Flavor Learning in Utero and Infancy

February 01, 2010

In my previous columns about food behavior, I have contrasted the hard-wired affect for taste with the learned affect for flavor. This month, I present an interview with Julie Mennella, the pioneer who showed us that learning to like flavors begins even before we are born. My first exposure to this idea was as a graduate student studying taste at Brown University in the 1960s. I encountered a foreign student with a pregnant wife who was very concerned about getting a supply of spices traditionally consumed at home. He explained that for their child to like the foods of their culture, his wife needed to consume the traditional spices during pregnancy and breast feeding. At that time, I found this belief surprising. Now, Mennella has shown us that it is based on solid psychological science.

Mennella obtained her MS in Biology (Reproductive Endocrinology to be exact) at DePaul University in Chicago and then her PhD at the University of Chicago in Biopsychology working with Howard Moltz and Martha McClintock. Her earliest studies dealt with social control of parental behavior in rodents. For example, one study involved communal nursing behavior among rat mothers [Mennella, Blumberg, McClintock, & Moltz, 1990]. A growing interest in olfaction took Mennella to the Monell Chemical Senses Center and to do postdoctoral work on the chemical senses in the laboratory of Gary Beauchamp (now the Director of Monell). At the time, it was well known that the milk of many mammalian species (e.g., dairy cows) reflected the diets of the mothers. Mennella received a National Research Service Award to determine whether this was the case in humans and, if so, whether the infant could detect such flavor changes. Mennella's work showed that like the milk of other mammals, human milk acquires the flavors of the mother's diet, and babys' experiences with these flavors biases their responses to similarly flavored foods. She subsequently joined the faculty at Monell where she still conducts her research on a variety of topics including taste and addiction, drug pharmacokinetics and pharmacodynamics during lactation, strategies to increase fruit and vegetable consumption in children and the sensory world of children (http://www.monell.org/faculty/people/mennella). Mennella will be sharing some of the latest work on "The Sweet Taste of Childhood: From Basic Biology to Culture" in her Bring the Family Address at this year's APS Annual Convention.

Bartoshuk: In your earliest human studies you tested garlic. What made you select garlic and what did you learn?

Mennella: Many families around the world, including those who have immigrated to new countries, continue to eat traditional family foods common to their homeland. I'm fascinated by how such deep-rooted traditions get passed from generation to generation. Why do those foods have such special meanings and give pleasure?

As a third generation Italian American, garlic is a part of my Italian food culture. But garlic is in the diets of other species as well. When I began my work, there was little research in humans. I went to the

vast literature on dairy cows which gave us one of the first glimpses on how flavor cues in milk may be a potential source of chemosensory information for the suckling animal enabling, it to learn about the dietary choices of the mother. For example, a variety of odors from various feeds and weeds (e.g., wild onion, garlic) eaten by the cow, or from the air it breathes, can be transmitted to the milk while it is in the udder [Bassette, Fung, & Mantha, 1986]. Perhaps the most common and readily recognized transmitted flavor is that which results when the cow grazes on wild garlic! Building upon this research, Gary Beauchamp and I developed a research program that aimed to systematically study the transfer of dietary volatiles to human milk and determine what effects, if any, this has on the breastfed infants' behavior. The experimental study had a psychophysical, component to it wherein a trained sensory panel evaluated samples of amniotic fluid or mothers' milk taken before and at fixed intervals after ingesting the garlic or placebo capsules. We showed when mothers ingest garlic, amniotic fluid [Mennella, Johnson, & Beauchamp, 1995] and breast milk [Mennella & Beauchamp, 1991] take on a garlic odor. Further, nursing infants like the flavor of garlic — they attach to the breast and suck more and feed longer when the milk emits a garlic odor [Mennella & Beauchamp, 1991].

While I was collecting breast milk samples for this study I stumbled on one of my most significant research findings — that the flavor of alcohol transfers from a woman's diet through her breast milk — quite by accident. It happened during the course of a routine experiment. It was a placebo day, so the mother was asked to donate breast milk before and several times after she consumed a small sugar capsule (which would not alter the milk). The sensory panelists, whose job was to evaluate whether breast milk flavor changed as a function of what the mother ate, sniffed one of the samples and described it as smelling like it was fermenting. I soon discovered that this particular sample came from a woman who drank a glass of beer an hour before we collected her milk!

