

The Addiction Potential of Hyperpalatable Foods

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Abstract: Scientific interest in “food addiction” continues to grow due both to neurobiological and behavioral similarities between substance dependence and excessive food consumption. An important next step is to examine the addictive potential of highly processed foods. In this paper, we explore addiction-related changes in the modern food environment (e.g., increased potency, elevated speed of absorption), examine the historical and modern understanding of addictive substances as applied to hyperpalatable foods, and outline shared factors that increase the public health costs of both addictive drugs and certain foods.

Keywords: Food addiction, food environment, high fructose corn syrup, obesity, substance dependence, withdrawal.

INTRODUCTION

Although the concept of *food and addiction* is receiving widespread attention from the popular media, and is woven into popular language and culture as seen with terms such as “chocoholic” and “carbohydrate craving”, it has become credible in the scientific community only recently [1-4]. Since 2006 there has been an exponential increase in the number of academic publications relating to this topic (Fig. 1), due in part to a shift in perspective to the view that addictions should be reframed as unusually strong and maladaptive desires to ingest a substance or engage in a behavior despite negative consequences [5, 6].

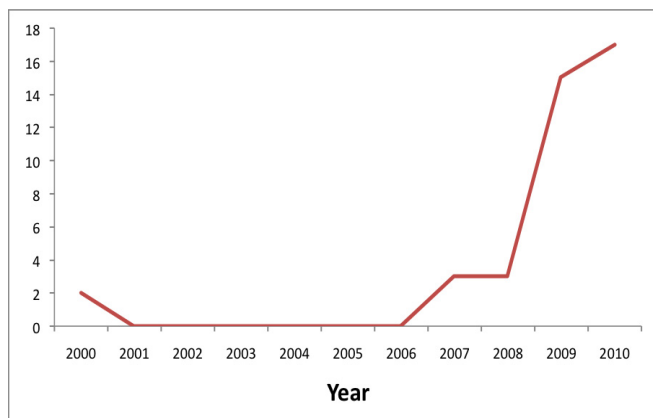


Fig. (1). Number of publications containing the words “food addiction” obtained from the *Web of Science* database, and plotted for the years 2000-2010.

The term ‘food addiction’ might be seen as an oxymoron since eating is quintessentially necessary for our health and survival. We argue the opposite - that many of the highly-processed foods in modern diets that damage health are more similar to drugs of abuse than to the natural energy resources people consumed historically (Table 1). Humans evolved to prefer foods high in fat, sugar, and salt, but in the quantities

and availability these ingredients now occur in processed and refined foods, they appear to have an abuse potential similar to addictive drugs like cocaine and alcohol [7-9].

A growing body of research has identified many similarities between conventional addiction disorders and excessive consumption of calorie-dense foods. Presently many of the studies on the addictive potential of certain foods are based on examinations of rats exposed to sugar, fat, or highly processed foods [3, 10]. The eating behavior of rats may provide an especially useful analogue for human food consumption, as both rats and humans are omnivores who have developed the ability to ingest a diverse array of foods [11]. For both rats and humans the dopamine and opioid neural circuitry implicated in drug addiction is also associated with the motivation for food and food-related reward [12, 13]. It has also been demonstrated that rats given sugar, fat, or highly processed foods exhibit reward-related neural changes seen in drug addiction, as well as the behavioral signs of withdrawal, tolerance, and continued use despite negative consequences [3, 10]. Scientific evidence of the parallels between substance use and food consumption in humans is also building. For example, drug and food cravings foster similar patterns of neural activation in the brain’s mesocorticolimbic pathways [14]. Further, genetic (i.e., *DRD2 Taq1A* allele) and personality factors (i.e., elevated reward responsivity) linked with addiction have also been implicated in obesity and binge eating disorder [15]. Moreover, individuals who endorse symptoms of food addiction as indicated by the Yale Food Addiction Scale are more likely to exhibit patterns of craving-related neural activation in response to food cues and disinhibition-related neural activation during palatable food consumption [16].

