Abstract

Our ability to perceive the broad range of flavors imparted by foods involves the assimilation of multiple chemosensory sensations: primarily those of taste and olfaction. Due to their adaptive value, these chemosensory systems are functional before birth and continue to mature throughout childhood. As a result, children live in their own flavor world, preferring foods that are high in sugar and salt over those that are sour and bitter tasting, such as fruits and vegetables. Although these flavor preferences are not consistent with a healthful diet, they can be ‘fine tuned’ by sensory experiences beginning prenatally. Through exposure to the flavors of amniotic fluid and breast milk, which reflect the foods within the mother’s diet, infants become more accepting of foods within their culture. In contrast, exclusively formula-fed children, who do not benefit from the ever-changing flavor profile of breast milk, learn only about the flavor of their formula. Early learning about flavors continues at weaning, through repeated exposure to a variety of foods. Thus, mothers who consume an array of healthy foods themselves throughout pregnancy and lactation, and subsequently feed their children these foods at weaning, can promote healthful eating habits in their children and families.

© 2016 Nestec Ltd., Vevey/S. Karger AG, Basel

Introduction

Over the past several decades, with the emergence of developmentally appropriate methodologies for testing taste and odor sensitivity and preferences in children, we have begun to gain important insights into the unique flavor world in which children live [for a review, see ref. 1]. Based on this work, we are beginning...
to understand some of the factors involved in children’s maladaptive food choices. In this chapter, after providing a brief overview of the basic biology of taste and smell, advances in our understanding of sensory capabilities and acceptance patterns of the human fetus and infant will be reviewed. We will then discuss how early sensory experiences during feeding interact with the plasticity of the chemosensory system to shape subsequent preferences for foods.

Taste, Smell and Flavor Perception

According to its precise definition, taste refers to the sensations that occur when chemicals dissolved in saliva come into contact with taste receptors that are arranged in groups of 50–100 cells called taste buds throughout the oral cavity. These clusters of cells send messages to the brain via three cranial nerves, the facial (VIIth), glossopharyngeal (IXth) and vagal (Xth) nerves, which allow us to perceive a small number of primary taste qualities, namely, sweet, salty, bitter, sour and savory.

Olfaction arises from receptors located in the epithelium of the nasal cavity, which are innervated by a single cranial nerve (I). Unlike the limited number of primary tastes, there are thousands of distinctive odors with separable sensations. As shown in figure 1, odor stimuli reach olfactory receptors either through inhalation through the nostrils, which comprises the orthonasal route, or volatile chemicals from foods may travel along the retronasal route through the back of the nasopharynx towards the roof of the nasal cavity. The latter occurs during chewing and swallowing in adults and children and suckling in infants when the nasal passages are open. When the nasal passages become blocked, as sometimes occurs when suffering from a cold, the aroma of foods is prevented from traveling along the retronasal route. As a result, many cold sufferers complain that their food ‘tastes’ bland or lacks flavor.

The latter description is more accurate given that flavor, which in everyday language is often used interchangeably with taste, is elicited by a combination of taste and olfactory sensations. Indeed, it is olfactory sensations that contribute many of the distinctive characteristics of foods, such as the sensations of vanilla, strawberry or garlic, which are often erroneously described as tastes.

Prenatal Development of Taste and Odor Sensitivity

Relative to other sensory capacities such as vision and audition, the sense of taste begins to emerge relatively early. Just 8 weeks after conception, taste buds begin to appear and by the 13th–14th week they begin to morphologically resemble
those of the adult. Taste pores, which provide tastants with access to taste bud receptor cells, are generally considered to be markers of functional maturity [2]. Such pores have been identified in fetal fungiform papillae before the end of the 4th month [3]. Soon after (i.e. between 18 and 24 weeks), sucking and swallowing behaviors emerge and by 35–40 weeks of gestation these actions become coordinated [4]. This behavior stimulates the taste buds, influencing their synaptic connections and representing a major route of amniotic fluid absorption. Behavioral studies using a variety of techniques suggest that by the last trimester, taste buds are capable of detecting and communicating information to structures that are responsible for organizing and controlling affective behaviors within the central nervous system [5, 6]. Because the amniotic fluid is in constant flux throughout pregnancy, with the concentrations of sugars, sodium and potassium salts, and various acids constantly changing, the fetus is therefore exposed to a rich taste environment [5].

It has been estimated that the near-term human fetus swallows 500–1,000 ml of amniotic fluid per day [4] and actively inhales more than twice this volume. The olfactory bulbs and receptor cells, which attain adult-like morphology by
the 11th week of gestation, are functional by this time. As a result, they are capable of detecting the continually changing odor profile of the amniotic fluid. In addition to containing chemicals with distinct taste properties, amniotic fluid contains volatile chemicals transmitted from the maternal diet [7]. The fetus not only perceives these olfactory changes, but as will be discussed later, there is evidence that these experiences are encoded and remembered.

Given the extensive prenatal development of the taste and smell systems, it is not surprising that the newborn is sensitive and responsive to odor and taste stimuli after birth. These chemosensory systems continue to develop and change throughout childhood as a result of the interplay between children’s basic biology and their sensory experiences. In combination, these sensory changes will ultimately contribute to dietary habits and preferences in adulthood.