This serendipitous finding opened up a whole new area of research. First, we verified that alcohol did indeed alter the flavor of breast milk and also discovered that, contrary to the age-old folklore that claims that alcohol promotes lactation, breast-feeding infants actually consume less milk after their mothers drink an alcoholic beverage [Mennella & Beauchamp, 1991, 1993; Mennella et al., 1995]. I received a First Award grant from NIAAA and then several R01s to study the short- and long-term effects of alcohol on the behavior of breast-feeding infants during feeding, sleep, and play, and the mechanisms underlying the alcohol-induced disruptions in lactational performance. Our recent work is focusing on lactating women because, despite the resurgence in breastfeeding across all socioeconomic classes in the United States, there has been almost no scientific research into the effects of alcohol consumption on lactation in breast-feeding mothers and the consequences for their infants, as well as the effects of lactational state on the pharmacokinetics and pharmacodynamics of alcohol [Pepino, Steinmeyer & Mennella, 2007; Pepino & Mennella, 2008]. Evidence-based studies in lactating women will help in the development of sound guidelines for alcohol consumption by nursing women, and strategies to promote breastfeeding success.

Bartoshuk: What are some of the other flavors that have been demonstrated to enter mother's milk?

Mennella: Our research revealed that human milk is not a food of invariant flavors. Rather, it provides the potential for a rich source of varying chemosensory experiences to the infant. To date, a wide variety of volatiles either ingested (e.g., alcohol, garlic, mint, cheese, vanilla, carrot) or inhaled (i.e., tobacco) by the lactating mother are transmitted to her milk [see Mennella & Beauchamp, 1991, 1993, 1996, 1998, 1999]. No such changes occurred on the days the mothers consumed the placebos. In general, there were

significant increases in the intensity of the milk odor within a half hour to an hour after consumption, and the intensity of the flavor decreased thereafter. For all cases, the flavor change in the milk (after an acute dosage of the flavor) was transient. That amniotic fluid and breast milk have the potential to share a commonality in flavor profiles with the foods eaten by the mother suggests that breast milk may bridge the experiences with flavors in utero to those in solid foods.

Sweetness and textural properties of human milk, such as viscosity and mouth coating, vary from mother to mother. This contributes further to the rich source of variety provided by breast feeding, unlike formula feeding. The types and intensity of flavors experienced in breast milk may be unique for each infant and serve to identify the culture to which the child is born.

When studying the effects of drinking alcohol or smoking a cigarette on the flavor of human milk, we also measured alcohol and nicotine, respectively, in the milk. In both cases, the sensory change paralleled the changing concentrations of ethanol or nicotine in the milk [Mennella & Beauchamp, 1991, 1996].

Bartoshuk: What is the evidence that flavors in amniotic fluid and mother's milk affect later behavior?

Mennella: Flavor memories can form during milk feedings that, in turn, facilitate the transition to solid foods. For example, the growth rate of weanling pigs improved when a flavor that had been incorporated into the sow's feed during lactation was added to the weanling's feed. Moreover, weanling animals actively seek and prefer the flavors of the foods eaten by their mother during nursing and are more likely to accept unfamiliar flavors if they experience a variety of different flavors during the nursing period.

One striking example of the plasticity and stability of the flavor memories formed comes from research on the European rabbit (*Oryctolagus cuniculus*). Learning occurred when flavors were experienced in either amniotic fluid or mothers' milk [Bilko, Altbäcker, & Hudson, 1994]. After feeding pregnant and lactating does aromatic juniper berries, newborn, weanling, and even adult animals demonstrate a preference for juniper flavor without subsequent postnatal experience. We found the same thing when we looked at the infants whose mothers drank carrot juice during either pregnancy or lactation — when compared to the control group, both enjoyed the carrot-flavored cereal more at weaning. Such redundancy of dietary information may be important biologically because it provides complementary routes of transferring information on the types of foods available in the environment, should the mothers' diet change during the course of pregnancy and lactation.

The mammalian mother can produce milk to nourish her young. Invariably, the time must come for the young animal to accept plants or animal foods or both. Thus, developmental processes must act to insure that young mammals learn not only what to eat but how to forage. One of the first developmental processes (not the only one) by which young mammals learn about the dietary choices of the mother is through transmitted flavor cues. All else being equal, these are the flavors that are associated with nutritious foods, or at least, foods she has access to, and hence the foods to which the infant most likely will have the earliest exposure.