Examining how hyperpalatable substances have addictive properties is an important next step in evaluating the validity of the food and addiction construct. This may be especially true for understanding the utility of an addiction perspective in preventing and treating diet-related disease and obesity. In this paper, we will explore addiction-related changes in the modern food environment, examine the historical and modern understanding of addictive substances, and outline shared factors that increase the public health costs of both addictive drugs and certain foods.

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Table 1. Similarities Between Hyperpalatable Foods and Addictive Drugs

1. Activate dopamine and opioid neural circuitry
2. Trigger artificially elevated levels of reward
3. Absorbed rapidly into the blood stream
4. Alter neurobiological systems
5. Cause compensatory mechanisms that result in tolerance
6. Combined with additives to enhance rewarding properties
7. Elicit cue-triggered cravings
8. Consumed in spite of negative consequences
9. Consumed in spite of a desire to cut down
10. Impact disadvantaged groups to a disproportionate degree
11. Cause high public health costs
12. Exposure <i>in utero</i> can result in long-term alterations

DEFINING FOOD

Prior to examining the addictive potential of food, it is useful to consider what constitutes a food. A wide-variety of substances is consumed for sustenance, as well as pleasure, and definitions of what is considered a food varies based on cultural definitions. For example, insects are a staple of diets in some regions (e.g., China) [17], but they are not commonly eaten in the Western world. Further, the increasing prevalence of chemicals, flavor enhancers and lab-developed compounds in the food supply has led to the question of whether ultraprocessed foods should no longer be called food and should instead be relabeled as food-like products [18]. To add another layer of complexity, alcohol (which is typically considered an addictive substance) is a natural product of ripe fruits, may be a standard part of a hunter-gather diet, and provides calories and some nutrients in a similar manner as substances classified as food [19]. Although no one definition is able to succinctly capture the complexity of this topic, in the current review we use the term food to reference caloric items that are consumed as part of the Western diet (i.e., might be purchased at a grocery store) with special attention given to macronutrients that are frequently manipulated during food processing, like fat and sugar. Although alcohol may fall under this definition, in the current paper we include ethanol-containing products in the category of substances traditionally considered addictive.

ADDICTIVE-LIKE FOODS

The food environment has changed drastically, which has resulted in foods with increasingly addictive-like properties. In the pre-industrial era humans survived on a diet that was minimally processed, high in protein, grains, and produce, and relatively low in salt [20]. Foods that had greater caloric value through elevated sugar and fat content, such as berries and animal protein, were relatively scarce. As an adaptation to motivate consumption of calorically dense foods, we evolved to find foods high in sugar and fat more hedonically rewarding than foods low in these substrates [20]. As industrialization occurred and food-related technology

evolved, the environment changed from one with limited access to calorie-dense foods to one of abundance with artificially elevated levels of fat, sugar, salt, caffeine and flavor enhancers in the meals we eat [21].

Many highly processed foods have been altered in a similar manner as addictive drugs. Both the elevated potency of a substance, and its rapid absorption into the bloodstream, increase a substance's addictive potential [22]. Many drugs of abuse derive from plant materials that are refined into highly concentrated substances (e.g., grapes into wine; the coca leaf into cocaine). As a result of processing, these substances became more potent and the active ingredients is more quickly absorbed into the bloodstream. For example, when the coca leaf is chewed or stewed as tea, it produces only mild stimulation and is thought to have little addictive potential [23]. Further refinement provides a more potent drug in the form of cocaine and crack, which is hedonically very rewarding, quickly absorbed, and highly addictive [24]. Many highly palatable foods follow a similar process that results in the quicker absorption of sugar and a higher level of reward. For example, corn is a frequently consumed starchy vegetable that has been part of the human diet for centuries. With technological advances, corn was refined into high fructose corn syrup (HFCS) – a highly concentrated and very sweet simple carbohydrate, which is not found in natural foods that comprise most traditional diets [25].

