

Neurophysiological Pathways to Obesity: Below Awareness and Beyond Individual Control

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A global obesity epidemic is occurring simultaneously with ongoing increases in the availability and salience of food in the environment. Obesity is increasing across all socioeconomic groups and educational levels and occurs even among individuals with the highest levels of education and expertise in nutrition and related fields. Given these circumstances, it is plausible that excessive food consumption occurs in ways that defy personal insight or are below individual awareness. The current food environment stimulates automatic reflexive responses that enhance the desire to eat and increase caloric intake, making it exceedingly difficult for individuals to resist, especially because they may not be aware of these influences. This article identifies 10 neurophysiological pathways that can lead people to make food choices subconsciously or, in some cases, automatically. These pathways include reflexive and uncontrollable neurohormonal responses to food images, cues, and smells; mirror neurons that cause people to imitate the eating behavior of others without awareness; and limited cognitive capacity to make informed decisions about food. Given that people have limited ability to shape the food environment individually and no ability to control automatic responses to food-related cues that are unconsciously perceived, it is incumbent upon society as a whole to regulate the food environment, including the number and types of food-related cues, portion sizes, food availability, and food advertising. *Diabetes* 57:1768–1773, 2008

There is a growing consensus that the global obesity epidemic is the result of increasing urbanization and globalization, coupled with significant changes in the food environment (1,2). Obesity was initially highest in developed countries, but developing countries are quickly catching up (3). The dominant thinking about obesity is that prevention and treatment is a matter of self-control and individuals making wiser food choices. However, if this is really the case, then it implies that 30 years ago, before obesity increased, the population had more self-control and made wiser choices, and since then, our collective capacity for self-control must have diminished. It also suggests that people who live in other countries with lower rates of obesity have more self-control than Americans.

Just as the suppositions that a change in genetics and/or metabolism is responsible for the increase in obesity over

the past three decades are implausible due to lack of evidence of mutations over this short period of time, the idea that the levels of personal responsibility, knowledge, intelligence, or moral character of a majority of the population are rapidly declining is also not a credible explanation of this phenomenon. It is unlikely that the nature of people has changed so dramatically. What has changed dramatically, however, is the environment in which we now live.

The availability and affordability of food has increased, due to a combination of technological advances in food preservation and packaging, increased food production and crop yields, and decreases in food costs relative to total income (4). In many parts of the world, food is available to all socioeconomic classes 24 h/day, 7 days a week. Moreover, while food advertising is not new, greater sophistication in marketing—including the development of branding, expanded use of vending machines and other mechanisms for self-service, technologies like eye movement tracking, and the application of social psychology—are all widely used to increase impulse buying and sales of highly processed foods. The techniques are increasingly more sophisticated, customized, and targeted to increase their efficacy (5).

Could the increases in food availability, food salience, and the sophistication of modern marketing explain the obesity epidemic? If so, there must be neurophysiological pathways within humans that facilitate consumption of readily available food. Further, these mechanisms should affect all population groups similarly, regardless of income or level of education. Although individuals with a higher level of education have lower rates, the prevalence of overweight and obesity is increasing in well-educated individuals at roughly the same rate as in less educated individuals (6). It is not unusual to see doctors, nurses, and dietitians possessing expert knowledge about nutrition and weight control who are themselves overweight or obese. Thus, it is likely that the mechanisms affecting food intake are not a matter of conscious decision making based on knowledge but are operating below the level of individual awareness and beyond individual control.

This article will review the interaction between the food environment and human neurophysiology to provide some initial evidence that, to a large extent, obesity is the consequence of automatic and largely uncontrollable responses to an environment with excessive food availability and aggressive and unrelenting cues that cause people to eat too much. Ten possible neurophysiological pathways are proposed that, in conjunction with unprecedented increases in food availability and food marketing, might explain how and why people consume more calories than they expend, especially without their full awareness or control of their behavior. The mechanisms include 1) physiological reflexive response to food and images of food; 2) inborn preferences for sugar and fat; 3) hardwired

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See accompanying commentary, p. 1786.

