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FOOD ADDICTION (A MEULE, SECTION EDITOR)

Nutritional Aspects of Food Addiction

Kirrilly M. Pursey[1,2] · **Caroline Davis**[3] · **Tracy L. Burrows**[1,2]

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Abstract
Purpose of Review Behavioural and neurobiological similarities have been identified between the consumption of certain foods and addiction-related disorders. However, few studies have investigated what components of food may promote an addictive-like response in humans. This review evaluates recent research concerning the nutritional aspects of addictive-like eating.
Recent Findings Based on the current evidence base, highly processed, hyper-palatable foods with combinations of fat and sugar appear most likely to facilitate an addictive-like response. Total fat content and glycaemic index also appear to be important factors in the addictive potential of foods. Despite public interest and evidence from animal studies, few studies have reported an association between sugar and addictive-like eating.
Summary Due to the paucity of studies, it is difficult to conclusively identify a specific food or ingredient as capable of triggering an addictive-like response in humans. Future studies using validated dietary assessment tools are essential and may inform the development of novel strategies to treat maladaptive eating behaviours.

This article is part of the Topical Collection on *Food Addiction*

✉ Kirrilly M. Pursey
Kirrilly.pursey@newcastle.edu.au

[1] School of Health Sciences, Faculty of Health and Medicine, University of Newcastle, Callaghan, NSW, Australia

[2] Priority Research Centre in Physical Activity and Nutrition, University of Newcastle, Callaghan, NSW, Australia

[3] School of Kinesiology and Health Sciences, York University, Toronto, ON, Canada

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Introduction

Over recent decades, the food environment has changed dramatically, paralleling the rise in the prevalence of obesity [1]. Globally, 36.9% of males and 38.0% of females are classified as overweight or obese [2], and projections estimate that 58% of the population will be overweight or obese by the year 2030 [3]. Alongside this, there has been an increased availability of energy-dense, nutrient-poor foods that can be produced and purchased inexpensively, when compared to healthier options [4, 5]. Globally, dietary intake patterns have shifted towards higher energy-density diets [6], with a 450-kcal/day increase in the availability of calories per capita worldwide from the 1960s to the 1990s [7], and even greater increases (600 kcal/day) per capita in the USA [8]. Increases in certain food portion sizes [9, 10], snacking frequency [11] and density of fast food restaurants [12] have also been documented. The omnipresent nature of hyper-palatable foods may contribute to problematic eating behaviour and potential weight gain in vulnerable individuals [13, 14].

A burgeoning body of evidence suggests that there are behavioural [15, 16], neurobiological [16–18] and genetic [19–21] similarities between the consumption of certain foods and addiction-related disorders and that these may have the potential to facilitate overeating and weight gain in susceptible individuals [16, 22]. The relationship between dietary patterns, brain function and mental disorders has been the subject of intense research over recent years [23•]. However, while the term "food" addiction has been well-accepted by the general public [24], few studies have sought to investigate the specific components of food that promote an

addictive-like response in humans. Such a gap in our knowledge has prompted the question of whether addictive-like eating is better conceptualised as a *substance-related* or *behavioural* addiction [13, 25]. This review aims to evaluate current research concerning the nutritional aspects of addictive-like eating.

Food Selection

Food selection and dietary patterns are influenced by a variety of factors, including physiological or homeostatic needs [26], the sensory characteristics of the food [27], environmental exposure [28, 29], socioeconomic status [30], as well as social and cultural norms [31, 32]. Eating is intrinsically rewarding and reinforcing, and food consumption is known to activate the dopaminergic reward-related centres in the brain due to its palatability and post-ingestive increases in glucose and insulin [18]. These same brain areas are also involved in reward processing of addictive substances [33]. Foods can be manipulated in a variety of ways to enhance consumer sales and consumption. To remain competitive in an ever changing environment, the "bliss point" of a food—that is, the optimal amount of fat, sugar and salt to maximise palatability, texture and aroma—is highly sought after by the food industry [34]. Food colours and glazes, stimulating packaging and the use of food advertisements can also improve the visual appeal of food [35]. These alterations enhance the rewarding qualities of the food and may also have the potential to enhance the addictive properties of certain foods and beverages.

