

RESEARCH ISSUES: THE FOOD ENVIRONMENT AND OBESITY

Variety, Palatability, and Obesity^{1–4}

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ABSTRACT

Among the key characteristics of the Western obesogenic food environment is a highly palatable and varied food supply. Laboratory investigations of eating behavior in both humans and animals established key roles for palatability and variety in stimulating appetite, delaying satiety, and promoting excessive energy intake. There is a robust effect of food palatability and variety on short-term food intake, and increased variety and palatability also cause weight gain in animal models. However, laboratory paradigms do not replicate the complexities of eating in a natural setting, and there is a shortage of evidence to estimate the magnitude of effects on weight in humans. There are substantial individual differences in susceptibility to the palatability effect and this may be a key determinant in individual vulnerability to weight gain. The understanding of pathways through which palatability and variety can affect eating is advancing, and epidemiologic and intervention studies are needed to translate laboratory findings into applications in public health or clinical domains, and to establish whether there is a role for greater regulation of the food environment in tackling increases in obesity. *Adv Nutr* 2014;5:851–859.

Introduction: Defining the Issue

Environmental increases in palatability and variety in the food supply are potential contributors to the rise in adiposity seen worldwide. Both developed and developing countries have seen increasing diversity in the food supply, with a decline in the consumption of staples, such as cereals, and increased consumption of a variety of more palatable foods including meat, fish, sugar, and vegetable fats (1,2). The increasing dominance of supermarkets, which offer greater variety to the consumer, together with the proliferation of convenience foods engineered for maximum palatability, are among the many social, economic, and cultural

factors contributing to these trends (3). In susceptible individuals, such environmental changes may be triggers for overconsumption leading to obesity (4–8).

Although all consumers are exposed to high and rising levels of food variety and palatability, exposure to these features of the food environment vary by social, economic, and cultural groupings, individual lifestyle, and purchasing decisions (9–12). The impact of environmental exposures are further moderated by genetic and acquired characteristics, with some individuals being more vulnerable to aspects of the food environment that enhance appetite and delay satiety (6,13–15). Variation in self-regulatory ability could also influence the individual's ability to resist palatability and variety effects (16,17).

This review will summarize evidence for the influence of variety and palatability on appetite, intake, and weight gain, and discuss future research directions to translate the scientific work into public health and clinical applications.

Effect of Food Palatability on Eating Behavior and Weight

The sensory properties of foods (primarily taste and smell) are highly influential in motivating food selection (5,18,19), indicating a central role for palatability in determining eating behavior. In evolutionary terms, human taste preferences were shaped by the need to seek out foods that are high in energy, which can explain the sensory appeal of

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sugars and fats (20). A review of human laboratory studies showed that greater palatability is reliably translated into higher short-term intake (21), and effects are seen even when the nutritional composition of the food is held constant (22–24). Correlational studies also showed that people eat more when food is palatable. Two studies in which participants recorded what they ate and rated the palatability of their meals over 7 d found that highly palatable meals were 44% larger than the average meal (25,26). However, these studies did not test cause–effect relations by varying meal palatability systematically to examine effects on intake.

Palatable foods are thought to influence intake through the activation of hedonic motivational pathways (6,27,28). Palatability has a greater effect on intake in a satiated state than in a hungry state (29), suggesting that although homeostatic mechanisms dominate in the hungry state, hedonic mechanisms become more important once homeostatic needs are met. However, studies that measured liking for foods (distinct from wanting to eat them) reported that ratings for liking are higher when hungry, indicating some overlap between the hedonic and homeostatic motivation to eat (30–32). Exposure to palatable foods reliably increases self-reported appetite, with ratings of hunger actually increasing during the early stages of a highly palatable meal (22,30). Some studies also found faster recovery of appetite following a more palatable meal (33,34), suggesting that later compensation for increased intake may be less likely following a palatable meal.

A wider effect of palatable food on hedonic responsiveness is suggested by animal studies. The “reward threshold,” which is the level at which stimulation of reward-related brain areas produces a hedonic response, elevates gradually in rats with daily access to a highly palatable diet in a way that is comparable to threshold elevations resulting from regular infusions of opiates (35). Consumption of palatable foods can induce striatal dopamine transmission deficits (4), and over time consumption of a highly palatable diet may lead to reductions in brain reward response capacity. Hence it has been suggested that these acquired alterations in reward sensitivity can augment stimulation-seeking, resulting in an increasing tendency to overeat palatable food (36).