TABLE 1
Ten human characteristics exploited to make people eat too much

Characteristic	Mechanism	How it is exploited
Physiological response to food and to images of food	Dopamine secreted when food is perceived; dopamine creates motivations for food	Ubiquitous availability of food and food images in multiple settings
Inborn preferences for sugar and fat	Under stress, people choose items that provide immediate calories to respond to increased energy demands	Excessive availability and production of high-fat and high-sugar content foods
Hardwired survival strategies	Automatically respond to abundance and variety by greater consumption	Increase shelf space and abundance of high-calorie foodstuffs; increased introduction of product variety without nutritional variety
Inability to judge calorie content	Visual system cannot judge volume or content; signals of satiety are imprecise, based more on volume than energy density	Excessively large portion sizes
Natural tendency to conserve energy	People prefer labor-saving innovations to reduce calorie expenditure	Marketing convenient, ready-to-eat foods, drive-ins
Mirror neurons	People unconsciously mimic others' eating behaviors	Modeling eating behaviors
Conditioned responses to stimuli	Hunger (dopamine secretion) stimulated by associating food products with other human wants and needs	Pairing food advertising with images promising fun, pleasure, love, power, and sex; use of inaccurate labeling
Priming	Automatically respond to items made salient through indirect methods	Use of music, lighting, images, symbols, to enhance purchase of foods
Automatic stereotype activation	Automatic responses to items that are associated with the self and with social groups and expectations	Use of racial/ethnic groups and celebrities to model eating behaviors
Limited cognitive capacity	People can be distracted or overwhelmed with too much information and influenced to eat impulsively or make unwise dietary choices	Lack of labeling or warnings, or use of confusing and inaccurate labels; e.g. "no cholesterol" labels on foods that are high in sugar and salt

survival strategies, including foraging behaviors in response to food variety and novelty, also without awareness; 4) inability to judge volume or calories either through visual perception or internal signals of satiety; 5) natural tendency to conserve energy; 6) mirror neurons that lead people to mimic the behavior of other humans, often without awareness; 7) automatic stereotype activation; 8) conditioned responses that result in desire for food when confronted with food-related cues; 9) automatic responses to priming; and 10) limited cognitive capacity and self-regulatory control (Table 1). In addition, speculations on specific mechanisms that deserve further study and direction for obesity control are discussed.

PHYSIOLOGICAL REFLEXIVE RESPONSE TO FOOD AND IMAGES OF FOOD: FOOD MAKES US HUNGRY

Studies of the brain have shown that when people are shown a picture of food, they secrete dopamine in the dorsal striatum, which results in cravings and motivations to eat (7). The sensations associated with dopamine to obtain and consume the available food may not be easily distinguished from true hunger sensations caused by low blood glucose. Although weaker in magnitude, the neurophysiological events triggered at the sight of food affect the same part of the brain and appear identical to what drug addicts experience when shown images of their drugs of choice. In both cases, the dorsal striatum is active and secretes dopamine (8). While studies of dopamine secretion and eating behaviors are limited, taken together, they indicate that the external environment is responsible for triggering dopamine secretion in normal-weight as well as obese individuals and that this reflexive response cannot

be avoided when people are exposed to food or images of food (9). Given the growth in the number of food outlets (10) and vending machines, increased food advertising, and increased sales of food in outlets not primarily in business to sell food (e.g., hardware stores, bookstores, car washes), people cannot easily avoid this source of dopamine stimulation and the associated artificially induced feelings of hunger in modern society (9).

INBORN PREFERENCES FOR SUGAR AND FAT: LIMITS TO SELF-CONTROL

People are born with natural preferences for sweets (11). When offered different liquids, newborns drink greater quantities of sweet solutions than plain water or sour solutions (12). People also prefer fats because they too activate the brain's reward system; fats also reduce physiological satiety signals (13). Sales of items made of predominately fats and sugars represent the fastest-growing segment of and provide the highest profits for the food industry (14). Because sugar and fats are impulsively favored, they are easy to sell, especially when techniques are used to promote impulsive behaviors. For this reason, supermarkets typically place items such as candy in the checkout aisles to tempt people while they wait in line. The longer that people are exposed to such innately desirable foods, the more difficult it is for them to resist. Self-control (the ability to resist temptations), on the other hand, has been found to fatigue like a muscle (15) and most people cannot endlessly control themselves without paying a price in the short term, or losing control in the long term. In one study, people who were first asked to resist chocolate chip cookies for 20 min were found to

have significantly reduced performance on solving a puzzle, giving up after an average of 8 min compared with 21 min for those individuals not shown any cookies (16). Long-term failure is the typical outcome for most people who initially lose weight on diets; they usually regain within 6 months to 1 year (17).

