in relation to obesity or increasing BMI. Very few studies have identified brain changes associated with behaviors related to food addiction or in clinically relevant populations, such as those with BED (170). Therefore, the findings described above should be understood in terms of BMI rather than food addiction per se. The extant neuroimaging literature is unable to support a food addiction model in humans (169), but a clearer picture may emerge as better-designed studies are conducted to test such models (9) using the YFAS or in clinical populations, such as individuals with BED (170).

It is also important to remember that many obese individuals do not display differences in brain structure and function. Differences identified in neuroimaging and cognitive studies represent averaged differences among groups of overweight or obese individuals and their normal-weight counterparts. Significant intragroup variation and overlap exist among individuals within these groups. For example, many severely obese (BMI>40) individuals exhibit striatal D2R levels that are similar to those of the normal-weight controls (162). Subsequent studies have not been able to replicate the reduced DA receptor levels described above, and we therefore cannot state conclusively that DA receptor levels are altered as a consequence of obesity in humans (169).

Many of the neuroimaging and behavioral findings in response to food-related stimuli or stress have been inconsistent or not replicated (169). Neuroimaging and cognitive studies are often conducted in small samples and are affected by publication bias (80, 81). Studies in larger populations are needed to resolve these inconsistencies. It is also not clear whether these differences are a cause or a consequence of overeating. Differences in the dopaminergic reward pathways in compulsive overeaters may be a causal mechanism that leaves some individuals more likely to engage in overeating and may also be a consequence of the overconsumption of energy-dense foods. The evidence is predominantly cross-sectional, so the direction of the relationship between impaired executive functioning and obesity is unclear. Prospective longitudinal research is needed to elucidate whether the consumption of "addictive" foods contributes to these alterations or, conversely, whether selective deficits in higher-order cognition increase excessive food consumption and weight gain.

Although it is clear that obesity is a highly heritable disorder, the contribution of genetics in the processing of food rewards is less clear, as the majority of research has focused on the genetics of obesity. More research on the role of specific genes in a variety of cognitive phenotypes (e.g., reward sensitivity, inhibitory control) may provide useful insights. However, the history of genetics research on complex behaviors suggests that caution is warranted when predicting the clinical utility of these findings. The effect sizes for the most strongly associated genes involved in excess weight are small (135). Although twin and adoption studies suggest that the heritability of obesity is substantial, the candidate genes thought to explain this heritability account for a marginal amount of disease risk. This is true for many complex behaviors (18).

Although it may be premature to accept a food addiction model of obesity, it would be unwise to rule it out as an explanation of obesity in a subpopulation of overeaters (9, 170). Ignoring

similarities may prevent us from enacting important public health policies that have been effective in other areas, such as tobacco control, or developing more effective treatments. It is important, however, that we do not misinterpret or misrepresent the neuroscience of overeating in ways that may have unintended adverse impacts on persons who are overweight or on the general public more broadly.

IMPLICATIONS OF NEUROSCIENCE FOR OBESITY TREATMENT, PREVENTION, AND POLICY

Emerging Neurobiological Treatments of Obesity

Neuroscientists hope that treatments based upon the recognition of obesity as a form of food addiction will prove more effective than current therapies. Weight loss increases overall health and reduces cardiometabolic risk factors by improving lipid profiles and reducing blood pressure. Dietary interventions, exercise prescription, and therapeutic support groups are the most widely used weight-loss interventions (159); however, these interventions are not effective in reducing weight and overeating in many individuals.

Lifestyle interventions may be supplemented with pharmacological treatments. Weight loss with these medications is modest, however, averaging 3% to 8% at one year (for a review, see 104). Surgical treatments for obesity are reserved for patients who have failed to respond to a combination of lifestyle and pharmacological treatments. The most common interventions are gastric banding, Roux-en-Y gastric bypass, laparoscopic sleeve gastrectomy, and biliopancreatic diversion. The average long-term excess weight loss is 47% to 70% (49); however, bariatric surgery can produce postoperative complications, including infection, metabolic disorders, and cardiovascular events. Individuals may also circumvent the surgical intervention by eating high-calorie foods in smaller amounts more often.