Cognitive factors were shown to modulate sensory perceptions in humans (5). A taste paired with the words “rich delicious flavor” was perceived to be more pleasant and produced more activation in the reward-related orbitofrontal and pregenual cingulate cortex than the same taste paired with the words “boiled vegetable water” (37), suggesting potential for cognitive interventions to address sensory perceptions of palatable foods. Human eating behavior is also strongly influenced by food availability, social and cultural norms, and health and appearance considerations (38,39), and reward value may not always be the main factor determining intake in situations in which social, cultural, and food environment factors exert their own pressures.

Effects of palatability on weight. If highly palatable foods increase intake in the short term, do they increase weight in the long term? Animal studies consistently show that so-called “cafeteria” diets (composed of a choice of highly palatable foods) induce greater weight gain than standard laboratory diets (40–42), although this is likely to be due not only to differences in palatability between the diets, but also to differences in energy density and variety (see below). In humans, no studies have systematically manipulated dietary palatability to examine long-term effects on weight. There is a similar lack of epidemiologic studies examining associations between exposure to more palatable diets and weight change, meaning that direct effects on weight in humans remain untested.

Variation in susceptibility to palatability. Although most studies look at normative effects, i.e., how modifications of palatability affect the typical respondent, responsiveness to palatability also varies between individuals (43). One of the earliest laboratory studies of individual differences in eating behavior (44) showed that obese participants ate more highly palatable food than normal-weight participants, but there were no differences for less palatable food. This was replicated in a number of subsequent laboratory studies (45,46), and a graded association between obesity and the palatability effect was demonstrated (47,48). Observational studies of eating behavior also showed an interaction between weight and the presence of palatable food in predicting overeating (10).

Much of the work to understand the nature of vulnerability to food environments used psychometric measures of eating style to index differential responsiveness to food stimuli. Two well-established measures of eating style in adults (the Three Factor Eating Questionnaire and the Dutch Eating Behavior Questionnaire) both include items on “external eating” (e.g., “If food tastes good to you, do you eat more than usual?”), with evidence for variability across the population (49,50). Individuals scoring high on these dimensions might be expected to be particularly vulnerable to a highly palatable food environment. Similar scales for children (the food responsiveness scale of the Child Eating Behavior Questionnaire) and infants (the Baby Eating Behavior Questionnaire) also demonstrate individual variation (51,52). Twin and family studies using these measures found strong evidence for heritability of food responsiveness (the tendency to eat when prompted by sensory cues) in both adults and children, indicating that there may be a biologic basis for variation in this trait (52–55). It was also suggested that these tendencies can be exacerbated by parental feeding approaches [for example, using food as a reward and imposing excessive restrictions on the child’s eating (56,57)]. Greater food responsiveness is linked with higher body weight in cross-sectional studies in children (58) and a recent prospective study showed that higher food responsiveness in infancy predicts greater weight gain from 3 to 15 mo

(59). In adults, results of cross-sectional and prospective studies of external eating style and body weight were more mixed (60–65), perhaps because many adults who have a vulnerability to overeating highly palatable food attempt to control their intake with dietary restraint (66).

Despite some evidence linking responsiveness to foods with higher intake and higher weight, both hyper- and hypo-responsiveness to food reward were observed in obese adults (67–71). This apparent inconsistency was explained in terms of a tendency toward hyperactivity in the cortico-lymbic areas involved with food reward or food-seeking behavior in obese individuals, in conjunction with lower reward responses to ingestion resulting from their more frequent intake of palatable foods (4,27). This may lead to further consumption to compensate for the reward deficit (71). A cyclical relation between hedonic responses to taste and obesity is likely, whereby individual differences predispose to overeating, and the resulting obese state further alters hedonic processing (36).

Effect of Food Variety on Eating Behavior and Weight

Food variety has been studied widely as a promoter of increased intake. Providing a variety of foods varying in taste, texture, and appearance stimulates intake both within meals and across eating episodes in humans (7,15,72) and laboratory animals (7,72). This tendency may have evolved to maximize the probability of adequate nutrient intake by stimulating renewed eating when a new food type became available, but behavior that was adaptive in conditions of food scarcity can confer a risk of overeating in an environment in which a varied, palatable, and energy-dense food supply is the norm.

