Understanding the basic biology underlying the flavor world of children

Julie A. MENNELLA*, Alison K. VENTURA

Monell Chemical Senses Center, 3500 Market Street, Philadelphia, PA 19104, USA

Abstract Health organizations worldwide recommend that adults and children minimize intakes of excess energy and salty, sweet, and fatty foods (all of which are highly preferred tastes) and eat diets richer in whole grains, low- and non-fat dairy products, legumes, fish, lean meat, fruits, and vegetables (many of which taste bitter). Despite such recommendations and the well-established benefits of these foods to human health, adults are not complying, nor are their children. A primary reason for this difficulty is the remarkably potent rewarding properties of the tastes and flavors of foods high in sweetness, saltiness, and fatness. While we cannot easily change children’s basic ingrained biology of liking sweets and avoiding bitterness, we can modulate their flavor preferences by providing early exposure, starting in utero, to a wide variety of flavors within healthy foods, such as fruits, vegetables, and whole grains. Because the flavors of foods mothers eat during pregnancy and lactation also flavor amniotic fluid and breast milk and become preferred by infants, pregnant and lactating women should widen their food choices to include as many flavorful and healthy foods as possible. These experiences, combined with repeated exposure to nutritious foods and flavor variety during the weaning period and beyond, should maximize the chances that children will select and enjoy a healthier diet [Current Zoology 56 (6): 834–841, 2010].

Key words Flavor learning, Infants, Children, Preferences, Dietary intake, Prevention

1 Introduction

The unhealthy eating habits that plague adults – too many unhealthy foods and not enough healthy foods – are rampant in the youngest members of society. For the purposes of this review, we will conceptualize unhealthy eating as a diet that does not meet recommendations for the number of calories and food group servings (i.e., fruits, vegetables, grains, meats) required to satisfy macro- and micronutrient needs for optimal health, growth, and development (Insel et al., 2010). There is no international standard for dietary recommendations, as each country must make dietary recommendations to reflect its specific cultural beliefs, dietary practices, and food availability (Painter et al., 2002). However, the conceptualization of what constitutes as healthy food is strikingly similar across international recommendations: large quantities of whole grains, vegetables, and fruits and moderate quantities of meat, milk and dairy products (Painter et al., 2002). Unfortunately, the diets of many members of most developed countries do not follow dietary recommendations, containing too many calories, too few fruits and vegetables, and too many salty, sweet, and fatty foods (Chinese Nutrition Society, 2005; Health Canada, 2007; U.S. Department of Health and Human Services, 2000; World Health Organization European Region, 2003).

Infants and toddlers consume an estimated 10%–31% more energy than is recommended (Devaney et al., 2004), but this excess energy intake is not attributable to overconsumption of universally recognized healthy foods such as fruits, vegetables, whole grains, or lean proteins. Rather, French fries are the “vegetable” most commonly consumed by infants and toddlers (Fox et al., 2004; Mennella et al., 2005b). Eighteen to 33% of infants and toddlers do not consume any servings of vegetables on any given day and 23 to 33% do not consume any servings of fruits (Fox et al., 2004). Almost half of infants and toddlers do, however, consume desserts, sweets, or sweetened beverages on a daily basis (Fox et al., 2004; Mennella et al., 2005b).

The negative impact of these concerning dietary patterns is illustrated by the increasing global prevalence of obesity among children, which constitutes a worldwide public health crisis (Chen, 2008; Lobstein et al., 2004; Lobstein and Frelut, 2003; Rios et al., 1999; Veugelers and Fitzgerald, 2005; Wang and Lobstein, 2006). Health professionals worldwide recommend that children re-
duce their intakes of added sugars, sodium, and saturated fats, while increasing their intakes of whole grains, fruits, and vegetables (with a special focus on increasing intakes of dark green leafy vegetables) (Chinese Nutrition Society, 2005; Health Canada, 2007; U.S. Department of Health and Human Services, 2000; World Health Organization European Region, 2003). However, this advice is difficult for adults to comply with, let alone young children who typically eat what they like and leave the rest (Birch, 1998). This difficulty leaves health professionals asking the question: “Why is it so difficult to encourage healthy eating during childhood and what can we do about it?”

