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Promoting Children's Healthy Eating in Obesogenic Environments: Lessons Learned from the Rat

Leann L. Birch, Ph.D. and Stephanie Anzman-Frasca, M.S.

The Center for Childhood Obesity Research, The Pennsylvania State University

Abstract

Current statistics on children's eating patterns and obesity rates are consistent with the idea that genetic taste predispositions, traditional feeding practices, and the obesogenic environment combine to increase the likelihood of unhealthy outcomes in many individuals. In this paper, we focus on one particular level of analysis through which this unhealthy combination of factors may begin to be disassembled: children's learning about food and flavors. Much of the research on children's learning about food and flavors has been inspired by the animal literature, which has a long history of carefully controlled studies elucidating the mechanisms through which rats and other animals learn to prefer and avoid foods and flavors. This literature provides many clues as to the processes by which learning paradigms may be used to encourage the intake of healthy foods, altering the implicit learning of obesogenic eating patterns that is likely to occur without intervention in the current environment. Overall, the implications of the literature are that children should be repeatedly exposed to a variety of flavors early in life, and that new flavors should be paired with already-liked flavors and positive contexts. This message is consistent with recent research results from our laboratory, showing that familiarization and associative learning paradigms may be used to increase young children's acceptance of, preference for, and intake of previously-unfamiliar, healthy foods.

Keywords

Learning; Intake; Obesity; Children

Introduction

Until recently, most infants and young children learned to eat in environments characterized by food scarcity. The availability of food was unpredictable, and when food was available, it was usually low in palatability and energy density. Traditional child feeding practices evolved in this context to promote adequate intake. Children's genetic taste predispositions also evolved in response to such food environments. From birth, infants reject bitter tastes and accept sweet tastes, and by age 4 months, a preference for salt is evident [1, 2]. Sweet and salty tasting foods signaled the presence of rare but needed nutrients in the case of food scarcity. With the exception of these readily-accepted foods, children are predisposed to be neophobic, avoiding most new foods, a trait that is adaptive in the case of an unpredictable

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Corresponding author: Leann L. Birch, The Center for Childhood Obesity Research, The Pennsylvania State University, 129 Noll Laboratory, University Park, PA 16802, Phone: 814-863-0053, Fax: 814-863-0057, llb15@psu.edu.

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and potentially dangerous food supply. Although these predispositions were adaptive in traditional environments, the food environment has changed drastically and is now obesogenic, characterized by large portions of easily accessible, inexpensive, energy-dense foods and sedentary lifestyles. Rather than promoting healthy intake patterns, children's genetic predispositions currently promote the intake of palatable, accessible, energy-dense foods and limit the intake of less palatable, less familiar, nutrient-dense foods like vegetables.

In addition, the continued use of traditional feeding practices, which developed in environments where food was often scarce, unpredictably available, and low in palatability, can exacerbate the impact of children's genetic predispositions by promoting excessive intake and obesity risk. Intake-promoting practices were used and were adaptive in contexts of food scarcity where limited food availability made malnutrition a major threat to child health. Traditional practices include feeding frequently, and feeding in response to distress, offering large portions, pressuring children to finish them, and offering palatable preferred foods if available, even if these are not healthy or developmentally appropriate. Traditional feeding practices continue to be a part of parents' customary behaviors in many societies, including our own. Such customs are difficult to change [3], and tend to persist, despite the dramatic changes in the food environment that render them no longer adaptive [3-5]. Considering the combined effects of children's genetic taste predispositions, traditional feeding practices, and the broader obesogenic environment, it becomes clear why there is a childhood obesity epidemic. Currently, 31.7% of American children aged 2 to 19 are overweight, and 16.9% are obese. Even the youngest children are affected by this problem; approximately 10% of infants and toddlers have a weight status at or above the 95th percentile for age and sex [6].

Consistent with the idea that genetic predispositions, traditional feeding practices, and obesogenic environments combine to encourage unhealthy eating and obesity, research indicates that children's current eating habits stray far from the nutritional guidelines for young children. A recent, nationally-representative survey showed that approximately one-third of American infants and toddlers consumed no vegetables on an average day, and French fries were widely consumed. In addition, the percentage of infants and toddlers regularly consuming desserts and sweetened beverages were high: for example, 43% of 9-to-12 month olds and 74% of 18-21 month olds consume these foods at least once per day [7]. In general, diet quality begins to decline as soon as the foods of the adult diet begin to be introduced during the first two years of life. This pattern continues: diet quality is relatively stable, but continues to decline during middle childhood and into adolescence [8]. Children learn to prefer and eat those foods that become familiar, and the patterns of preference and intake that develop in the contemporary food environment increase obesity risk.