In the past 40 years or so, HFCS has been added to a large variety of processed products, such as soft drinks, baked goods, and cereals. Indeed, our consumption of this simple sugar has increased exponentially – from about 4 to 12% of our daily caloric intake in a few generations [26]. In this capacity, the special physiological properties of fructose render it similar to other drugs of abuse. The most direct parallels are seen between fructose and alcohol because the two are biochemically and evolutionarily congruent. Ethanol is simply the fermented byproduct of fructose [27] and can have some health benefits when consumed in small doses. For example, not only is ethanol an energy resource due to its caloric content, but it may also serve as a stimulant to further feeding. Given that ethanol is associated with the valuable nutrients found in ripe fruit, Dudley [19] suggested that a short-term advantage of ethanol might be to increase the rate of food intake, which, in turn, would increase blood-ethanol content and foster further consumption. Similarly, HFCS provides the body with calories needed to maintain functioning. Thus, consuming either HFCS or ethanol in small doses may provide some benefits.

However, as both HFCS and ethanol are legal, relatively cheap, widely available, and socially sanctioned in most Western cultures, they are frequently consumed to excess. When taken in large quantities, HFCS and alcohol may cause biological changes that encourage further problematic use. Excessive alcohol consumption causes mesolimbic dopamine down-regulation, which fosters increased intake, pronounced cravings, continued use despite negative consequences and physical withdrawal symptoms during periods of abstinence [28]. High fructose consumption tends to promote insulin resistance and chronic hyperinsulinemia, and this occurs largely through its capacity to induce increased release of triglycerides in the liver [29]. We have

also learned that the metabolic impact differs substantially depending on the type of sugar that is consumed. For instance, the monosaccharide fructose raises triglyceride levels and lowers high-density lipoprotein, whereas glucose does not have these effects [30]. Fructose also blunts leptin signaling thereby promoting sensations of hunger and activation of the reward pathways creating a desire for consumption independent of energy needs [31] – a phenomenon that is directly comparable to what occurs when alcohol is used excessively [27]. This seems to occur because HFCS bypasses the insulin-driven satiety system. In other words, while glucose stimulates the release of insulin, decreasing the desire to eat, fructose has this effect to a very weak degree [31]. Therefore, ingesting elevated amounts of either ethanol or fructose can result in biological changes that promote overconsumption.

Another consequence of processing for both food and drugs of abuse is that the refined substance is combined with additional products to enhance its rewarding properties. The tobacco plant, for example, is harvested and processed into a form that can be either inhaled as smoke, or ingested as a result of chewing. Although the nicotine in the tobacco plant is the main active ingredient, the tobacco industry has added hundreds of additional ingredients to enhance the flavor and aroma of the product, speed absorption into the lungs, and increase cigarette shelf life [32]. The resulting tobacco product is significantly more rewarding and addictive than unprocessed tobacco.

A similar process occurs with hyperpalatable foods. HFCS is not consumed on its own, but is combined with other ingredients, such as sweeteners, fat, salt, flavor enhancers, and caffeine. For example, a frosted chocolate-fudge Pop Tart combines HFCS with refined flour, sugar, oil, salt, cocoa, flavor enhancers, and preservatives. In total, the resulting product has approximately 37 ingredients. Thus, similar to cigarettes, the substance that results from processing is often significantly more rewarding than minimally processed foods.