Two major factors conspire to predispose children to consume diets high in sugar, fat, and salt that may lead to obesity. First, humans are predisposed to prefer foods that taste sweet or salty and reject all that tastes bitter. Second, children must be repeatedly exposed to the flavors of healthy foods beginning early in life if we hope to promote their acceptance of these foods. This review will discuss these factors and how they drive children’s eating behaviors, with a focus on how the findings gleaned from basic research can help improve children’s dietary intakes.

2 Biological Substrates of Taste and Food Preferences

Taste and flavor perception develop and function in utero, and these senses continue to develop and mature postnatally (Bradley and Mistretta, 1975). The fetus begins to swallow and inhale large amounts of amniotic fluid around the 12th week of gestation (Pritchard, 1965; Schaffer, 1910) and by the last trimester the receptors underlying taste and flavor perception begin to communicate with the central nervous system in response to a variety of taste and flavor stimuli (for a review see Ganchrow and Mennella, 2003)). Amniotic fluid, the first food of mammals, contains a wide range of nutrients, such as glucose, fructose, lactic acid, fatty acids, and amino acids (Liley, 1972), as well as flavors of the foods consumed by the mother (Mennella et al., 2001; Mennella et al., 1995). The fetus can detect these tasters and flavors, as evidenced by the preferential responding of infants to those flavors (e.g., garlic, anise, alcohol) experienced in amniotic fluid (Faas et al., 2000; Hepper, 1988; Schaal et al., 2000).

Fetal swallowing frequency increases in response to the introduction of sweet solutions into the amniotic fluid and decreases in response to the introduction of bitter solutions (DeSnoo, 1937; Liley, 1972), which may be one of the first indications that our basic biology favors sweet tastes and avoidance of bitter tastes (Beauchamp et al., 1991). A similar pattern of response is seen shortly after birth: within hours and days of being born, young infants react as would be expected to pleasurable and aversive taste stimuli (Beauchamp and Pearson, 1991; Desor et al., 1975; Desor et al., 1977; Fox and Davidson, 1986; Ganchrow et al., 1990; Maller and Desor, 1973; Rosenstein and Oster, 1988; Steiner, 1973a; Steiner, 1973b; Steiner, 1987; Steiner et al., 2001). Specifically, provision of sweet or umami solutions to neonates elicits rhythmic tongue protrusions, lip smacks, lip and finger sucking, and elevation of the corners of the mouth, all of which have been interpreted as a positive or hedonic response (Steiner, 1987; Steiner et al., 2001). In contrast, neonates gape, wrinkle their noses, shake their heads, flail their arms, and frown in response to a bitter solution (Desor et al., 1975; Steiner et al., 2001). Sour tastes elicit lip pursing and, to a certain extent, gaping, nose wrinkling, and arm flailing, but some infants show positive hedonic tongue protrusions and lips smacking (Steiner, 1977; Steiner et al., 2001). Unlike the other basic tastes, neonates typically respond neutrally to salt taste; a preference for salt taste develops later in infancy and continues throughout childhood (Beauchamp et al., 1986).

These specific affective reactions to differing taste stimuli are strikingly similar across cultures (Rosenstein and Oster, 1988; Steiner, 1973a; Steiner, 1977; Steiner, 1987) and species (Beauchamp and Mason, 1991; Brining et al., 1991; Ganchrow et al., 1990; Grill et al., 1996; Steiner et al., 2001) suggesting there may be a biological underpinning for the flavors and foods young children prefer and avoid. Thus, when we examine children’s dietary patterns from the perspective of the ontogeny of taste development, the foods children consume often, e.g., salty French fries, and sweet desserts, candies, and beverages (Fox et al., 2004; Mennella et al., 2005b) reflect their basic biology.