Early Learning as an Opportunity for Caregiver Intervention

Children can learn to like new foods as they become familiar, allowing them to overcome their neophobic tendency to reject new foods and flavors. Because the current food environment is characterized by the availability of a variety of energy-dense sweet and salty foods that do not require familiarization in order to be liked, it is likely that without conscious efforts to encourage alternative behaviors, children will develop patterns of intake where sweet, salty, energy-dense foods are preferred and consumed, and nutrient-dense foods, which are lower on sweetness, saltiness, and energy density, are avoided. Yet early life is a time of plasticity, including rapid development of physiological, neurological, and psychological systems, and changes in one or more levels of analysis could alter the course of development and thus the probability of attaining obese phenotypes. In considering individuals' genetic predispositions, traditional feeding practices, and the broader obesogenic

environment, we argue that feeding practices are most amenable to relatively rapid change. Early life is characterized by rapid and drastic learning about foods and flavors, and the learning that takes place in micro-level environments like the home can modulate the effects of the broader obesogenic environment.

In humans, food neophobia peaks between ages 2 to 6 and then declines [9]. By age 5, many of the rapid transitions in physiology and behavior have slowed, highlighting the first five years of life as an important but challenging period for affecting eating habits. Traditional feeding practices can promote picky eating in obesogenic environments. For example, offering preferred foods can decrease opportunities to learn to like new foods. Research findings point to alternative feeding practices that may be used to facilitate children's learning to like healthy foods and flavors. Much of the research on children's learning about food and flavors has been inspired by the animal literature, which has a long history of carefully controlled studies elucidating the mechanisms through which animals learn to prefer and avoid foods and flavors. In particular, the rat model has been widely used to study food and flavor learning as rats are small, quickly-developing omnivores that had been studied extensively in the realms of brain function, learning, and motivation. This literature provides many clues about how learning affects the development of food preferences and intake in children and suggests approaches that could encourage preferences for and intake of healthy foods; this literature also has inspired a much smaller body of research on familiarization and associative learning among young children.

Familiarization

The simplest learning paradigm by which flavor acceptance and preference may be enhanced is familiarization, or the effects of mere, repeated exposure to a stimulus. Capretta and colleagues demonstrated that increased experience with flavors leads to increased preference for those flavors. For example, rat pups that experienced garlic flavor during 21 days of nursing (in mother's milk) and 5 days after weaning showed increased preference for garlic solution immediately after, as well as 1 month after, the exposure period. Rats were offered garlic solution and tap water during these test trials. Rats that experienced garlic flavors during only one of the periods (nursing or weaning) drank relatively less garlic solution than the group that experienced garlic during both periods but more than control rats that did not experience any garlic [10]. Capretta and colleagues also demonstrated that previous experience with a variety of flavors can enhance preference for a novel flavor in immature rats [11]. Compared to immature rats who had been exposed to only one flavor (black walnut, rum, or vanilla), immature rats who were repeatedly exposed to all three flavors showed a higher percentage of intake of a novel flavor in two-bottle tests consisting of a novel, chocolate-flavored solution and plain water. The effects persisted into maturity as these rats chose the chocolate solution over tap water in a second post-test when they were 80 days old. However, this "variety effect" did not occur if rats were mature at the time of exposure: when two-bottle tests were administered to these rats post-exposure trials, the group that had previously experienced a variety of flavors was no more likely to prefer a novel flavor than any other group, suggesting a potential early, sensitive period for this type of learning where early exposure to variety promotes subsequent acceptance of other new foods.