Bartoshuk: Milk allergy runs in both my and my husband's family. After our son was weaned, we gave him a soy formula. When our daughter was born, she was allergic to the soy as well as cow's milk. Although she was breast fed, our pediatrician recommended introducing her to a supplemental formula

in which the proteins were broken into constituents that would not trigger her allergies. I tasted the formula and I could not believe that she liked it. Because of this experience, I was especially interested in your work on infant formulas. Would you tell our readers about this work?

Mennella: As part of a research program aimed at understanding the underlying basis for individual and cultural food differences, we compared flavor preferences of infants raised on two different types of infant formula. One was a standard milk-based formula. The second formula is called a protein hydrolysate because the proteins are "pre-digested" to help babies absorb them more easily; that's the kind of formula your daughter was fed. The two formulas are similar nutritionally, but they differ markedly with regard to flavor: milk-based formulas are described as bland and cereal-like, while hydrolysates are exceedingly unpleasant to most adults, tasting bitter and sour with a horrible after-taste.

In another NIH-funded study, reported in *Pediatrics* [Mennella, Griffin, & Beauchamp, 2004], babies were fed one of the two infant formulas for seven months. Starting at about two weeks of age, one group was fed only the standard formula while a second group received the hydrolysate formula. Two additional groups combined three months of hydrolysate feeding with four months of standard formula. Because infants accept hydrolysate formulas readily during the first four months of life, all babies were content regardless of the formula they were fed.

At the end of the exposure period, all infants were videotaped while feeding the milk-based formula, the hydrolysate formula, and a second hydrolysate formula never tasted by any of the infants. Previous exposure influenced the amount the babies drank. Babies who had never been fed the hydrolysate formula strongly rejected it. In contrast, infants accustomed to the formula appeared relaxed and happy while feeding and drank more of both the familiar hydrolysate and the novel formulas. Longer exposure led to greater acceptance, as babies fed hydrolysate for seven months drank more than those who received the same formula for only three months. Although your daughter's formula tasted terrible to you, it was probably like a delicious milkshake to her.

These effects may persist to influence flavor preferences during childhood — and perhaps longer. In earlier studies from my laboratory, 4-to-5-year old children fed hydrolysates during infancy were more accepting of sour taste and aroma —sensory qualities associated with hydrolysates – than children fed other formulas [Liem & Mennella, 2002; Mennella & Beauchamp, 2002]. All of this suggests that the establishment of eating habits in the growing child begin even before the child eats solid food.

Bartoshuk: There is tremendous concern these days about consumption of sugar and salt. Earlier columns noted that liking for these substances appear to be hard-wired in the brain in contrast to the way we learn to like flavors.

Mennella: During the past decade, I (and others) have been studying sweet taste in children — from their liking of this taste in foods and beverages to how sweets make children feel. The liking for things that taste sweet is universal and a hallmark of development [Mennella et al., 2005]. Similarly our liking of salt ensures that we are attracted to sources of sodium. This explains why foods targeted to children are so high in sweets and salt. At birth, sweet liking ensures the acceptance of that which infants need to survive — the sweet taste of their mothers' milk. Heightened preferences for sweet tastes, which persist throughout childhood and adolescence, may have an ecological basis since, in nature, sweet-tasting foods, such as fruits, are associated with energy-producing sugars, minerals, and vitamins. If the goal is

to limit consumption of sweet foods and beverages, children's preferences for sweetness may not be the only barrier. Sweet liking may also have its roots in how sweets make children feel [Pepino & Mennella, 2005]. A small amount of a sweet solution can blunt expressions of pain in babies [Blass & Hoffmeyer, 1991] and children.

Although children as a group prefer higher levels of sweetness and saltiness than adults, there is variation in the intensity of liking sweet and salt; this individual variation may make limiting or reducing intake of sweet- and salt-tasting foods/beverages particularly difficult for some children. We need more research to identify strategies that are most effective in reducing intake of sweets in different subsets of children.

Bartoshuk: Although bitter taste appears to be nature's signal for poison, some bitters are beneficial. As a parent, I've tried a variety of strategies to get my children to take medications that taste bitter.