Characteristics of Food Associated with Addictive-Like Eating

The concept of food addiction has generated considerable interest and debate in both the media and the scientific arenas [36–38]. While there is no universal definition for food addiction, the construct has been operationalised according to the Diagnostic and Statistical Manual of Mental Disorders IV (DSM) criteria for substance dependence [16] and more recently to the DSM-5 [39]. Schulte and colleagues [25] have discussed the substance-related model of food addiction, arguing that not all foods have the same addictive potential. Other authors have suggested that addictive-like eating may be better conceptualised as a behavioural addiction [13, 40, 41]. This viewpoint proposes that while hyper-palatable foods are rewarding, it does not necessarily follow that a specific component of the food is driving this process; rather it may be related to continuous, compulsive overeating of a variety of foods, irrespective of nutritional composition. Further research is necessary to untangle these apparently opposing viewpoints.

Identifying potentially addictive components of food is a challenging enterprise, as we typically consume a combination of ingredients in the food we eat. Animal models have been useful in investigating the mechanisms and possible ingredients associated with addictive-like eating. Evidence from animal studies suggests that sugar is the most likely agent to facilitate an addictive-like response due its activation of opioid receptors [42], as well as its ability to foster tolerance, withdrawal, cross-sensitisation and neurochemical changes in a similar way to addictive drugs [43]. However, addictive-like adaptations to sugar intake have not always been associated with weight gain [44], limiting the application to human obesity [40]. Another problem with the extrapolation from animal studies to humans is that in animal research, sugar is generally added to water, while the solid food (chow) remains balanced and not enhanced [45]. Intermittent access to a high-fat diet has been shown to induce binge eating behaviour in rats [46], but not opioid-induced withdrawal symptoms [42]. Diets with a combination of sugar and fat can induce both weight gain and addictive-like symptoms [47, 48], but addictive-like behaviours occurred to a lesser degree than when the diet was supplemented with sugar only [40]. However, animal models are limited in their generalisability as they do not account for social and environmental influences on human eating behaviour. Nevertheless, these findings have encouraged the investigation of which food components are potentially capable of triggering an addictive-like response in humans.

Foods with a Combination of Ingredients

In 1956, addictive-like eating behaviours were linked to foods such as corn, wheat, milk, potatoes and coffee [49]. Over time, developments in agricultural practices and food processing have led to more efficient and cost effective production and the development of novel foods. Correspondingly, the types of foods associated with addictive-like eating have evolved alongside changes in the food environment. It is now thought that processed foods, with added fat and refined carbohydrate (i.e. sugar), are more likely to trigger an addictive response compared to naturally grown foods [36, 50, 51]. These foods, or food-like substances, more easily override biological satiety mechanisms and facilitate an addictive-like eating process in vulnerable individuals [18]. Foods, such as chocolate, cookies and chips, are often reported as highly craved [52] and involved in typical binge eating episodes [53], compared to fruit and vegetables. However, the intensity and duration of food cravings are typically experienced to a lesser degree than drug craving [54]. Humans are biologically driven to seek energy-dense foods as a potent energy source to maximise energy stores in times of famine. In nature, energy-dense foods are often hard to obtain; however, now they are abundant in Westernised food systems and in many developing nations [55]. One of the major critiques of the substance-related model

is that unlike drugs, food is necessary for human survival [38, 56]. While food is necessary for survival, energy-dense, nutrient-poor foods are clearly not an essential part of a healthy balanced diet [57].

Scientific studies investigating addictive-like eating tendencies have often relied on tools that target single aspects of addiction, such as craving and impulsivity [58–60], or self-identification, such as "chocoholics" [61–63] and "carb cravers" [64]. In 2009, Gearhardt and colleagues [65] developed the *Yale Food Addiction Scale* (YFAS), a 25-item tool that assesses the behavioural indicators of food addiction according to the DSM-IV. More recently, the YFAS 2.0 has been developed according to the DSM-5, with similar psychometric properties and prevalence to the original YFAS [66]. However, studies are yet to use this tool in combination with specific foods or nutrients.

In an Australian study of predominantly young females [67••], higher YFAS food addiction scores were associated with higher percentage energy intake (%E) from energy-dense, nutrient-poor foods, such as confectionary and take-out foods, assessed via a validated food frequency questionnaire (FFQ). "Junk" foods, such as candy, chocolate, cookies, ice-cream and cakes, were also associated with addictive-like eating in self-reported food addicts [68]. These findings have been echoed in the study by Schulte and colleagues [69••] during a forced-rank task of a pre-selected list of 35 foods chosen by the authors, which varied in levels of processing. Palatable processed foods, with added fats and refined carbohydrates, including pizza and ice-cream, were reported as more likely to be associated with addictive-like eating behaviours, while fruit and vegetables were ranked as those foods that were least likely. This is similar to a study by Meule and colleagues [70] who used a predefined list of foods specified in the YFAS, with the most frequently self-selected addictive foods including chocolate, candy, cookies and chips. However, these two studies only investigated a predetermined list of foods in developed countries and therefore may not be reflective of foods across a wider range of countries or cultural groups. Addictive-like eating, assessed via the YFAS, has also been associated with increased visual attention [71] and accelerated reaction times [72] to energy-dense, nutrient-poor foods.