The classic animal work on repeated exposure to flavors and variety in early life has inspired human research with infants and young children. Consistent with the animal literature, it has been demonstrated that repeated exposure to flavors in utero, during lactation, and in early childhood can enhance acceptance of and preference for those flavors [e.g., 12-13]. Findings that breastfed infants are more likely to accept new foods than formula-fed infants [e.g., 14-15] are consistent with the idea that repeated exposure to a variety of flavors promotes acceptance as breastfed infants experience the ever-changing flavors of the mother's diet in

breast milk. Formula-fed infants can also learn to accept new foods following exposure to a specific food [15] or to variety [16] at weaning. In a study examining breast- and formula-fed infants with and without exposure to variety, breast-fed infants who were exposed to variety of vegetables at weaning showed the greatest acceptance of new foods (in this case, meat and fish; [16]). Mennella and colleagues also showed that exposing infants to a variety of vegetables enhanced acceptance of a novel vegetable [17]. Repeated exposure can still be effective as children enter the period of peak levels of neophobia: for example, two-year-olds' preferences for novel fruits and cheeses increased with exposure frequency [7]. However recent research reveals a sensitive period of flavor learning in human infants and suggests that familiarization effects may be particularly rapid and robust during the first months of life: Mennella and colleagues randomly assigned infants to six groups, varying the timing and length of exposure to protein hydrolysate formula. Infants who were not exposed to protein hydrolysate formula rejected its flavor. In contrast, a one-month exposure period promoted subsequent acceptance of the formula at age 7.5 months; this effect was most pronounced when the exposure took place before 3.5 months, highlighting the early months of life as a sensitive period for rapid familiarization learning [18].

Results from a recent intervention study in our laboratory [19] demonstrate long-term effects of early familiarization [20]. Infants of mothers in the treatment group were given guidance on how to use repeated exposure to reduce neophobia and promote their infants' acceptance of a variety of pureed vegetables following the introduction of solid foods (~6 months); control group mothers did not receive this guidance. The treatment group's exposure period lasted four weeks; a different pureed vegetable was offered each week for six consecutive days. When offered a novel food (cottage cheese, plain yogurt, or hummus) at age 12 months, infants who had experienced the early, repeated exposures to vegetables were less likely than controls to reject the novel food [21], suggesting the potential for early interventions focused on feeding practices to affect children's subsequent acceptance of new foods.

Associative Learning

Although carefully controlled laboratory studies have allowed researchers to isolate and demonstrate familiarization effects, familiarization processes seldom operate in isolation in real-world contexts. Familiarization effects may be strengthened or attenuated depending on the subjects' motivational states when they consume a new flavor [e.g., 22] and depending on the stimuli that are experienced along with the new flavor. In real-world contexts, new flavors are experienced with other flavors and experiences that have already attained a hedonic valence. Using the terminology of Pavlovian conditioning, familiar flavors or experiences act as unconditioned stimuli (US), and as they are paired with novel flavors (conditioned stimuli, or CS), subjects begin to associate the previously-neutral CS with the positive or negative valence of the US. Three specific associative learning paradigms include flavor-consequence learning, flavor-flavor learning, and flavor-context learning.

In flavor-consequence learning, the CS is a new flavor that is followed by a positive or negative physical consequence (the US). Garcia and colleagues' classic animal work on conditioned taste aversions, where CS's are subsequently avoided following pairing with negative physical consequences like illness, revealed that rats who experienced the flavor of saccharin in combination with radiation exposure learned to avoid saccharin, consuming a greater percentage of plain tap water in subsequent two-bottle tests [22]. Perhaps more relevant to the problem of promoting intake of healthy foods in an obesogenic environment, Sclafani and colleagues' findings have provided evidence that novel flavors can attain positive valence through pairings with positive postingestive consequences. In this model, a novel flavor (CS+) is experienced in conjunction with intragastric infusions of a caloric substance (the US). The rats also experience a control flavor (CS-) along with intragastric

infusions of water or saline. In subsequent two-bottle tests where the two flavors are presented without the caloric US, rats prefer the CS that was previously paired with calories. This paradigm also affects acceptance; when rats are provided with only one bottle at a time, they demonstrate increased intake of the CS+ flavor [23].

Such flavor-consequence learning has been demonstrated using many different US's (e.g., glucose, corn oil) and multiple CS's, including CS's that are initially aversive [22]. For example, Myers and Sclafani [24] used this model to condition rats to prefer bitter and sour flavors previously paired with glucose infusions over the sweet flavor of fructose. The effects of this model on flavor preferences have been demonstrated both in deprived and non-deprived rats although overall intake of the CS+ is attenuated when rats are not hungry [25]. Increased flavor acceptance in deprived rats is more apparent when the CS+ is sweetened [e.g., 26]. It is clear that many factors contribute to the final result in the case of flavor-consequence learning, but also that this paradigm in general is quite robust. Myers, Ferris, and Sclafani [27] carried out a series of experiments to test whether this robust program of research extended to immature rats. When they paired intraoral infusions of a grape or cherry flavor with glucose (caloric) or saccharin (non-caloric), rats learned to prefer the flavor previously paired with glucose. Preweanling rats also learned to prefer the CS flavor that was paired with intragastric infusions of a milk-based formula with added corn oil. This study showed that flavor-consequence learning affects preference for arbitrary flavors even prior to weaning, adding weight to the argument that early flavor experiences may be particularly important in establishing later eating patterns.