Unfortunately, for many obese and overweight individuals, the initial weight loss from these treatments is often followed by weight regain. The neuroscience of food addiction is thought by some to explain this rebound. Proponents claim that acknowledging that a certain subpopulation of individuals may be suffering from a food addiction may allow researchers and clinicians to build upon effective treatments for addiction (8, 67). Psychotherapies and cognitive training approaches targeting cognitive processes involved in addiction may provide new avenues for increasing weight loss in the long term. These approaches include selective inhibition training to strengthen impulse control (149), episodic future thinking to improve self-regulation (40), and psychotherapies to improve emotional regulation and tolerance and to replace food as a source of reward and pleasure (42).

Contingency management—an intervention based on operant conditioning principles that provides rewards or incentives (e.g., payments) for achieving certain outcomes—has proven effective in reducing drug use in addicted individuals while the contingencies remain in place (123). It also has the potential to reduce overeating and encourage weight loss in overweight persons (106). However, public support is limited for policies that pay drug-addicted or overweight individuals for taking actions that many believe they should take in any case. It is not clear what impact a wider acceptance of the food addiction model would have on public support for contingency management programs, although recent research suggests that it is unlikely to engender sympathy (96).

An addiction-based approach may also lead to novel pharmacological treatments that target the DA system and thereby make overeating less rewarding (152). Contrave (a bupropion/naltrexone combination) and Qsymia (a phentermine/topiramate combination) are dopaminergic medications

currently available in the United States for long-term weight management (152). Dopamine agonists have proven effective in preclinical trials in both drug addiction (119) and obesity (99). However, they have not been shown to be particularly effective in the long term in human clinical trials. The limited effectiveness and significant side effects of the current range of pharmacological treatments aimed at the DA pathway for drug addiction (86, 119) should temper enthusiasm for their use in treating overeating. Drugs that block the liking of food through the opioid system (e.g., the opioid antagonist naltrexone) are also being trialed (152). Naltrexone has been trialed for a range of drug and behavioral addictions but has had only minimal impact (119).

Neurobiological explanations of addiction and obesity have been used to justify trials of more invasive or high-risk interventions, such as deep brain stimulation (DBS) (142, 164). DBS is an invasive neurosurgical procedure that involves the insertion of microelectrodes into the target region of the brain. It has been widely used in the treatment of Parkinson's disease and other movement disorders (e.g., dystonia) (88). DBS is now being trialed in a range of psychiatric disorders (e.g., obsessive-compulsive disorder, depression) (88) and drug addictions (29), and it has been proposed for use in the treatment of eating disorders and obesity (98, 142, 164). Although there have been some positive case reports, the lack of adequate follow-up, small sample sizes, and the significant potential for publication bias suggest the need for extreme caution in interpreting these findings (29).

The growing interest in noninvasive brain stimulation (e.g., transcranial magnetic stimulation, transcranial direct current stimulation) or modulation (e.g., real-time neurofeedback) techniques may provide safer methods of attempting to reduce some of the addictive cognitions associated with overeating (20, 66), particularly when combined with other forms of psychotherapy or lifestyle interventions (145). However, more research of their effectiveness in sufficiently large samples is needed before these techniques can be considered a worthwhile proposition.

An overemphasis on neurobiology may also result in an overreliance on medicalized interventions at the expense of more broadly effective public health approaches or those that address the social drivers of obesity (e.g., poverty, stress, food availability, and sedentary lifestyle) (70, 94). A focus on obesity as a neurobiological disorder of addictive eating may distract attention from the significant role of exercise in reducing weight. In addition to the health benefits associated with weight loss, exercise can have important neurobiological, psychological, and behavioral benefits that may support decision making (129). Exercise may not always be possible at the outset for severely or morbidly obese individuals, who may first require surgical or pharmacological intervention.