The variety effect over a single meal has been attributed to sensory-specific satiety (73). Consumption of any 1 food ultimately leads to a decline in ratings of its pleasantness (liking) and the desire to eat it (wanting) relative to ratings of nonconsumed foods (74–76). In the standard experimental paradigm, presentation of a new, palatable food often reinstates eating, even in conditions of satiation (77). Even small differences in the sensory properties of foods can induce the variety effect (78,79), although effects are strongest when the foods differ substantially, e.g., sweet vs. savory (80).

A number of studies examined the effect of increasing variety of foods on intake over days or weeks in humans. These studies showed that a high-variety vs. a low-variety diet results in higher palatability ratings, greater intake of the test foods, and higher energy intake (81,82). Similarly, the reverse, known as the monotony effect, is well documented in experimental and field studies, whereby repeated presentation of the same foods over several meals or days results in sharply declining palatability ratings and reduced food intake (83–91).

Habituation (i.e., response to a stimulus decreasing over repeated presentations) was proposed as the neural mechanism underlying both the sensory-specific satiety and monotony effects (89,92). The phenomenon was studied in animals and humans, with responses to foods measured in a variety of ways including neural activity (93), salivation (94), and motivated responses (95). Habituation can also be observed in response to olfactory cues or food presentations of no nutritive value (92), demonstrating the central role of sensory, rather than homeostatic, processes.

Effects of variety on body weight. The long-term effects of dietary variety on body weight have not been directly tested. One 7-d experimental study reported that dietary variety was associated with short-term weight change in lean but not obese men (81). Observational studies showed associations between variety of foods in the diet and adiposity in free-living humans (96–98), although this association is moderated by the macronutrient content of the varied food in the diet. In U.S. adults, variety in self-reported usual diet was associated with greater adiposity across the majority of food groups examined, with the exception of fruits and vegetables, for which variety was associated with lower adiposity (96). A similar study in a Hong Kong Chinese population (97) found that a variety of snack foods consumed over 1 wk was associated with greater adiposity, whereas a variety of grains and meats was associated with lower adiposity. There was no association for fruits and vegetables. Correlational studies associated monotonous diets with weight loss in anorexia nervosa patients (99) and elderly adults (100). However, these studies examined effects of the variety of foods consumed rather than variety as an exposure, and do not necessarily demonstrate that access to variety affects weight; the results may be due to heavier people selecting differently, rather than varied options creating heavier people.

Animal studies often demonstrated that increasing dietary variety results in weight gain, although, as discussed above, in the majority of studies using cafeteria-style feeding, differences in the energy density and palatability of the varied vs. monotonous diets could account for some of the differences in hyperphagia and weight gain. Two studies comparing nutritionally balanced diets that either were monotonous or had varied flavors and textures found conflicting results. One showed an effect of variety on intake and weight in rats (101), but the other showed no effect (102), although it was suggested that the latter finding is due to the fact that many of the flavors used in the varied diet were less palatable than the standard form.

Variation in susceptibility to variety. A review of internal and external moderators of the variety effect concluded that there was little evidence for individual differences (15). Age is associated with earlier satiation and reduced sensitivity to

food cues, and as people age they show a reduced variety effect (15), but variety is still associated with increased intake among older adults.

Obese individuals are less responsive to satiety processes (103) and habituate more slowly to food stimuli (104–106), so they might be expected to be less susceptible to the variety effect. However, several studies manipulating the variety of food during 1 meal found no differences between obese and normal weight participants; both groups ate equivalently more when there was a greater variety of food available (104,107–109). Two studies have reported differences in the variety effect by body weight. In a small-scale ($n = 12$) 8-d feeding trial, an effect of dietary variety on intake and weight was seen in lean but not obese men, but this may result from the small sample size and older age of the obese group (81). The reverse effect was seen in a study of overweight and normal-weight children, in which overweight children increased their energy intake more than lean children in response to variety (110). At present, the balance of evidence suggests that the variety effect does not appear to differ consistently by body weight status.

Manipulating variety for weight management. Two randomized studies examined the effect of manipulating variety as part of a weight-loss intervention. The first of these compared limiting snack food variety with limiting snack frequency (89). Hedonic ratings of the snack food and snack consumption declined more in the reduced variety condition, but the 2 groups lost similar amounts of weight. The second examined the effect of limiting variety of energy-dense, nutrient-poor foods in an 18-mo weight loss intervention (111). Restricting variety was successful in reducing energy intake from this food group, but did not result in reduced energy intake overall or increased weight loss, leading the authors to suggest that restriction of variety may need to be extended to a wider range of food types if it is to contribute to weight loss.