These experiments demonstrating flavor-consequence learning carefully isolate the experience of ingesting calories as the causal agent increasing preference for novel flavors (e.g., by infusing the calories intragastrically, so that subjects do not taste the US). However, there is evidence that, in reality, these processes are likely to work in concert with flavor-flavor learning processes. In flavor-flavor learning, acceptance or preference for a novel flavor increases when that flavor is paired with a familiar flavor that is already liked. This is different from the previous situation because it is the *taste* and not the consequence of the US that is relevant. For example, Fanselow and Birk [28] provided rats with solutions consisting of a neutral CS flavor (vanilla or almond) and a liked (saccharin) or disliked (quinine) US and demonstrated a learned preference for the flavor that was previously paired with saccharin. Sclafani and colleagues also acknowledge the importance of the flavor context in which new flavors are experienced. When testing their model of flavors paired with caloric intragastric infusions, they found that a sweet taste paired with polyucose infusions led to higher intake and more weight gain than the pairing of a bitter taste with polyucose infusions. In the case of the latter CS, intake was only slightly higher than in the control condition [29].

Given the abundance of easily accessible, palatable, energy-dense foods in the current environment, flavor-consequence and flavor-flavor learning are likely to occur frequently in humans' real-world contexts, especially in young children who have had fewer flavor experiences and who therefore experience more flavors as unfamiliar (i.e. as potential CS's). The animal literature on flavor-consequence and flavor-flavor learning has inspired research in our laboratory to investigate associative learning in young children. When 2-5 year old children consumed novel-flavored yogurts that were high or low in fat and energy density, they showed greater increases in liking for the high-energy paired flavor [30]. In a similar study, 3- and 4-year-old children were assigned to one of two groups: a conditioning group in which children consumed 150-gram servings of two novel-flavored yogurt drinks paired with high or no fat, and a mere exposure control condition in which children tasted 16-gram servings of the same drinks. Post-tests were conducted when children were hungry and again when they were satiated. The conditioning group demonstrated increased preferences for the

yogurt flavor previously paired with fat, and these flavor-consequence learning effects were greater in the deprived state. Children in the control group showed increased preferences for both flavors, and their post-test results did not depend on deprivation, providing further evidence that children in the conditioning group were learning to associate the flavor with the postingestive consequences of consuming energy [31].

More recently, we have been conducting studies comparing multiple learning modalities' effects on children's preferences for and intake of initially-disliked vegetables. We compared the effects of simple repeated exposures to a disliked vegetable (e.g., red pepper or yellow squash) versus flavor-flavor learning where the vegetable is repeatedly paired with a small amount of a liked, "yummy" dip. In both between-subjects and within-subjects manipulations, both paradigms increased liking and intake of the vegetable [32].

In addition to flavor-consequence and flavor-flavor learning, children also experience new flavors as they are paired with hedonically positive or negative contexts. In the case of this learning paradigm, effects are thought to be more complex in humans, and correspondingly, much of the research on flavor-context learning is on humans [33]. Some related animal work has shown that rats learn to prefer foods after observing other rats consuming that food [e.g., 34]. Weingarten and colleagues have also collected data on Pavlovian conditioning and context where food serves as the unconditioned stimulus. Rats learn to respond to previously-neutral cues paired with food (e.g., by initiating a meal; [35]). This work has been replicated with children in our laboratory: in two experiments, foods were paired with auditory and visual cues and with a change in location, and preschoolers were conditioned to initiate a meal based on these contextual clues [36]. Although the effects of these experiments were small, it is notable that conditioning still occurred as the pairings of the stimuli and foods took place during only one of children's daily eating episodes. It can be assumed that effects would be larger if the same stimuli were paired with repeated meals and snacks throughout the day, a more likely scenario in everyday contexts.