**Taste Sensitivity and Acceptance throughout Childhood: The Role of Biology**

Studies have used a variety of techniques to reveal that newborn infants can distinguish and differentially respond to basic tastes by emitting a combination of consummatory and reflexive responses, such as facial expressions that reflect hedonic or distaste reactions [1]. These studies have shown that newborn infants can perceive and display hedonic responses, such as licking, facial relaxation and smiling, to umami in soup broth and sweet tastes [8, 9]. Although little is known about the developmental progression of children’s sensitivity to and preferences for umami taste, we know that within days after birth, infants are adept at detecting dilute sweet solutions, differentiating varying degrees of sweetness and different kinds of sugars [10]. Preference for sweet taste remains heightened throughout childhood and declines to that observed in the adult during late adolescence [11].

Newborn infants respond with indifference to salty tastes [8, 9, 12]. This ability to detect and respond to salt, occurring between 2 and 6 months of age, is likely a result of postnatal maturation of salt detection mechanisms [12]. Subsequently, between 3 and 11 years of age, a preference for salt emerges that is greater than that of adults [13, 14].

In contrast, neonates generally respond to bitter and sour tastes with aversive responses. At birth, concentrated bitter solutions elicit strong orofacial responses, such as gaping and nose wrinkling [8, 9]. However, consumption tests indicate that rejection of low-to-moderate concentrations of bitter is not evident until the 2nd week of life [15], suggesting a developmental change in bitter perception and/or the ability to regulate the intake of bitter solutions. Although initial reactions
to sour taste are negative (i.e. eye squinting and lip pursing [8, 9]), for some children, these responses transform into preference by 18 months of age [16].

That the aforementioned responses to the basic tastes are remarkably similar across cultures [9] and species [17], and can be elicited in newborns with limited feeding experience [8, 9, 17, 18] as well as in those with anencephaly [18], suggests that they are innate and a function of children’s basic biology. From an evolutionary perspective, these responses are thought to enhance survival. Preference for salty, sweet and savory tastes is thought to attract us to foods such as salty-tasting minerals, energy-producing sugars, and vitamin- and protein-rich foods (such as glutamate which imparts a savory taste) that are important for growth and development. This is supported by research suggesting that preferences for sweet-tasting foods are correlated with periods of high growth [19]. Rejection of bitter and sour tastes is thought to inhibit ingestion of potentially dangerous substances such as poisons, many of which are bitter. Thus, children’s innate taste preferences help to explain why they like to consume the foods and beverages they do.

Although research indicates that age is a particularly good predictor of differences in taste preferences, additional factors, such as our genes, contribute to individual differences in sensory perception and acceptance. To date, the TAS2R38 gene, which is responsible for variance in bitter taste perception, has been the most extensively studied. This work has demonstrated that variation in the TAS2R38 gene causes individual differences in perception of a class of bitter-tasting compounds commonly found in cruciferous vegetables [20]. Depending on their genotype, some individuals have a high sensitivity threshold for this class of bitters (nontasters), and as a result typically enjoy eating cruciferous vegetables. While those who have a lower threshold perceive the bitterness in cruciferous vegetables as either moderately intense (medium tasters) or very intense (supertasters). Research has shown that for medium tasters, the strength of the phenotype-genotype relationship for bitter sensitivity varies with age. That is, these children are more sensitive than adolescents, who are in turn more sensitive than adults to these bitter compounds [21]. These findings suggest that bitter taste sensitivity can decline throughout childhood, allowing some children to become more accepting of foods that contain these compounds over time.

**Early Flavor Experiences and Their Role in Food Acceptance**

**Amniotic Fluid and Breast Milk**
As discussed above, sensory capacities emerge during the fetal period that allow the baby to respond to and learn about stimuli within the environment.
These stimuli include a wide range of odor volatiles (e.g. alcohol, garlic, vanilla and carrot) ingested by the mother, which have been shown to be transmitted to amniotic fluid and breast milk [see ref. 22 for a review]. Early exposures to these flavors serve to enhance acceptance and preference for similarly flavored foods at weaning. This has been demonstrated in human studies in which mothers consumed foods or beverages containing a particular target flavor (e.g. carrot juice) during pregnancy or lactation, while mothers in a control group did not. Several weeks after birth, infants whose mothers consumed the carrot juice flavor demonstrated a preference for baby cereal when carrot was added as a flavorant [23] relative to infants in the control groups. Thus, repeated exposure to flavors within amniotic fluid or breast milk may be one of the first ways that children learn about the foods within their culture. Research has supported this finding by showing that breastfed infants are more accepting of fruits and vegetables than formula-fed infants, but only if their mothers regularly eat these foods during lactation [24]. Hence, it appears that breast milk functionally serves as a ‘bridge’ that extends and connects the olfactory experiences of the fetus to the infants’ flavor experiences at weaning.