3 Heightened Sensitivity to Bitter and Preferences for Sweets and Salt in Young Children

Like infants, children live in different sensory worlds than adults. Children have higher preference for sweet (Desor and Beauchamp, 1987; Maller and Desor, 1973), salt (Beauchamp and Cowart, 1990), fat (Fisher and Birch, 1995; Johnson et al., 1991), and sour (Liem and Mennella, 2003) tastes compared to adults. Additionally,
children appear to be more sensitive to some bitter tastes compared to adults (Mennella et al., 2005a).

Why would young children have heightened responses to the taste of foods? A vast amount of learning occurs during infancy and childhood, and a significant portion of that learning is about what and how to eat. Thus, taste qualities likely evolved to detect and reject that which is harmful and to seek out and ingest that which is beneficial (Cowart, 2005). Sweetness is associated with readily available calories from carbohydrate sources such as mother’s milk or fruits (Reed and McDaniel, 2006), salt is associated with needed minerals (Jacobs et al., 1978), whereas bitterness signals toxins and poisons (Glendinning, 1994). Hence, from an evolutionary perspective it makes sense that preferences for sweet and salty foods are inborn while preferences for bitter-tasting foods (e.g., coffee, dark green vegetables) must be learned. It also makes sense that it would be protective for young children, who are trying to learn about what and how to eat, to be more sensitive to the cues proffered by foods; this heightened sensitivity would allow young children to quickly learn which foods give pleasure and which cause harm.

The increased levels of sugar, fat, and salt in processed foods cater to children’s natural taste predispositions. These sensory and biological considerations shed light on why children are predisposed not to favor low-sugar, low-sodium, and vegetable-rich diets and why it is difficult for children to eat nutritious foods when these foods are unfamiliar and do not taste good to them. While we cannot easily change children’s basic, ingrained biology of liking sweets and avoiding bitterness, we can modulate children’s flavor preferences by providing early exposure, starting in utero, to a wide variety of healthy flavors available within the culture.

4 The Role of Repeated Exposure and Familiarity

Learning from mother is a fundamental feature of all mammals (see Galef and Laland, 2005) for a review). One of the first ways young mammals learn about what and how to eat is from their mothers (Mennella, 2007). First experiences with flavors occur long before young animals first taste solid foods (see Fig. 1), and, as we will discuss, flavor experiences in mothers’ milk bridge the experiences between amniotic fluid and solid foods. Young animals learn from mother about foods and flavors in a variety of ways, from repeated exposure to particular flavors or variety of flavors to complex social modeling.

![Fig. 1](#) Types of flavor learning that can occur during various stages of mammalian development: prenatal, neonatal and weaning periods.
Amniotic fluid is the first medium for flavor learning, providing repeated opportunities for the fetus to experience the flavors of the mothers’ diet. As mentioned above, flavors and chemicals consumed by the mother appear in the amniotic fluid (Mennella et al., 2001; Mennella et al., 1995) and the fetus detects and responds to the appearance of these things in the amnion (DeSnoo, 1937; Liley, 1972). Human infants orient toward the odor of their own amniotic fluid within days of birth and prefer this odor to new odors experienced during the first few days of formula feeding (Marlier et al., 1998a; Marlier et al., 1998b), which suggests that neonates respond to that which they have had repeated exposure in the womb. This response extends to the realm of the flavors of the foods eaten by the mother. Shortly after birth, infants will respond differently to flavors experienced in amniotic fluid. For example, neonates whose mothers consumed an anise-flavored beverage or ate garlic-containing foods throughout pregnancy were more accepting of and interested in (as measured by mouthing and orienting) anise and garlic odors in the immediate postpartum period (Hepper, 1988; Schaal et al., 2000). Similar findings were observed with alcohol odors (Faas et al., 2000).