HARDWIRED SURVIVAL STRATEGIES, INCLUDING FORAGING BEHAVIORS

Human beings evolved as hunter-gatherers, which meant that for survival, they gathered foods in abundance when available (18). One survival strategy was to select varieties of food rather than depend on a single source. Thus, people are by nature omnivores, able to consume a wide variety of plants and animals. The more varied the human diet, the greater the likelihood of obtaining the wide variety of micronutrients and vitamins that our bodies need for optimal functioning. As a consequence of these atavistic survival strategies, people respond to variety by consuming larger total quantities of food. The food industry is very aware of how attracted to variety people are, and, as a consequence, introduces more than 10,000 new processed food products annually (19). For example, people offered a combination of 10 colors of jellybeans consumed 43% more than those offered a seven-color combination (20). However, individuals themselves are typically unaware of how variety influences the amount of food they consume.

Abundance is another factor that influences consumption. When people are provided with large quantities of food, they consume greater quantities. In one study, people given larger portions consumed 30% more than those given smaller portions (21). Supermarkets exploit the human response to abundance and variety by devoting large amounts of shelf space to a wide variety of highly profitable sugar-sweetened beverages, salty snacks, and cookies. While the quality of nutrients within these items may not vary significantly, the packaging, flavors, names, and other characteristics of the other products vary and may be falsely perceived by the human subconscious as representing nutritional variety.

If people automatically forage in response to availability, in today's marketplace, they will more easily obtain energy-dense and high-calorie snack foods with little nutrient value. In supermarkets, it is estimated that "junk foods" occupy ~33% of all shelf space (14). Convenience stores often carry such snack items while stocking no or very few nutritious foods like fruits and vegetables, which, at best, occupy a fraction of all shelf space (22). Simple techniques such as increasing salience with end-aisle or eye-level displays can increase sales as much as fivefold (23), and these displays are typically stocked with the high-profit items that have low nutritional value.

INABILITY TO JUDGE VOLUME OR CALORIES EITHER THROUGH VISUAL PERCEPTION OR INTERNAL SIGNALS OF SATIETY

Studies have shown that humans lack the ability to estimate volume and portion amounts based on appearance. For example, in two studies, both adults and children underestimated the amount of liquid in short and wide glasses (24,25). In addition, people cannot accurately estimate the calories in various food items and underestimate calories depending on the context in which the foods are presented (26).

Restaurant food portion sizes have been increasing

since the 1970s, and a typical restaurant meal now provides two to five times more calories than needed (27). Since people cannot judge portion sizes or energy density, it is not surprising that people can unknowingly consume too many calories. Furthermore, people have no internal cues allowing them to regulate precisely the number of calories they consume (28) nor do they compensate by eating less at one meal if they have overeaten at another. Volume of food, rather than calories, causes people to feel more full, while calories are important in weight gain (29). In one study, the group that consumed two servings of low energy-dense soup daily had 50% greater weight loss than the group given the same calories as high energy-dense snack food (30). While internal homeostatic mechanisms work to keep adult body weight constant, these mechanisms can be easily overridden by external factors, termed "hedonic responses," which are stimulated by external factors including visual, olfactory, and auditory signals (31).

NATURAL TENDENCY TO CONSERVE ENERGY

Besides being hardwired to respond to food with the desire to eat, humans are also hardwired to conserve energy through shortcuts or labor-saving methods and devices. This means that people are automatically more attracted to food that is convenient compared with food that requires work to prepare. Marketers have tried to capitalize on this tendency by developing products that make eating quick and easy, including packaging that allows people to eat on the run, eat in their cars, and eat with only one hand (32). Furniture-makers and auto-makers have created products that also allow people to eat wherever they are (e.g., reclining chairs with built-in refrigerators). People favor labor-saving innovations, since the impulsive part of the brain responds to short-term cues that guide our immediate daily behaviors.

Although the appeal of convenience has a great deal of face value due to the increasing sales of fast and prepared foods, there is a movement to promote "slow foods." However, the purpose goes beyond obtaining nutrition and becomes a social event or entertainment. No studies have yet determined whether adherents to "slow food" consistently eat that way on a daily basis or whether they are less likely to be overweight than others.