Brain-imaging techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have provided another method to assess the addictive potential of certain foods. Imaging studies have identified the activation of reward-related dopaminergic brain regions by the sight [73], smell [74, 75] and taste [76, 77] of food in a similar way to addictive substances. However, in many published studies, the nutrient composition has not been reported, and often subjective descriptions such as "palatable" or "disgusting" foods have been used [78]. Therefore, it remains unclear as to what specific characteristic of the food may elicit this response. One study has used fMRI in combination with the YFAS to investigate the activation of brain regions in response to a palatable milkshake (ice-cream, milk and chocolate syrup) compared to an unflavoured beverage [22]. In this study, individuals with higher addictive-like eating tendencies displayed greater activation of reward circuitry in response to visual food cues, while food intake reduced activation of inhibitory regions, in a pattern similar to that seen in other addiction disorders [22]. Future studies are essential to tease out what nutritional component of the milkshake may have the capacity to activate neural circuitry in this way.

One of the major limitations in existing food addiction research is the lack of validated dietary assessment tools. Collecting accurate, comprehensive dietary intake data that reflects usual intake is challenging due to the reliance on self-report and recall in retrospective methods such as FFQ's and alterations in food intake during the reporting period in prospective methods such as weighed food records [79]. Newer technology-based methods assist in reducing both researcher and participant burden in the collection and analysis of dietary data [80]. Research of this kind is necessary to advance the food addiction field, identify possible dietary treatment targets and inform future nutrition-related policy and treatment programs.

It is highly unlikely that all foods are equally capable of triggering an addictive-like response [36]. However, other than caffeine, there is currently insufficient human evidence to label a specific food, nutrient, ingredient or combination of ingredients addictive [13, 81]. From the limited number of studies to date, it appears that if any foods are addictive, it is likely to be energy-dense, nutrient-poor foods with a combination of fat and sugar. However, there is a lack of high-quality, well-powered trials that recruit representative samples. Further research using randomised controlled designs is essential to identify the characteristics, combinations and concentrations of ingredients which are potentially addictive.

Macronutrients

Carbohydrates

Carbohydrates encompass a range of substances in food, including sugars, starches and fibres. Humans have evolved to prefer sweet foods as they are a rapid source of energy and sweet taste typically signals that the food is not poisonous [82]. Following results from animal studies, sugar may be the most likely macronutrient to facilitate an addictive process in susceptible humans, and as such "sugar addiction" has received the most attention in scientific research [43, 81, 83•] and from the media [84, 85].

The relationship between food addiction and carbohydrate intake has been investigated in a small number of human studies [67••, 69••, 86•, 87]; however, only one has reported a significant association [86•]. Higher total carbohydrate per kilogramme of body weight, assessed via a FFQ, was

consumed in a sample of obese individuals classified as food addicted compared to their control counterparts [86•]. The relationship between YFAS scores and brain activation in response to a high- and low-sugar beverage has also been investigated in adolescents [88]. Addiction-related neural pathways were activated across all participants when tasting the high-sugar compared to the low-sugar beverage. However, no relationship was identified between YFAS scores and brain response to the high sugar beverage [88]. In addition, no relationship was identified between intake of total sugars and food addiction in a sample of young Australians [67••]; however, this study did not discriminate between added sugars (e.g. sugar added to processed foods such as sugar-sweetened beverages) and naturally occurring sugars (e.g. lactose in milk). It is proposed that those refined, added sugars are those that increase the addictive potential of foods, due to the higher dose compared to naturally sourced food [69••].