That these early flavor experiences can influence the acceptance of foods was first demonstrated in a randomized, controlled study of mothers who consumed carrot juice or water during their last trimester of pregnancy. Infants of mothers who consumed carrot juice or water during their last trimester of pregnancy were more accepting of fruits and vegetables than formula fed infants (Mennella et al., 2001). Similarly, breastfed infants were more accepting of fruits and vegetables than formula fed infants (Birch, 1987; Birch, 1989; Birch and Marlin, 1982; Birch et al., 1987; Koivisto et al., 1994; Wardle et al., 2003a; Wardle et al., 2003b).

Exposure to a variety of flavors, not just repeated exposure to a single flavor or food, also appears to facilitate acceptance of novel foods. Infants who were repeatedly exposed to a different starchy vegetable each day ate as many carrots after the exposure as did infants who were repeatedly exposed to carrots (Gerrish and Mennella, 2001). Similarly, repeated dietary experience in mother’s milk, as evidenced by changes in their suckling rate, patterning and duration of feeding and intake (Mennella and Beauchamp, 1991a; Mennella and Beauchamp, 1991b; Mennella and Beauchamp, 1993; Mennella and Beauchamp, 1996).

Flavor memories created in the amnion are reinforced during milk feeding, and serve to ease the transition to solid foods by guiding offspring’s food selection behaviors. For example, weanling pigs consumed more feed and showed better growth when a flavor that had been incorporated into the sow’s feed during lactation was also incorporated into the weanling’s feed (Campbell, 1976). Additionally, several studies have illustrated that weanling animals actively seek and prefer the foods consumed by their mother during lactation (Bilko et al., 1994; Capretta and Rawls, 1974; Chotro et al., 1991; Galef and Clark, 1972; Galef and Henderson, 1972; Galef and Sherry, 1973). Thus, redundancy of flavor experiences in the amniotic fluid and breast milk teaches offspring about which foods and flavors are safe and acceptable to eat.

Similar to other mammals (see (Mennella, 2007) for review), human infants show greater liking and acceptance for flavors and foods to which they have had early exposure. They were more accepting of carrot-flavored cereal if they experienced this flavor in mother’s milk (Mennella et al., 2001). Similarly, breastfed infants were more accepting of fruits and vegetables than formula fed infants, but only if their mothers regularly ate these foods themselves, thus highlighting the importance of a varied diet for both pregnant and lactating women (Forestell and Mennella, 2007a). Several experimental studies have also shown that when breast- or formula-fed infants are repeatedly exposed to a single fruit or vegetable for anywhere between 9 to 20 days, their preference for that fruit or vegetable increases and is higher than infants who were not repeatedly exposed to that food (Forestell and Mennella, 2007a; Gerrish and Mennella, 2001; Mennella et al., 2008). Similar effects have been seen in studies with preschool-age children (Birch, 1987; Birch, 1989; Birch and Marlin, 1982; Birch et al., 1987; Koivisto et al., 1994; Wardle et al., 2003a; Wardle et al., 2003b).

Exposure to a variety of flavors, not just repeated exposure to a single flavor or food, also appears to facilitate acceptance of novel foods. Infants who were repeatedly exposed to a different starchy vegetable each day ate as many carrots after the exposure as did infants who were repeatedly exposed to carrots (Gerrish and Mennella, 2001). Similarly, repeated dietary experience
with a variety of fruits enhanced acceptance of a novel fruit but had no effect on infants’ acceptance of green vegetables (Mennella et al., 2008). Because rejection of bitter taste is innate, infants may need actual experience with bitter taste, or more exposures to enhance acceptance of green vegetables (Forestell and Mennella, 2007a; Gerrish and Mennella, 2001; Mennella et al., 2008). The ability of varied sensory experiences with food flavors to increase food acceptance may help explain why children who were breastfed are less picky during childhood (Galloway et al., 2003).