Stigma and Public Attitudes Toward Obese Individuals

Obesity is highly stigmatized in most Western countries (126). Obese individuals are often seen as lazy and lacking self-control, motivation, and intelligence (126, 131). Weight-based discrimination has increased substantially since 2000 and is comparable to race-based discrimination (125); the stigma associated with obesity has also significantly increased. Weight bias can negatively affect employment outcomes for overweight individuals, including salaries and hiring and promotion decisions (126). Weight-based stigma can have significant adverse health consequences for obese individuals, including depression, body dissatisfaction, and poor physical health (97). Stigma can also undermine attempts to lose weight, exercise (147), and regulate food consumption by reducing self-esteem and increasing emotional eating (102) or other disordered eating behaviors (e.g., BED) (73, 126).

Individuals who are not held responsible for their condition, such as persons with Alzheimer's disease, receive more sympathy than those believed to be personally responsible, such as obese and

drug-addicted persons (37). The belief that obesity and weight are primarily personal issues and not a corporate or government responsibility prevents critical policy change that may reduce the prevalence of overweight and provide better treatments and prevention (26, 127). Some argue that neurobiological explanations of obesity that mitigate personal responsibility might help to reduce stigma and change these attitudes (93, 121, 131). However, the limited empirical evidence on the impact of neuroscientific explanations on the stigmatization of obesity, alcohol dependence, and other mental illnesses suggests that optimism may be misplaced. A recent survey of public attitudes in the United States found that increased public endorsement of neurobiological explanations of alcohol dependence was not accompanied by any reduction in stigma (122). Other studies have found that biogenetic explanations of mental illness may in fact harden people's attitudes toward addicted or mentally ill individuals (6, 91). A recent survey of people from the United States and Australia found that holding the view that obesity was a food addiction did not reduce weight-based stigma (95). However, another recent study did find that exposure to the view that obesity was the result of a food addiction did reduce the blame and stigmatization attributed to obese individuals (93). More research is needed to assess the impact that a view of obesity as a food addiction may have on the understanding and treatment of obese individuals. We cannot simply assume, as many commentators do (39), that neurobiological explanations of obesity or drug addiction will reduce stigma.

Self-Efficacy, Eating, and Weight

Proponents of a food addiction model of obesity point out that it may reduce some of the blame and self-stigmatization that go along with being significantly overweight (59, 93). Similar views have been proposed for brain-based explanations of drug addiction (15, 39, 108). Pearl & Lebowitz (121) found that biological explanations of obesity decreased self-blame. However, describing overeating as a form of food addiction may have unanticipated adverse impacts on addicted individuals' beliefs about their ability to reduce their weight or control their eating. Pearl & Lebowitz (121) also found that those exposed to biological explanations of obesity thought that their weight was less under control (i.e., reduced their self-efficacy) and expressed more negative views about their weight.

A diagnosis of food addiction may also affect the sorts of treatments for, or efforts made by, obese people to reduce their weight. On the one hand, the perception that a medical solution to their condition exists may increase their willingness to seek treatment. On the other hand, telling overweight individuals that they are addicted to foods because of long-lasting changes in their brain may undermine their motivation to reduce their caloric intake or to adopt healthy eating and exercise patterns (94). It is also not clear what impact neurobiological explanations may have on the majority of the population who struggle to avoid highly palatable foods but are not obese. We currently do not know what impact telling people that they have a food addiction will have on their eating and weight. The clinical and social repercussions need to be empirically investigated before we assume that neuroscientific explanations of obesity will produce only desirable changes in individual and public perception and attitudes (94).

Public Policy Implications of a Food Addiction Model of Obesity

Tobacco control provides important policy lessons that may prove more effective and cost-effective in reducing excess weight and overconsumption of food than treating obese individuals (27, 62). As some commentators have pointed out, it will not be possible to clinically treat our way out of the current obesity epidemic (24, 94, 170). Although clinical treatment is important for obese individuals, public health approaches are needed to modify obesogenic environments and to curb overweight and obesity on a population level (25). Unfortunately, little public support exists for

many of the public health policies that professionals believe will be most effective in reducing population obesity (96), such as taxation of hyperpalatable foods and better regulation of the sale and promotion of energy-dense foods, including regulations on labeling and product formulation and restrictions on where they can be sold (68).