No human studies have investigated specific subtypes of sugar, such as monosaccharides (e.g. fructose, glucose) or disaccharides (e.g. sucrose), in relation to addictive-like eating. Consumption of high fructose corn syrup (42–55% fructose), particularly from sugar-sweetened beverages, has increased dramatically and appears to contribute to weight gain and obesity [89]. Fructose has received attention in relation to dysregulation of appetite control, hyperphagia and weight gain in animal models [45, 90]. However, such studies have used fructose in concentrations higher than consumed in the normal human diet [91, 92], while other studies have found that there is no significant difference between fructose and other types of sugars such as glucose or sucrose on human appetite [93–95]. Differentiating between added and naturally occurring sugars, as well as specific types of sugar, is an important area of future food addiction research. In addition, the form in which sugar and other nutrients are found in the diet (e.g. food vs beverages) requires investigation, with sugar in liquid form resulting in poor satiety compared to solid food, leading to overconsumption [96, 97].

Despite public perception, scientific evidence supporting the addictive potential of carbohydrates, and more specifically simple sugars, in humans is not compelling [81, 83•]. However, this does not mean that it should be dismissed due to the limited evidence base. The results from animal studies encourage further human investigation.

Fats

Fat contributes to the flavour, smell, mouthfeel and energy density of food [98]. Evidence also suggests that fat may be an important factor in the addictive potential of certain foods. In young adults, %E from total fat was positively associated with YFAS symptom scores and higher odds of food addiction diagnosis [67••]. High-fat foods are also more likely to be perceived as addictive [69••]. In two studies by Pedram and colleagues, %E from fat was significantly higher in food-addicted individuals compared to non-addicted counterparts in both a community sample [87] and an obese sample [86•]. Self-reported food addicts also consumed a greater number of calories from high-fat foods and greater energy intake overall in a laboratory task [99]. With further investigation into the specific types of fat associated with addictive-like eating, two studies have found a significant positive relationship between YFAS food addiction and saturated and monounsaturated fat [67••, 86•]. The significant relationship with saturated fats is particularly concerning, with national recommendations to limit these in the diet [100].

It is important to note that in many cases, fat is not necessarily palatable on its own, but is often combined with other ingredients to improve the flavour profile. The relationships reported between fat intake and food addiction may be reflective of the way in which fat is consumed in the diet, often in energy-dense, nutrient-poor foods in combination with other nutrients such as carbohydrates and salt (e.g. fried foods, pastries). Such an occurrence provides further support for the hypothesis that the combination of these ingredients in hyper-palatable, highly processed foods may be the most likely to facilitate addictive-like eating episodes.

Protein

Protein has received little attention in food addiction research. A single study reported that energy from protein was positively related to YFAS scores in a community-based sample [87]; however, this has not been replicated in other studies [67••, 86•]. While these findings are interesting, they are rather counterintuitive given that protein induces satiety via hormonal mechanisms and modulation of the brain reward pathways [101–103]. Therefore, protein may play an important role in future treatment strategies to prevent overconsumption.

Micronutrients

Sodium, added to food in the form of salt, is the micronutrient that has received the most attention in food addiction research [104]. Salt can be added to processed foods to improve palatability, as well as to preserve perishables and improve texture [104, 105]. Salt is not always associated with savoury foods, since many sweet foods also contain high concentrations of added salt. One study has reported a relationship between symptoms of food addiction and dietary sodium [86•]. A self-identified group of female food addicts also reported salty foods to be perceived as addictive and highly craved [68]. However, not all studies have identified a relationship between sodium and addictive-like eating [67••]. The YFAS does not assess the frequency of addictive-like eating episodes, so periodic or infrequent addictive-like eating episodes may not impact dietary intake at the micronutrient level.

Alternatively, there may not be a specific dietary pattern followed by all individuals displaying addictive-like eating, but rather overeating of foods with differing composition, resulting in no single micronutrient excesses or deficiencies.

Food Additives and Non-nutritive Components

To date, there have been no studies investigating the addictive potential of certain food additives and non-nutritive components, except for caffeine [106]. Although caffeine addiction is not recognised as a clinical diagnosis, caffeine-related disorders have been highlighted in the DSM-5 as an important focus of future study due to similar behavioural and physiological effects as drugs of abuse [107]. A number of food additives and components may be significant in the context of addictive-like eating, such as sugar substitutes, artificial colours and flavouring agents. Glutamates, added to some take-out and processed foods as a taste enhancer in the form of monosodium glutamate (MSG) [108], naturally occur in some foods, so it may be likened to added sugars in that the added form may increase the potency. Food additives may have the potential to enhance the addictive properties of certain food or nutrients as do chemicals added to cigarettes to enhance the addictive potential of tobacco [36, 57] and therefore require further investigation.