In addition to the increased levels of hedonic reward, the processing of foods may also result in other addiction-related changes, such as tolerance and cue-reactivity. For example, individuals have a tendency to consume greater quantities of foods they find palatable, as evident in the ever increasing portion sizes of highly processed foods [33]. The consumption of food, especially in large quantities, increases the level of glucose into the bloodstream, which disrupts the homeostasis of the biological system [34]. As a compensatory mechanism, the pancreas begins to secrete cephalic insulin in response to food-related cues or at the beginning of food consumption to allow the body to tolerate greater levels of food ingestion [34]. Similarly, ingestion of drugs of abuse also stresses the body and biological responses occur to compensate for these disruptions, which increases the body's tolerance to the addictive substance [35]. Thus, the body adapts to the ingestion of either food or drugs of abuse in a manner which results in higher levels of tolerance. The development of elevated tolerance may then drive even more problematic levels of consumption. Additionally, consumption of sugar or addictive drugs can result in elevated dopaminergic activation in response to related cues, which is associated with an enhanced

motivation to seek out the substance (i.e., wanting) without a corresponding increase in the hedonic pleasure received during consumption of the substance (i.e. liking) [36, 37]. The sensitization of dopaminergic activity to cues may result in cue-triggered cravings playing a large role in both problematic eating and drug-taking behavior. In summary, the elevated hedonic nature of highly processed foods may initially encourage overconsumption, but other factors (e.g., increased tolerance, elevated wanting) may also drive addictive-like eating behavior.

THE CONTROVERSIAL NATURE OF ADDICTION

Like the food environment, the conceptualization of an addictive substance has changed throughout history. In the 19th century, substances that are now classified as addictive were commonly consumed as a part of daily life. For example, heroin was an ingredient in over-the-counter tonics for both children and adults, cocaine was included in *Coca-Cola*, and alcohol was consumed as an alternative to contaminated water [38]. In the late 1800s and early 1900s, public concern about these substances grew, and some, like heroin and opium were thought to be a threat to societal and personal wellbeing [39]. As the impact of these substances on the body and brain became more evident in the latter part of the 20th century, the list of problematic drugs increased. Nevertheless, the classification of what constitutes an addictive substance has often been controversial. Frequently, the substance at the center of debate has been associated with some central features of addiction (e.g., escalating use, inability to stop despite problems), but lacks other typical addiction markers. For example, cocaine is associated with almost no physical withdrawal symptoms, which created controversy about its addiction potential until the late 1980s [40]. The addictive nature of tobacco was also the focus of debate, in part due to its lack of a strong intoxication syndrome [41].

Hyperpalatable foods are also associated with some of the factors that once caused cocaine and tobacco's addictive nature to be debated. Although there is evidence that sugar consumption is associated with pronounced physical withdrawal symptoms in animals [3], evidence of withdrawal from hyperpalatable foods in humans is largely anecdotal and based on reports of people experiencing headaches, elevated cravings, irritability, and temperature dysregulation while dieting [42]. Like cocaine, the limited exploration of food-related withdrawal in humans has increased skepticism about the addictive nature of highly processed foods [43]. Moreover, in a similar manner as tobacco, consumption of highly processed foods does not result in an obvious intoxication syndrome. However, the level of intoxication triggered by an addictive substance does not directly correlate with the degree of negative consequences. Tobacco is currently the number one cause of preventable death in the United States despite the lack of an intoxication syndrome [44]. The greater public health cost associated with tobacco is partly because of the ease of accessibility, increased social acceptability, heavy marketing practices, and low cost [21]. Hyperpalatable foods are also ubiquitous, socially acceptable, highly marketed, and inexpensive [21] and their public health consequences are enormous. Furthermore, despite the lack of an intoxication syndrome, ingredients in

highly processed foods appear to have reinforcing properties on par - or possibly exceeding - drugs of abuse. For example, Lenoir and colleagues [45] found that cocaine-addicted rats will choose saccharin, a calorie-free sweetener, over cocaine in a forced choice task, which led to the conclusion that the rewarding properties of sweetness may surpass that of drug reward.

Although hyperpalatable foods may differ in some ways from the typical conceptualization of addictive drugs, they share many features with traditionally addictive substances. First, highly processed foods and drugs of abuse are both capable of triggering cravings [14, 46]. Second, consumption of highly processed foods and drugs of abuse can both be associated with compulsive overuse in the face of severe negative consequences [42]. And finally, in some individuals there is evidence of chronic relapse and an inability to cut down consumption of both substances [42]. Thus, while highly processed foods may not be associated with a clear intoxication syndrome, and evidence of withdrawal is just now building, there are significant areas of overlap with conventional addiction disorders.