The food industry has employed sophisticated industrial techniques to enhance the rewarding properties of their products, such as manipulating salt, sugar, fat, and other food additives to make foods more like addictive commodities (35, 61). The spike in obesity rates has tracked the increased availability of cheap, highly refined, calorie-dense foods (23). A number of jurisdictions (e.g., Denmark, Hungary, and some US states) have attempted to impose regulations or taxes on the sale of certain food products, including sugar and fats (56, 68), with minimal success (56).

The food industry, like the tobacco industry, has actively resisted any policies that would affect the consumption of their products across the population because such policies would reduce their profits (27). Proponents of the food addiction model of obesity argue that highlighting the addictive nature of energy-dense foods, particularly those high in refined sugars and fats (103), may increase support for public health measures to reduce weight and overconsumption in the population (4, 59, 62). The recognition that nicotine was an addictive commodity was instrumental in shifting public and political support for greater regulation of tobacco products, which ultimately contributed to the rapid decline in current smoking rates (21).

Little empirical evidence is available to test the claim that acceptance of the food addiction model of obesity will increase public support for public health policies toward obesity. In one study, over 80% of a sample of the general public agreed that some foods were addictive, but few believed that policies, such as taxes on high-sugar or high-fat foods, or regulations on the sale or advertising of these foods would be effective in reducing consumption or weight (96). Further research is needed to establish how food addiction models of obesity would affect support for these policies.

A further risk is that a focus on food addiction may distract attention from policies that modify obesogenic environments (94), that is, social environments that promote overconsumption by making high-calorie foods readily available at low prices (68). These policies include financial incentives to increase physical activity (e.g., tax breaks or insurance coverage, implementing community-based support groups) and the design of more active urban environments with features such as bicycle paths, parks, and walkable neighborhoods (87). A focus on therapeutic treatments of food addiction may undermine public health policies that aim to limit the availability of foods with a higher potential for overconsumption and weight gain (109, 24).

Commercial industries often have an interest in promoting strategies that focus on high-risk groups, distracting attention from and undermining broad-based approaches that reduce total consumption in the population (12). The alcohol industry has promoted a view of alcoholism as a rare form of addiction to oppose increased taxes and restrictions on the marketing of alcohol (11, 12). The alcohol industry has used brain disease models of addiction to argue that alcohol problems affect only a minority of individuals who can be identified using genetic and neurobiological screening and targeted for preventive or therapeutic measures (109). The food industry may similarly support research into identifying the genetic and neurobiological bases of individual vulnerability to food addiction. Although this support may appear to promote scientific research, it also serves the food industry's interests by deflecting attention away from obesogenic environments and toward obese individuals, mimicking tactics used by the alcohol, tobacco, and gambling industries (11, 12). Fixating narrowly on medical treatments of food addiction is also unlikely to be cost effective (24).

The argument for the substantial regulation of foods is perhaps stronger in the case of children, given their greater susceptibility to advertising, their underdeveloped cognitive capacities

(71, 72), and the significant impact that advertising has on their food choices (165). Much greater public support exists for public health strategies that aim at children, notably advertising bans (96). This support may allow policy makers to argue for a broader regulatory approach to reduce overconsumption by changing the obesogenic environments children are exposed to (25), including stricter regulations on the foods available at schools (59). Regulation of this domain could be an efficient way to reduce the alarming rates of childhood obesity, although the ubiquitous and embedded nature of food advertising through modern media (e.g., Internet, mobiles) would make such regulation challenging (110). Education programs that communicate the addictive as well as harmful qualities of certain foods could also a play a role (59). Incorporating public policy changes to protect children could well be the first step in regulating adult access to "addictive" foods.