MIRROR NEURONS

People have a tendency to mimic the behavior of others, including behavior related to food consumption. Developmental psychologists have noted that children typically mimic others as a way to acquire adult behaviors and actions (33); "mirror neurons" that fire when both observing an action and engaging in the activity are thought to be responsible for hardwiring imitative behaviors in the brain (34). Mimicking behavior continues throughout life, and people tend to automatically mimic the expressions, body language, and behaviors of others, often without awareness. People who do a good job of mimicking others generate positive feelings and are better liked (35). People mimic the eating behaviors of others, including choices of food and portions (36). Mimicry also leads people to prefer the foods favored by others whose eating behavior they have mimicked (37). de Castro and Brewer (38) noted that people tend to consume more during a meal when there are more people sitting at a table. While this result may be due to the time spent at the table, it is also possible that

mimicking behavior was partly responsible for the increased consumption and for causing people to spend more time at the table in the first place, given the number of people to mimic. One recent study has suggested that obesity is contagious within social networks (39); mirror neurons could be the mechanism through which this is possible. Although the existence of mirror neurons is not new, in the current environment, they can serve as a mechanism to amplify increases in energy consumption, since mimicking represents an independent neurophysiological pathway to stimulate overeating.

AUTOMATIC STEREOTYPE ACTIVATION

Eating behaviors may also be influenced by automatic responses to stereotypes. Many studies have indicated that people respond to others based on stereotypes and that the responses are unintended, efficient, and outside the awareness of the perceiver (40). As measured by changes in skin conductance, individuals are fearful when confronted with others who appear different than they are and exhibit greater trust when people appear similar to them. Advertisers exploit the fact that we respond more favorably to images of people like ourselves and now customize their marketing to reflect the appearance of the target groups. The methods appeal to our automatic unconscious responses and may undermine our ability to make thoughtful cognitive decisions.

CONDITIONED RESPONSES

Just as Pavlov was able to condition dogs to salivate at the sound of a bell when the sound was paired with food, people are also conditioned to respond when such techniques are applied, including imbuing food products with symbolic meaning and status (41). Marketers exploit this tendency for humans to respond to conditioning through the use of branding—a name, term, design, symbol, or other feature to distinguish one product or service from competitive offerings (42). Over time, customers learn to buy the brand rather than the product. The brand becomes the shortcut or heuristic that motivates action (e.g., purchase or consumption).

Prices are also a heuristic that guide the choices people make on food consumption (43). Prices play a role in the kinds of foods that are consumed, with people eating more less expensive energy-dense items than more expensive, nutrient-rich items like fruits and vegetables. Nevertheless, in many places, the status associated with a product may be more important than price in determining consumption. In many cultures, people will purchase items perceived to be associated with high status items, such as sugar-sweetened beverages, and forego less expensive but more nutritious items. As a consequence of the current food environment, in countries undergoing the “nutrition transition,” many children with nutrient-poor diets become stunted at the same time as the adults in the household are becoming obese (44). Food choices are not occurring at the level of rational decision-making, but are governed by the impulsive, emotional, and nonrational parts of the brain simply because of the way the foods are marketed.

PRIMING

Priming is another technique that marketers use to influence food purchases and to increase consumption. Priming is used to evoke specific memories or associations that

make a person more disposed to act in a particular way. Just as violent television programming can prime children to be more aggressive and violent (45), images, sounds, smells, and even lighting prime people to be hungry or desire food. In one study, customers were more likely to buy French wines when a liquor store played French music and more likely to purchase German wines when German music was played (46). People usually do not recognize the prime and, even when they are aware of it, they usually do not realize that their behavior is influenced by the prime. In fact, most people deny that they are influenced by images or advertising, even though they think others are influenced (47).

Other primes are more subtle and priming can occur even through subliminal exposures. Restaurateurs know that playing slow music increases the time that people spend at their tables, while fast music increases turnover (48). Thus, the type of music played can influence the amount of food consumed, since people consume larger quantities the more time they spend at a dinner table (38). In one study, people who were thirsty (they didn't drink for some time before the experiment) were invited to taste and rate an energy drink. Beforehand, they were exposed to subliminal images: one group was shown a person smiling, the second group was shown a person with neutral expression, and the third group was shown a person frowning. The images lasted 16 milliseconds and could not be perceived by conscious awareness. Nevertheless, individuals shown the smiling person consumed more of an energy drink, drank more, and rated it more favorably than the other groups, with those shown subliminal pictures of an individual frowning drinking least and rating it worst. Here, it would be impossible for individuals to recognize that their consumption was being primed.