In addition to nosological debates, the application of an addictive label has also been marked by societal controversies. For individuals, stigma is often associated with a substance dependence diagnosis. The stereotype of persons with addiction as weak-willed and untrustworthy can be a barrier for those thinking of seeking treatment and may result in occupational and social discrimination [47]. In contrast, the conceptualization of addiction as a disease has also led to more widespread support for those seeking treatment for substance use disorders, increased insurance coverage for addiction, and greater funding for addiction-related research [47]. Similarly, applying an addiction perspective to food may increase weight stigma or conversely may lead to greater support for the treatment of eating-related problems. Addictive substances have also been linked to questions of social justice. Certain addictive substances (e.g., crack-cocaine) have been linked to underprivileged groups (e.g., urban poor, African-Americans), which have resulted in stricter legal consequences for the use of these drugs relative to other substances [48]. Further, at-risk groups have often been disproportionately targeted for the marketing of legal drugs. For example, primarily African-American neighborhoods in metropolitan areas have a higher density of tobacco billboards and magazines designed for African-American readers are more likely to contain cigarette advertisements [49]. Currently, food-related problems, such as obesity, are impacting minorities and economically disadvantaged groups in disproportionately high numbers [50]. As with tobacco, advertisements for potentially addictive foods are specifically designed to appeal to these demographics and fast-food restaurants are more prevalent in poorer neighborhoods [51, 52]. The historical relationship of addiction with social issues may prove informative in considering the burden of potentially addictive foods on disadvantaged groups.

SHARED FACTORS THAT INCREASE THE COST OF ADDICTIVE SUBSTANCES

Although addictive substances appear to be somewhat heterogeneous in nature (i.e., varying levels of withdrawal, intoxication, etc.), the addiction rubric has been useful in identifying substances that are likely to be consumed

excessively despite negative consequences and to result in clinical levels of impairment/distress. Ultraprocessed foods appear to share many of the characteristics of addictive substances and excessive consumption of these foods is already associated with some clinical disorders (e.g., binge eating disorder). The consequences of potentially addictive foods, like drugs of abuse, will also likely extend beyond clinically significant disorders. Widespread use of addictive substances often results in steep public health costs due in part to sub-clinical problematic use. For example, alcohol consumption is prevalent in America, but only 5-10% of alcohol users develop alcohol dependence during their lifetime [53]. Despite the relatively low rates of dependence, alcohol is the third leading cause of preventable death in the United States, partially as a result of accidents and health conditions caused by sub-clinical alcohol use [44]. Highly processed foods may have a similar impact on public health by triggering problematic use in individuals that do not exhibit clinically disordered eating. Moreover, ingredients in highly processed foods are implicated in health problems beyond elevated body mass index. For example, research suggests that HFCS relative to sucrose is more likely to cause adipose fat in the abdominal region, increase circulating triglyceride levels, and result in metabolic syndrome [31, 54]. If hyperpalatable foods are capable of driving widespread overeating and metabolic dysfunction to a degree that impacts health, this may partially account for the high public health cost of excessive food consumption [44].

Protective factors against the development of addictive behaviors are also on the decline in the current food environment. Addictive substances consumed in the context of cultural and religious rituals appear to be less likely to be abused (e.g., [55]). If it is only socially appropriate to consume a substance in a specific context, social mores may restrain substance use and only a limited number of cues may be linked with the substance, which could result in fewer triggers for use. In a similar vein, food consumption has traditionally been linked with the experience of eating in a social or cultural context. For examples, meals were frequently eaten with family or friends while seated at a table and snacking between meal times was not a common practice. The current trends in food consumption find people eating more frequently in isolation, in a variety of setting (e.g., the car, at a work desk, in front of the television), and snacking regularly between meals [56]. The uncoupling of food consumption for social/cultural settings may also increase the likelihood that highly processed food consumption will result in an addictive behavior.