CONCLUSIONS

The classification of certain foods and eating styles as addictive—based on supportive evidence from animal and human research—has a seductive appeal. This approach promises to produce new treatment options and modify existing treatments for obese individuals. However, insufficient evidence currently exists to support the concept of food addiction; it is a classification that is underdeveloped and requires more rigorous research and analysis to better define and test its validity in obese humans. More rigorous human neuroimaging and neurocognitive research is needed in individuals that better represent the food addiction phenotype.

Assuming that neuroscience research is able to justify the diagnostic category of a food addiction, we will still need to thoughtfully consider the clinical, social, and public health policy impact of adopting such a view (see **Table 1**). Investigations should include empirical studies to examine what impact a food addiction diagnosis may have on those who receive it as well as the impact on the behavior of the general public, on attitudes toward overweight and obese individuals, and on views of various public health policies to reduce the harmful impact of overeating and excess weight. It is not sufficient to make plausible but unsubstantiated assumptions about the positive social impact of a food addiction model of obesity.

When considering policies that view obesity as a form of food addiction, researchers should heed the lessons from successful public health campaigns to reduce tobacco smoking, a common

Table 1 Implications of a food addiction model for treatment, prevention, and policy

	Positive implications	Negative implications
Treatment	More effective treatments of excess weight in some individuals that target cognitive processes involved in addiction; treatments include psychotherapy, cognitive training, and novel pharmacological approaches targeting the dopamine or opioid systems.	Distract attention from the beneficial role of exercise in weight loss, cardiovascular health, and cognitive enhancement. Justify the use of risky, more invasive treatment options (e.g., deep brain stimulation).
Policy	Increased public support for public health measures to reduce weight and overconsumption in the population.	An overreliance on medicalized interventions at the expense of broadly effective public health approaches that address obesogenic environments (e.g., taxation and regulation).
Attitudes	Reduced stigmatization of and discrimination toward overweight individuals. Reduced self-stigmatization and self-blame associated with being overweight.	Adverse effects on individuals' beliefs in their ability to reduce their weight or control their eating. Those exposed to biological explanations of obesity may view their weight as less under their control, thereby reducing their motivation to engage in weight-loss attempts.

addictive behavior. Policy makers, scientists, and clinicians should also be wary of the misuse of the concept of addiction by the food industry, as similar industries have done for other addictive commodities. It is important that neurobiological research findings, however compelling, are not used in isolation to treat severely obese people, but rather are incorporated into population-based approaches that use multiple levels of influence to improve obesity treatment and prevention.

FUTURE ISSUES

1. How is food addiction best defined? What are the core cognitive and behavioral phenotypes from which to measure food addiction?
2. Are the neurobiological alterations reported in the literature best understood in terms of BMI, or are these characteristics of an addiction to hyperpalatable foods? Which population of individuals does a food addiction model best fit?
3. Should future research focus on behavioral and cognitive characteristics of food addiction in subpopulations of overweight individuals (e.g., those with BED) rather than simply individuals above a certain BMI?
4. How might a diagnosis of food addiction affect obese or overweight individuals' beliefs in their ability to control their eating and lose weight or their willingness to seek treatment?
5. What impact would acceptance of a food addiction explanation of excess weight have on public support for public health policies (e.g., taxation and regulation on the sale and promotion of high-sugar and high-fat foods) that aim to reduce overconsumption at the population level?
6. Would a food addiction model reduce the stigma associated with obesity and being overweight, and what impact would reduced stigma have on people's eating and other lifestyle choices?

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

This research was funded by an Australian Research Council Discovery Early Career Award (DE140101097) and a Monash University Strategic Grant awarded to Adrian Carter. Antonio Verdejo-Garcia is funded by a Medical Research Grant of the Ian Potter Foundation (Victoria, Australia), and Murat Yücel is supported by a National Health and Medical Research Council of Australia Fellowship (APP1021973).

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