Beyond direct experiences with flavors, young animals beginning to consume solid foods look to their mothers to learn about what and how to eat. For example, calves or lambs who see their mother avoiding larkspur also do not eat this plant (Ralphs and Provenza, 1999). Mothers serve as models to their young, teaching them plants to avoid, which to eat occasionally, and when plants are at their peak nutritional content (Provenza et al., 2003). In humans, the extent to which mothers consume healthy foods and make these foods available to their children is positively correlated with their children’s intake of healthful foods (Birch et al., 1999; Fisher et al., 2000; Galloway et al., 2003; Wardle et al., 2005). Experimental studies have provided strong support for the influence of adult models on young children’s acceptance of novel foods (Addessi et al., 2005; Hendy, 2002; Hendy and Raudenbush, 2000; Jansen and Tenney, 2001). Thus, offspring are primed to learn that the flavors and foods eaten by mother are the flavors and foods that are nutritious and safe to eat or, at the very least, the foods she has access to.

**5 Flavor Learning in Formula Fed Infants**

Flavor learning is not specific to breastfed infants, as formula-fed infants learn to prefer the flavors of the formulas they are fed. Flavor learning is different for formula fed infants because the flavor of formula is monotonous, unlike the variety of flavors experienced in breast milk. However, the flavors of the different formulas may predispose infants to develop preferences for particular flavors. Specifically, traditional cow’s-milk based formulas have low levels of sweet, sour, and ‘cereal-like’ flavors; soy formulas have a combination of sweet, sour, and bitter flavors; and protein hydrolysate formulas have combination of sour, savory, and bitter flavors and odors (Cook and Sarett, 1982). Protein hydrolysate formulas are unpalatable to older children and adults who do not have prior experience with them, but, if introduced early enough, these formulas are preferred by the infants who feed them (Mennella et al., 2004). Regardless of formula type, children are partial to the specific formula they were fed throughout infancy (Mennella and Beauchamp, 2005).

The type of formula consumed modifies infants’ taste preferences both at weaning and later in life. Infants fed protein hydrolysate formulas showed greater acceptance of savory-, bitter- and sour-tasting cereals during weaning (Mennella et al., 2009). Additionally, 38% of breastfed infants and 25% of infants who were fed cow’s milk formula gaped while eating bitter flavored cereal, while none of the infants fed protein hydrolysate formula made this facial expression of distaste (Mennella et al., 2009). Four to five-year old children who were fed protein hydrolysate formula during infancy were more likely to prefer a sour-tasting apple juice while children who consumed soy formula during infancy were more likely to prefer bitter-tasting apple juices, compared to children fed cow’s-milk based formulas (Mennella and Beauchamp, 2002). Additionally, children fed protein hydrolysate formulas as infants were more likely to prefer broccoli, which has similar flavor notes to protein hydrolysate formula (Forney and Jordan, 1999; Mennella and Beauchamp, 2002).

It is important to note that, although we have focused on the social learning interactions between mother and offspring, a child’s broader culture also has an effect on which flavors and foods are experienced, as well as when and how they are introduced and consumed. Cultural factors influence the diets mothers consume during pregnancy and lactation, the degree of dietary variety, and the way in which solid foods are introduced and what foods are considered appropriate (Forestell and Mennella, 2007b). Overall, individual experiences can be perceived as the mechanism by which culture is absorbed.

**6 Conclusions**

Food habits are an integral part of all cultures and these habits have their beginnings during gestation and breastfeeding. There is an inherent plasticity in the flavor and food learning system of mammals that allows for new learning, but this plasticity is most apparent during early stages of development. As illustrated in the Fig. 1, mammalian young can learn about flavors early in life and such early learning can impact on their acceptance of foods. We have argued that if we are to understand the etiology of overconsumption and poor dietary habits, and to develop evidence-based strategies to
improve the diets of our children, we should continue to focus our scientific investigations on understanding the development and functioning of the chemical senses.

References