LIMITED COGNITIVE CAPACITY AND SELF-REGULATORY CONTROL

Human behavior does not typically originate with a conscious decision. In fact, the part of our brains that governs conscious awareness is relatively small and can process only 40–60 bits per second, roughly equivalent to a short sentence. However, our entire cognitive processing capacity, which includes the visual system and the unconscious, is estimated to be 11 million bits per second (36). One conceptualization of human brain function separates our thinking capacity into two components (49). One component is cognitive and allows us to make careful, considered decisions, but may be operating, on average, <5% of the time. The other component, the unconscious, is responsible for impulsive, automatic decision making, which happens quickly; is based on limited signals or cues, information, or heuristics; and dominates over cognitive decision making when there is too much information, or when a person is under stress, tired, or preoccupied. This unconscious part of our brain is estimated to function and guide our behaviors at least 95% of the time.

People can only process a limited amount of information at one time; when they are overloaded, they tend to make decisions impulsively. This is readily illustrated in an experiment in which participants were asked to choose between fruit salad and chocolate cake after memorizing either a two-digit or seven-digit number. Among participants who had to memorize the two-digit number, 45% chose the chocolate cake, while among those who memorized the seven-digit number, 62% chose chocolate cake.

Essentially, the group memorizing the longer number had less available brainpower to carefully consider the items and resorted to impulse (49).

Similarly, there is a limit to how many demands any person can meet in a given time period. Our resources for decision making and self-regulation (also called executive functioning) and our ability to engage in complex thinking tasks or use fine motor control can be depleted by a variety of factors, including too much information (50). When our executive functioning resources are depleted, we typically choose the default option that requires no processing demands. When it comes to food, the default options are items high in sugar and fat. We typically lack insight into this process and instead identify other causes for loss of self-regulation.

DISCUSSION

People were designed to overconsume and store excess calories to survive times when food may be scarce. However, given the advances in food production and technology, there is unlikely to be a famine in the U.S. in the foreseeable future. Human tendencies to overeat are being amplified by modern societal practices and techniques, which are not easily perceived nor resisted. Because food, images of food, and food marketing artificially stimulate feelings of hunger, and as food has become ubiquitous and is sold in increasingly larger quantities, it has become more difficult for people to control their consumption. People do not have the ability to ignore cues in their environment; in fact, the opposite is true. They are wired to attend to environmental cues and are automatically attracted to food. It is unknown at what point the number of cues to eat can no longer be resisted, but the threshold at which exposures to food and food cues lead to overwhelming desires to eat—as well as the moderating factors that can raise or lower the threshold—is likely to vary significantly across the population. No one can control things of which they are unaware.

Future studies on the variability of responses to the food environment may be important to let us know whether there is any justification for different levels of regulations for different groups or different food items. For example, are children more vulnerable than adults to food cues? Is the dopamine response higher when exposed to foods high in fat and sugar compared with foods that are nutritious? How quickly are people conditioned to respond to brands; is it a consequence of frequency or duration of exposure, a combination, and does that vary by age or sex? Is the response to brands mediated by dopamine or other neural pathways? Understanding how marketing is driving eating behaviors without awareness is critical to determining societal responses and future control of the obesity epidemic.

Because overconsumption of food leads to serious consequences, including morbidity from a wide variety of chronic diseases and premature mortality, the marketing techniques of which we are unaware should be considered in the same light as the invisible carcinogens and toxins in the air and water that can poison us without our awareness. Several approaches are possible to address the situation. To reduce people's overwhelming desire to eat in response to environmental cues, the number and type of cues can be limited and regulated. Cues and techniques that promote automatic behaviors can be made transparent with clearly understandable warnings, although this

option may not be able to prevent the automatic dopamine secretion that occurs reflexively and makes people feel hungry anyway.

It is often assumed that people make decisions about food and eating in rational conscious ways. However, if this were so, the obesity epidemic would not be happening. People overconsume in response to environmental cues and they lack insight into the extent to which their food choices and eating behaviors are being manipulated by sophisticated advertising and marketing techniques. They also have a limited capacity to sort through the increasingly overwhelming mountains of information and claims about food choices and, as a result, too often choose default option foods high in fat and sugar that, when consumed routinely, lead to chronic diseases. Society needs to act as a whole to reshape the environment to improve the quality and quantity of food we obtain, since the present environment makes it too difficult for most people to do by themselves. Regulations addressing food cues, food availability, portion sizes, and advertising are needed.

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