Food Processing

Emerging research highlights that it is important not only to look at dietary patterns and food composition but also how food is processed and prepared. It has been hypothesised that the degree of processing and refinement increases the addictive potential of foods [36, 50, 51]. These manufacturing processes increase the concentration of rewarding food ingredients (e.g. fat and sugar) and often remove healthful components (e.g. fibre), from naturally sourced food [55]. The effect of these processed foods on the body are thought to mimic the pharmokinetic properties of drugs of abuse, leading to a rapid, transient rise in blood sugar levels [57, 69••]. These food properties have been likened to the purification of other psychotropic plants into illicit drugs, such as the coca plant to produce cocaine [55].

In the study by Schulte and colleagues, the glycaemic load and degree of processing were related to the perceived addictive potential of a predefined list of foods, particularly the addition of fat and refined carbohydrates [69••]. In addition, individuals with new-onset substance use disorder following gastric bypass surgery perceived foods with a high glycaemic index (GI) as more addictive [109]; however, this study did not assess food addiction specifically. Lennerz and colleagues [110] reported that a high GI meal, compared to an isocaloric low GI meal, activated brain regions associated with reward and craving in the late postprandial period in males. While food processing is often associated with negative connotations and used to refer to energy-dense, nutrient-poor foods, it can have a range of beneficial effects including improved digestibility, preventing food spoilage, nutrient fortification [111] and improved nutrient bioavailability [112]. It appears that food processing, particularly where the GI is increased, is likely to be associated with the addictive potential of foods. The by-products produced by certain dry heat preparation methods (e.g. advanced glycation end-products) are also worth consideration in future nutritional psychiatry research [23•].

Potential Nutrition-Related Implications of Food Addiction

It has been suggested that addictive-like eating could be an important factor contributing obesity in vulnerable individuals [15, 33, 113–115]; however, other authors argue that most obese individuals do not display a convincing behavioural or neurobiological addictive profile [38]. Numerous studies have reported that YFAS assessed food addiction is associated with higher body mass index [116] and, more recently, visceral fat, a sensitive marker of cardiometabolic risk [117]. Higher YFAS scores and diagnosis have also been associated with an elevated BMI in type 2 diabetics [118, 119]. In addition, framing obesity in the context of food addiction resulted in the attribution of less stigma and blame to obese individuals [120]. As obesity is a modifiable risk factor, it may be important to identify and intervene in addictive-like eating early so as not to progress to chronic conditions.

Given the multifaceted nature of the proposed food addiction construct, novel treatment approaches may be necessary, involving a multidisciplinary team including psychologists, dietitians and medical management to optimise treatment outcomes, where other more traditional weight loss approaches have had limited success [121–124]. There are a number of popularised self-help treatments available (e.g. Overeaters Anonymous) [125, 126] based on principles similar to that of Alcoholics Anonymous, with membership now estimated at 60,000 worldwide [127]. However, the efficacy of these types of programs is yet to be scientifically evaluated. Future treatments may include the incorporation of therapy employed in addictive therapy, such as cognitive behavioural therapy (CBT) or harm reduction strategies, into existing models of nutritional counselling and weight loss advice. In a single case report of a 40-year-old female with cola dependency, CBT and guidance to reduce cola intake reduced addictive-like symptoms and mental function was improved [128]. Nutrition treatment may also focus on the modification of specific dietary patterns, foods or nutrients associated with food addiction.

The identification of potentially addictive foods also has the potential to inform better nutrition public health policy [129, 130], for example taxes on sugar-sweetened beverages,

which have been shown to reduce consumption [131, 132]. In addition, changes to food labelling and marketing may assist individuals to make more informed food choices, particularly for vulnerable groups such as children. Alternatively, behavioural approaches may focus more on behaviour modification at the individual level, rather than emphasising changes for the food industry.

Conclusions and Future Directions

Due to the paucity of studies in this area, there is currently little evidence to conclusively identify that a specific food, nutrient or ingredient is capable of triggering an addictive-like response in humans. However, preliminary investigations suggest that highly processed, hyper-palatable foods with combinations of fat, sugar and salt are those that have the greatest addictive potential. Future studies should use validated dietary assessment tools in combination with behavioural indicators (e.g. YFAS or YFAS 2.0) and/or neuroimaging techniques to characterise the foods or food properties associated with addictive-like eating. The identification of a specific food or component as addictive may warrant the development of strategies or interventions to minimise maladaptive eating behaviours, as well as reduce exposure and consumption of specific foods.

Compliance with Ethical Standards

Conflict of Interest Dr. Kirrilly M. Pursey, Professor Caroline Davis and Associate Professor Tracy L. Burrows declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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