We have also explored flavor-context learning where the context has taken the form of various positive US's. Whereas previous work would suggest that flavors paired with positive contexts will come to be liked, it appears that the relationship is not that simple in the real-world contexts of children. When snack foods were paired with praise or were given as rewards, both of these contingencies resulted in increased preference for the previously-neutral snack food [37]. Children also learn to like foods when they observe peer models eating those foods [38]. However, children learned to dislike foods when they were rewarded for eating those foods [39]. Although counterintuitive in some sense, this finding is consistent with psychological research showing that young children's preferences for activities decrease when they are extrinsically motivated. This "overjustification effect" is successfully demonstrated when extrinsic rewards are applied in situations where children previously had high intrinsic motivation to engage in the activity at hand, and the reward is tangible and expected [e.g., 40]. The social and cognitive worlds of children are complex, and these contextual factors are often interwoven into each of the learning processes discussed herein.

Conclusions

Although children's genetic taste predispositions and traditional child feeding practices have remained unchanged over much of human history, the food environment has changed dramatically in recent decades, producing a mismatch between intake-promoting predispositions and feeding practices, which are now being expressed in environments characterized by too much palatable food. The combination of these factors is likely to promote obesity in many individuals, and we highlight feeding practices as the factor most

amenable to intervention. The well-established animal literature on learning and a smaller body of human work suggests interventions designed to modify caregivers' feeding practices to attenuate the learning of unhealthy eating patterns and to promote the intake of nutrient-dense foods. Without intervention, it is likely that the learning paradigms of familiarization and associative learning will promote the intake of the energy-dense convenience foods that characterize the current environment and appeal to children's genetic taste predispositions. However, research suggests that it is possible to enhance preference and acceptance of healthier foods if these are the foods that children are repeatedly exposed to, alone or in concert with already-liked stimuli.

Although the animal model research has inspired some investigations in young children in the laboratory, additional research with children is needed to further elucidate how these learning processes occur in real-world contexts and how they occur in combination, given humans' complex ecologies and the emergence of an environmental context where energy-dense, palatable foods are ubiquitous. It is especially important to study flavor learning in early life. Parents and other caregivers have a high degree of control over children's eating environments during this period, facilitating the feasibility of intervention; early life is also important in terms of the rapid transitions in the dietary world of the child and in terms of developmental changes in food neophobia and learning. Research findings have revealed sensitive periods of flavor learning in other omnivores [11] and more recently, in human infants [18].

Simply stated, to promote acceptance of foods that comprise healthy diets, children need opportunities to become familiar with these foods. The lessons learned from research with rats and from limited studies of human infants and children indicate that providing repeated exposure to a variety of flavors early in life, pairing new flavors with already-liked flavors, or presenting them in positive contexts can promote acceptance. Prior to the introduction of solids, experience with a variety of flavors can be achieved via breastfeeding. Then, given that there may be an early sensitive period for learning flavor preferences during the first months of life, and this is when the introduction of complementary foods begins, this transition period may be a unique opportunity to promote acceptance of flavors that are not dominated by sweet and salty tastes. It is especially important to promote familiarization and associative learning in the case of less palatable, less familiar, nutrient-dense foods, and these processes might require many trials and multiple learning modalities during peak levels of food neophobia. Recent research with infants reveals the potential power of learning processes to foster liking for healthier foods early in life when many flavors are still unfamiliar, and eating behaviors are rapidly changing. The existing research supports the idea that neophobia can be readily altered with experience.

Without intervention, given omnipresent energy-dense, nutrient-poor foods that are high in sugar and salt, the effects of familiarization and associative learning are likely to be negative in the current environment. The research on the effects of learning on food and flavor preferences provides evidence that strategically structured early experience with nutritious food could promote healthier diets and reduce obesity risk. Reducing the prevalence of obesity at the population level will require policy changes that alter the marketing of food to children and the food supply to reduce the availability of foods high in energy density, sugar, salt, and that create local environments in which healthier foods are available, accessible, and affordable. However, even this is not sufficient to ensure that children will learn patterns of preference that will result in healthier diets. In addition, and in the meantime, we can make use of what is already known about the acquisition of food and flavor preferences to provide parents and caregivers of young children with anticipatory guidance on how to structure children's early eating environments and dietary experience, so

that healthy foods become familiar, liked, and consumed, resulting in higher diet quality and reduced obesity risk.

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Research Highlights

- We review animal literature that has inspired human work on early flavor learning.
- We also discuss our recent research on children's flavor learning.
- Learning paradigms were used to promote healthier intake patterns in early life.
- Repeated exposure to vegetables promoted acceptance of a new food at 1 year.
- Familiarization and associative learning increased preschoolers' vegetable intake.