In practice, dietary regimes that reduce variety are common both in therapeutic settings and among individuals who wish to lose weight independently. Meal replacement diets such as very low calorie diets involve replacement of some or all meals with a single nutritionally balanced, calorie-controlled product, often a milkshake. Very low calorie diets, which severely limit variety, often have relatively high ratings of acceptability, good adherence, and lower ratings of hunger than less restrictive diets (112–114). Some popular commercial diets, such as the high-protein, low-carbohydrate Atkins diet, eliminate large numbers of foods, and the reduced variety may be 1 of the mechanisms behind their short-term effectiveness (89). Fad diets often encourage exclusive consumption of a single food of limited palatability (e.g., the cabbage soup diet and the oatmeal diet). Although many of these monotonous diets are effective at producing weight loss in the short term (84,115–117), no studies used

comparison conditions that make it possible to attribute the effects directly to variety because the diets are often portion-controlled and differ in macronutrient composition, energy density, and palatability.

Effects of Palatability and Variety on Eating and Weight: Summary of Evidence Level

There is solid evidence for a causal role of food palatability on increased short-term energy intake based on experimental studies in humans and animals. Providing laboratory animals with a palatable cafeteria diet has also been shown to result in weight gain, but attributing this to effects of palatability alone is not possible, because these diets are also more energy-dense and varied than a standard diet. In humans, although it is highly plausible that the increasing palatability of the food supply has contributed to increasing weight in the population, studies have not been carried out that demonstrate unequivocally that personal exposure to highly palatable foods leads directly to weight gain.

Individual variation in responsiveness to food palatability can contribute to explaining weight variation. Food responsiveness varies from birth, and longitudinal studies showed that it is associated with weight gain in children (58,59). Epidemiologic data from adult studies are less conclusive. Imaging studies show that brain responses to palatable foods distinguish obese from normal-weight adults, but hypothesized causal mechanisms based on the effects of overexposure to palatable foods in susceptible individuals were not tested in humans.

Experimental studies demonstrate a robust association between an increased variety of foods available and increased intake within a meal in a laboratory setting. Although there is limited systematic research into the effect of variety on longer-term intake or weight change, dietary variety was associated with weight gain, and dietary monotony with weight loss, in several correlational and short-term experimental studies. There is little evidence of individual differences in responsiveness to variety, and obese and normal-weight individuals do not consistently differ in their susceptibility to sensory-specific satiety and the variety effect. The balance of evidence is consistent with the idea that exposure to a varied food supply will result in increased intake and weight gain in the long term, but this has not been conclusively demonstrated in any studies to date.

Tackling the Effects of Palatability and Variety

Primary obstacles to progress. High levels of variety and palatability are key features of modern diets, and this seems unlikely to change in the near future. Many foods in the Western diet have been engineered by the food industry to be “hyperpalatable,” i.e., to contain an optimum balance of fat, sugar, and salt to promote consumption (118). Similarities between responses to highly palatable food and addictive drugs in reward-related brain regions resulted in a

debate over whether overeating could be considered a reflection of food addiction (30,119,120). Human brain studies show that mesolimbic dopamine pathways activated in response to palatable foods are the same as those activated in drug addiction (121–123) and can trigger withdrawal effects similar to those seen with opioid drugs (124). These reward pathways can be triggered by environmental cues that indicate the availability of food (125).

These studies highlight some of the powerful biologic pressures working in opposition to attempts to change the eating behavior of individuals, and these are routinely exploited by the food industry in product development and marketing to stimulate appetite beyond metabolic need and to maximize purchase and consumption. There have been calls for greater control to be exerted over access to hyperpalatable food products through mechanisms similar to those used for alcohol and tobacco, such as taxation and restrictions on sales and advertising (30). However, manipulation of the food environment on a societal level is difficult, both politically and practically (126), and policies aimed at restricting food access are not likely to meet with support from consumers.

Increased awareness of our vulnerability to these aspects of the food environment may be helpful. The effects of variety and palatability on eating and satiety are not well recognized even in the public health and clinical fields. Many weight-loss dietary interventions aim to maintain levels of variety and palatability on the assumption that this will enhance acceptability and dietary adherence (127). Variety, in particular, is more often perceived to be a health-promoting feature in the diet, because it is associated with greater probability of nutrient adequacy (128,129). It has been suggested that the variety effect could be used to improve dietary quality by increasing the available range of health-promoting foods (e.g., fruits and vegetables) (130), although the contribution of this to weight control is doubtful, because it relies on the assumption that an increased intake of nutritious foods will be compensated by a decreased intake of energy-dense food, which may not occur.