**Formula Feeding**

In the United States, by 3 months of age, approximately 40% of infants are exclusively breastfed [25], while the remaining infants receive formula, either in combination with breast milk or exclusively. Because formula has a fixed flavor profile, infants who are formula fed miss out on the ever-changing array of flavors provided by breast milk. However, we now know that the flavors of certain formulas may also enhance children’s acceptance of healthful foods at weaning.

Cow’s-milk-based formulas (CMF) account for the majority of formula sales, as it is formulated for healthy infants. Extensively protein hydrolyzed formulas (ePHF), which contain hydrolyzed proteins in the form of peptides and free amino acids, is available to infants who suffer from cow’s milk protein allergies or intolerance. Because many of the free amino acids in ePHF taste sour and bitter, these formulas have an extremely unpalatable taste that is accompanied by an offensive odor. This is in stark contrast to CMF, which is described as having low levels of sweet and sour tastes and cereal-like odors.

Using these inherent differences between these formulas as a model system, studies have demonstrated clear differences in the acceptance of basic tastes as a function of the type of formula fed to infants [26]. In one study, infants were tested on six occasions to measure their acceptance of sweet, salty, bitter, savory, sour and plain cereals. Results demonstrated that ePHF infants ate significantly more savory-, bitter-, and sour-tasting and plain cereals and displayed fewer facial expressions of distaste while eating the bitter and savory cereals than did
infants who were breastfed or fed CMF. Other studies have shown that these learned preferences may extend past the weaning period. Four- to 5-year-old children who were fed ePHF during infancy were more likely to prefer a sour-tasting apple juice and were more likely to preferentially consume broccoli, which has similar flavor notes to ePHF compared to children fed CMF [27]. In combination, these studies revealed that the aromas and tastes to which infants are exposed during formula feedings will depend on the type and brand of formula they are fed, which will in turn affect infants’ acceptance of foods at weaning.

Introduction of Complimentary Foods

Complimentary foods, defined as all liquid, semisolid and solid foods that are fed in addition to breast milk or formula, are typically introduced to infants during weaning, which according to World Health Organization (WHO) guidelines generally should not occur before 6 months of age [28].

In addition to defining the optimal age for introducing complimentary foods, the WHO guidelines include recommendations about their nutritional content [28]. For example, drinks that are high in sugar content, such as soda, and excessive juice consumption should be avoided because they decrease the child’s appetite for more nutritive foods [28]. Such early experiences with sweet-tasting beverages may also have long-term effects; babies routinely fed sweetened water during the first months of life later exhibit a greater preference for sweetened water at 2 years [29] and at 10 years of age [30] compared to those who had little or no experience with sweetened water. Like experience with sweet, experiences with salt provide the infant with opportunities to learn about the level of saltiness to be expected in foods. Six-month-old infants’ acceptance of moderate and strong salt solutions [12] or salted cereals is enhanced by early experiences with foods that contain sodium. Because many foods and beverages manufactured for pediatric populations are high in refined sugar and salt content, children are learning to prefer and overconsume sweet and salty foods. This is of particular concern given that these dietary behaviors have been associated with obesity and high blood pressure, a leading risk factor for later health issues, such as heart disease and stroke.

Early food environments should instead acquaint children a variety of healthful foods that meet nutritional needs for optimal growth and development [28]. Through repeated exposure to a variety of these foods, children learn to like and prefer them. Experimental studies have demonstrated that it may take as many as 8–10 exposures before infants learn to like new foods [24]. Moreover, exposure to an array of foods that vary in flavor and texture both within and between meals additionally serves to enhance children’s acceptance of novel foods [31]. However, many children’s diets are limited because parents often hesitate to continue feeding foods (such as sour-tasting fruits or bitter green vegetables) that initially
induce aversive facial responses. As a result of their limited diet, these children may become less willing to accept novel foods. Our research suggests that although infants may continue to show facial expressions of distaste (e.g. grimace) upon repeated exposure to a new food, their intake will increase with repeated exposures [25]. These findings suggest that caregivers should focus on the infants’ willingness to consume a food and not solely on their aversive facial expressions.

**Closing Remarks**

The convergence of findings from basic research has revealed that children live in different sensory worlds than adults, preferring sweeter, saltier and in some cases more sour tastes, while more intensely disliking bitter tastes when compared to adults. This is especially true for medium tasters for whom sensitivity to certain classes of bitter tastes declines throughout development. Although children have very clear likes and dislikes, recurrent exposures to a variety of taste and flavor stimuli associated with healthful eating, beginning before birth and continuing throughout infancy, can override these biological responses to some extent. To be sure, these experiences will not generally lead children to prefer bitter green vegetables over candy. However, their preferences will shift from sweet and salty foods toward a healthier array of flavors. By building an array of healthful foods into the family’s daily diet, parents will help their children develop healthful preferences that are maintained into adulthood.

**Disclosure Statement**

The author has no financial interests to disclose.

**References**


19 Coldwell SE, Oswald TK, Reed DR: A marker of growth differs between adolescents with high vs. low sugar preference. Physiol Behav 2009;96:574–580.


21 Mennella JA, Pepino MY, Duke FF, Reed DR: Age modifies the genotype-phenotype relationship for the bitter receptor TAS2R38. BMC Genet 2010;11:60.