Additionally, the frequency and the duration of one's exposure to an addictive substance, as well as early age of substance use [57], increases the likelihood of becoming addicted [58]. There is some evidence that the same dosing effects may also apply to food high in sugar, fat and salt. While drug experiences typically begin during adolescence or early adulthood, direct exposure to processed and highly palatable food normally begins within the first few years of life. Indeed, recent research indicates that these influences can occur *in utero* and can substantially modify the fetal genome [59]. For instance, maternal consumption of a high-fat diet during pregnancy can induce long-term alterations in dopamine and opioid gene expression and preference for palatable foods in animal offspring [60]. In addition, there is

evidence that children of obese mothers are at increased risk for insulin resistance and subsequent obesity and metabolic dysfunction [61]. Therefore, the early age of exposure to processed foods and the chronic nature of its consumption may increase the consequences of potentially addictive foods.

CONCLUSION

In summary, although highly processed foods differ from the traditional conceptualization of addictive drugs in some ways, such as the lack of intoxication, the degree of overlap is significant and compelling. In addition to neurobiological and behavioral similarities, hyperpalatable foods and addictive substances both trigger artificially high levels of reward, cause biological compensations that result in tolerance, and become linked with associated cues. Factors that increase the addictive potential of substances, such as a lack of cultural context, frequent consumption and early age of use, are also relevant to highly processed foods. Further, the components that increase the public health consequences of alcohol and nicotine are also present in the modern food environment, such as the ease of accessibility, increased social acceptability, heavy marketing and lower cost of high-calorie foods. Due to the similarities between highly processed foods and addictive drugs, successful policies in reducing the impact of addictive drugs may also be useful in combating food-related problems. For example, tobacco consumption was significantly reduced in the United States when effective individual treatments were combined with tobacco-focused interventions, such as barring cigarette machines, increasing taxes and limiting marketing. Similar interventions have been proposed in response to the obesity epidemic, such as reducing nutrient-poor foods in school vending machines, implementing a soda tax and reducing marketing of high-calorie foods to children [62,63]. Given the similarities between highly processed foods and tobacco, these approaches may also prove effective in reducing the public health consequences of excess food consumption.

Future Research Questions:

- It is highly unlikely that all foods are equally capable of triggering an addictive process. What foods have the greatest addictive potential? What increases foods' addictive nature (e.g., elevated sugar, increased fat)?
- Does a reduction in the consumption of highly processed foods trigger a withdrawal syndrome? Do symptoms of withdrawal from hyperpalatable foods (e.g., anxiety, agitation, physical symptoms) increase the risk of weight gain or being unable to adhere to a healthier diet?
- Can the implementation of protective factors against the development of addictive behaviors (e.g., inclusion of consumption in social/cultural settings, reduced exposure to advertisements) also reduce problematic food consumption?

Key Learning Objective:

- The food environment has changed drastically in a relatively short period of time. One cause for concern is that foods are now being processed in ways that increase both their reward potency, as well as the speed of absorption of fat/sugar into the system. These are two factors that increase the addictive potential of other substances (e.g., coca leaves). This may have increased the likelihood that certain foods may be capable of triggering an addictive process.

- Labeling a substance addictive has been historically controversial. For example, the minimal physical withdrawal symptoms associated with cocaine and the lack of an intoxication syndrome linked with tobacco led to debates about their addictive nature. Hyperpalatable foods are associated with similar factors, which will likely lead its addictive nature to be a topic of controversy.
- Despite these differences, hyperpalatable foods and addictive drugs share a number of characteristics. They are both associated with loss-of-control, continued use despite negative consequences, high rates of relapse, public health costs and *in utero* influences. If evidence of the addictive potential of highly processed foods continues to build, effective policies for reducing the impact of other addictive substances (e.g., increased taxation, restricted advertising) may prove essential in dealing with the obesity epidemic.

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