Methodologies. A range of research methodologies was used to study the effects of variety and palatability. Experimental laboratory studies in adult humans and animals demonstrated the capacity of varied and palatable foods to enhance intake and delay satiety. Weight gain has also been demonstrated in longer-term animal investigations. Brain-imaging studies allowed progress to be made toward understanding the neural mechanisms that promote overeating and contribute to differences in the food responses of lean and obese individuals. However, there is a striking lack of ecologically valid longitudinal studies that could confirm associations with weight in humans and clarify the causal processes. There are also very few randomized, controlled intervention trials to inform public health and clinical applications. Most

of the human experimental work focused on adults, despite the fact that adult eating behavior is affected by a range of cognitive, affective, and social constraints (e.g., dietary restraint, peer pressure, and social desirability), as well as the effects of prior weight control attempts and current weight. The eating behavior of small (preschool) children is likely to be less influenced by these contaminating factors and studies focusing on eating in very early life may be particularly useful.

Questions for Future Research

What underlying mechanisms contribute to the effect of variety and palatability on eating behavior? Developing a more complete understanding of the biologic and neural correlates of palatable food consumption is important in establishing the extent of overlap between overeating and drug addiction. Further study of the similarities with addictive behaviors might be fruitful in terms of moving toward a change in the way in which society views hyperpalatable sugar-, salt-, and fat-laden foods, increasing public and political motivation to address these environmental risk factors. Establishing the specific sensory and nutritional characteristics of foods that are responsible for any addictive effects is also essential if any policy-level deterrents are to be targeted appropriately (126). Furthermore, a greater understanding of the neural mechanisms that mediate between the food environment and eating behavior could ultimately allow drug therapies to be developed to moderate the effect of environmental influences on eating (28).

Do variety and palatability exposures cause human obesity? The long-term effects of variety and palatability exposures on weight in humans have not been demonstrated. The existing literature focuses on short-term, often single-meal studies, which cannot ascertain whether energy compensation occurs. Large-scale longitudinal studies beginning in early childhood and using existing cohorts, in which participants at risk of future development of obesity can be identified, would be particularly valuable. These could establish whether food variety and palatability exposures (inside and outside the home) are a risk factor for excessive weight gain. They could also examine differences between micro-environmental exposures of children at high vs. low familial risk of developing obesity, and observe how far exposures interact with early appetitive traits (such as food responsiveness).

Establishing clear evidence of an effect of variety and palatability on weight in humans and estimating the magnitude of this effect could be a step toward the development of novel approaches to obesity treatment and prevention. Randomized, controlled studies to evaluate clinical interventions on the basis of modifying variety or palatability are needed. Studies that modify palatability and variety in settings in which at least some of the food provision is closed,

such as schools, would be valuable, because these are the settings in which larger public health interventions might be most effective and acceptable.

Can individual resilience to environmental pressures of a varied and palatable food supply be promoted? Because wider changes to the food environment are not likely to be forthcoming in the short term, individuals may need to be fortified with strategies to deal with these environmental challenges. It may be possible to assist people with structuring their personal food environment (17,131). Providing support and training to help individuals reduce their exposure to highly varied and palatable foods presents a potential novel approach to obesity prevention and management.

In addition to examining options for limiting personal exposure, training in cognitive and behavioral strategies may be possible to help individuals to increase their resilience. Increasing awareness by educating people about the effects of palatability and variety on tendency to overeat, and providing them with the skills to counter these effects, might offer some protection against continuing weight gain. Recent research highlighted the potential for training to enhance self-regulation in the face of tempting food environments (66), and there is some evidence that children trained in self-regulatory skills show weight reduction or reduced weight gain (132,133). However, this approach is controversial because of calls to move away from the idea that obesity results from personal choice (133,134); training people in self-regulatory skills might be seen as endorsing the idea that it is the responsibility of individuals to increase their will-power and learn to resist tempting foods. Although debate is likely to continue with respect to where most of the responsibility lies for tackling the consequences of the modern food environment, in practice, a focus on these questions may help to establish approaches that incorporate appropriate regulatory regimes, effective public health campaigns, and increased support for individuals to withstand the pressures of a highly palatable and varied food supply.

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