Mennella: Childhood may actually represent a time of heightened bitter sensitivity for some children. Rejection of bitter is most evident when you watch a child eat green vegetables for the first time or when you try to give them medicine in liquid form. Although many solid oral dosage forms of medicines (e.g., pills, tablets) have the advantage of masking or encapsulating the bitter tastes of pharmaceutical ingredients, such methods are ineffective for children since they often cannot or will not swallow pills or tablets, but yet their sensitivity to bitterness leads them to reject bitter liquid medicines [Mennella & Beauchamp, 2008]. Fortunately, research on bitter taste is leading to some ways to suppress bitter taste that may not only help children take bitter medications but may also suppress bitter tastes that prevent ingestion of healthy vegetables. For example, Robert Margolskee and his colleagues have shown that adenosine monophosphate (AMP) can block some bitter tastes [Ming, Ninomiya, & Margolskee, 1999]. Interestingly, AMP is found in breast milk.

We cannot easily change the basic ingrained biology of liking sweets and avoiding bitterness. If this is the bad news, the good news arises from our growing knowledge of how, beginning very early in life, sensory experience can shape and modify flavor and food preferences. In other words, what we can do is modulate children's flavor preferences by providing early exposure, starting in utero, to a wide variety of flavors that signal healthy foods.

References

Bassette, R., Fung, D.Y.C., & Mantha, V.R. (1986). Off-flavors in milk. *Critical Reviews of Food Science and Nutrition, 24*, 1-52.

Bilko, A., Altbäcker, V., & Hudson, R. (1994). Transmission of food preferences in the rabbit: The means of information transfer. *Physiology & Behavior, 56*, 907-912.

Liem, D.G., & Mennella, J.A.(2002). Sweet and sour preferences during childhood: Role of early experiences. *Developmental Psychobiology, 41*, 388-395.

Mennella, J.A., & Beauchamp, G.K. (1991). Maternal diet alters the sensory qualities of human milk and the nursling's behavior. *Journal of Human Lactation, 11*, 39-45.

Mennella, J.A., & Beauchamp, G.K. (1993). Beer, breast feeding, and folklore. *Developmental Psychobiology, 26,* 459-466.

Mennella, J.A., & Beauchamp, G.K. (1996). The human infant's response to vanilla flavors in mother's milk and formula. *Infant Behavior and Development, 19,* 13-19.

Mennella, J.A., & Beauchamp, G.K. (1998). Smoking and the flavor of breast milk. *New England Journal of Medicine, 339,* 1559-1560.

Mennella, J.A., & Beauchamp, G.K. (1999). Experience with a flavor in mother's milk modifies the infant's acceptance of flavored cereal. *Developmental Psychobiology, 35,* 197-203.

Mennella, J.A., & Beauchamp, G.K. (2002). Flavor experiences during formula feeding are related to preferences during childhood. *Early Human Development, 68,* 71-82.

Mennella, J.A., & Beauchamp, G.K. (2008). Optimizing oral medications for children. *Clinical Therapeutics, 30,* 2120-2132.

Mennella, J.A., Blumberg, M.S., McClintock, M.K., & Moltz, H. (1990). Inter-litter competition and communal nursing among Norway Rats: Advantages of birth synchrony. *Behavioral Ecology and Sociobiology, 27,* 183-190.

Mennella, J.A., Griffin, C.E., & Beauchamp, G.K. (2004). Flavor programming during infancy. *Pediatrics, 113,* 840-845.

Mennella, J.A., Johnson, A., & Beauchamp, G.K. (1995). Garlic ingestion by pregnant women alters the odor of amniotic fluid. *Chemical Senses, 20,* 207-209.

Mennella, J.A., Turnbull, B., Ziegler, P.J., & Martinez, H. (2005).Infant feeding practices and early flavor experiences in Mexican infants: An intra-cultural study. *Journal of the American Dietetic Association, 105,* 908-915.

Ming, D., Ninomiya, Y., & Margolskee, R.F. (1999). Blocking taste receptor activation of gustducin inhibits gustatory responses to bitter compounds. *Proceedings of the National Academy of Science, USA, 96,* 9903-9908.

Pepino, M.Y., & Mennella, J.A. (2005). Factors contributing to individual differences in sucrose preference. *Chemical Senses, 30*(Suppl. 1), i1319-i1320.

Pepino, M.Y., & Mennella, J.A. (2008). Breast pumping alters the pharmacokinetics and pharmacodynamics of alcohol during lactation. *Clinical Pharmacology and Therapeutics, 84,* 710-714.

Pepino, M.Y., Steinmeyer, A.L., & Mennella, J.A. (2007). Lactational state modifies alcohol pharmacokinetics in women. *Alcohol: Clinical and Experimental Research, 31,* 1-10.